Learning through materials – developing materials teaching in design education

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LEARNING

THROUGH

MATERIALS

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Developing materials teaching in the design education

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PhD dissertation
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September 2015

PREFACE

I’m a ‘material girl’! Not that I consider myself as being materialistic, but I fancy that everything is constituted of materials that bring along a story about their origins, traditions, use, and potential futures. Even in my office I’m exposed to extensive amounts of material that make the world I live in comprehensible. Just imagine how many different materials have been used to assemble my laptop and my smartphone lying next to it. The books, papers and post-it notes around me aim to explain materials in semiotics, but are made of materials themselves. The transparent glass on the table that contains flavored carbonized water. My headphones that play digitally composed music from my computer. It has probably never seen an instrument, but it makes me think of the record player in my living room at home that can play the same tunes, yet using analogue technology. The fabric my shorts are made of and the zipper that holds it together. The semi-transparent pattern in my knitted shirt and the seams that define its shape. I could continue daydream and reflect on the materials and technologies close to me. My point is that the presence of materials is fundamental to our existence, but because materials surround us, we tend not to value and consider how they frame our everyday lives and how we as human beings frame them.

As a child, my father made me explore and experience the world with my senses. We built tools in pinewood and I learned how trees and other living organisms are constructed and function. We went swimming in the ocean where we discussed, why seawater is salt, why the sea is blue and why edges of pieces of broken glass in the shoreline are rounded. We went on biking trips and talked about how bicycles and other vehicles work; about materials and constructions and about balance and mechanics. I still question the foundations of our existence and it’s no coincidence that I now find myself deeply entangled in materials, physically as well as mentally and emotionally. It has become part of who I am and I’m privileged that this has become my profession.

Understanding the fundamental properties of materials is essential for product designers. Material awareness, as I like to call the implicit interest and inclusion of materials, has to come from within and be a result of constant questioning and reflecting on your surroundings; society, nature and technology. It does not come easily, it’s a life-long journey, but with this project I wanted to create the best conditions for students to develop a similar interest in the multifaceted perspectives of the materials world.

I have enjoyed every second of this project and I hope you will enjoy and learn when reading this dissertation.

Karen Marie Hasling

August 2015, Kolding/Nørrebro

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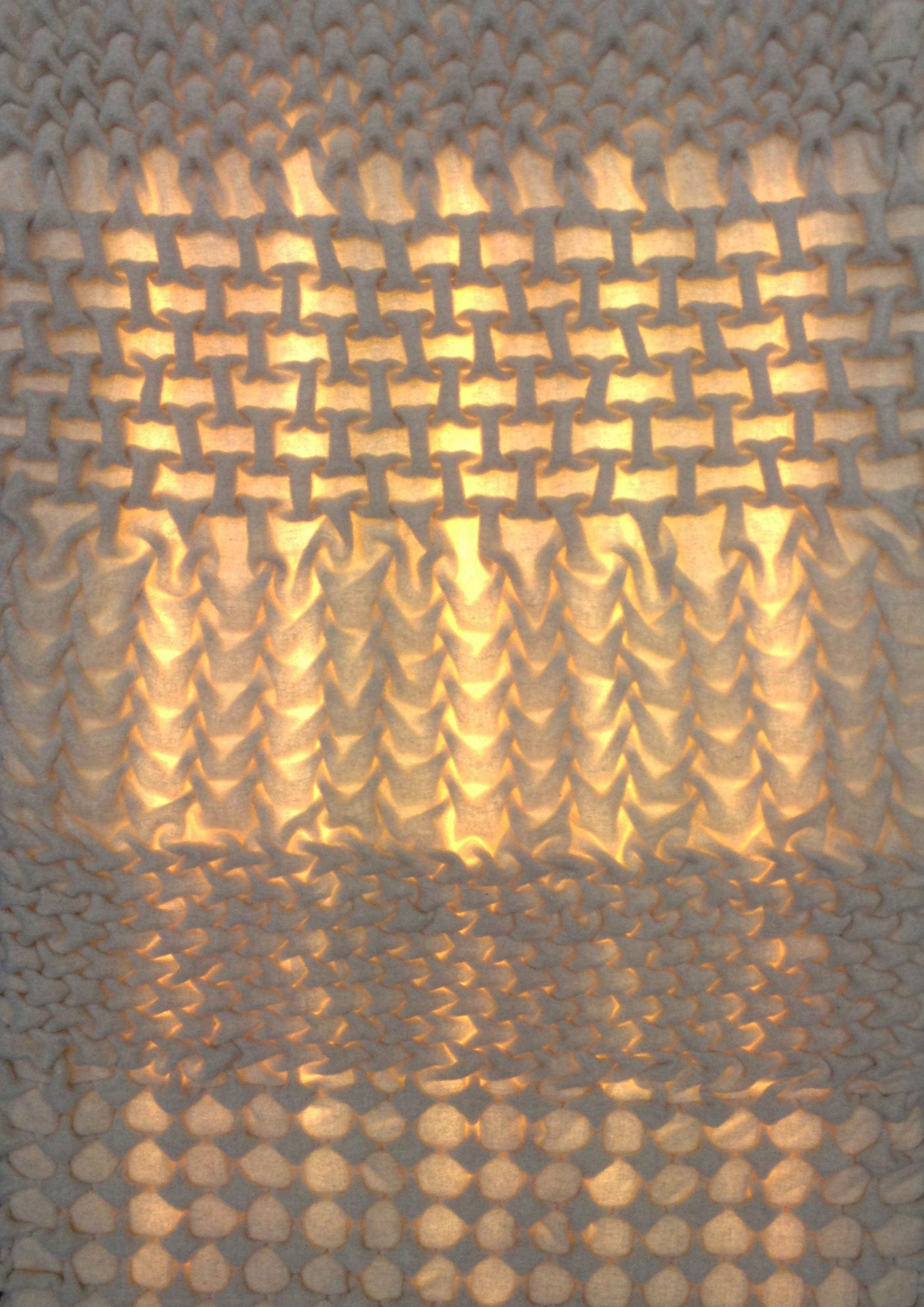

PRELUDE_

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ACKNOWLEDGMENTS

This is a project that involves people and I have a lot of people to thank. You have all been part of making this project, not easy, but easier and I am extremely grateful for that.

First of all I want to thank Design School Kolding for being such a wonderful place and for giving me freedom and space to develop this project, as I have found it most relevant. I feel fortunate to work in an educational institution that just flows with inspiration creativity, good ideas and not the least massive loads of materials. Thanks to all my colleagues that have listened to my sometimes strange and ambitious plans and ideas and for helping me executing a number of them. Thanks to my colleagues in the research department for providing me with different academic approaches to the design discipline. Thanks to the workshop leaders for having absolutely faith in my professional competences and for helping in times needed.

I especially want to thank my three supervisors, Vibeke Riisberg, Torben Lenau and Joy Boutrup for being the perfect trio and for guiding me in the process. I have felt very safe and secure knowing that you have been there to pick me up and guide me, if I felt lost.

Vibeke, thank you for your excellent support and great commitment in my project and I have enjoyed being ‘under your wing’ for the last three years. Especially thank you for your constructive comments and engagement in the last stage of finishing this dissertation.

Torben, I have appreciated and valued your structured overview and your analytical perspectives. Thank you for always asking the questions I don’t dare to ask myself and that force me to constantly reflect on my own work.

Joy, you have many fans and I am one of them. I feel honored that you see me as your successor and find me good enough to take over where you have left. The spark you initiate in students’ eyes when you teach is enviable.

I want to thank Anne Louise Bang for always listening and helping. I have found your work much inspiring and relevant and I look forward to hopefully many years of further collaboration.

I also want to thank the research faculties at the Section of Product Development and Construction at the Department of Mechanical Engineering, Technical University of Denmark (DTU) and the Section of Reliability and Durability, Department of Design Engineering, Faculty of Industrial Design Engineering at Delft University of Technology (TU Delft) for giving me the opportunity to experience other insights and turn my ideas upside down. At DTU I was glad to be back in the environment where I studied and to reconcile with my engineering identity. From Delft University of Technology, I would especially like to thank Dr. Elvin Karana for enabling me to spend half a year among some of the researchers I look up to and have based my project on and for letting me conduct a study in a materials and design course in the faculty. To my colleagues and fellow PhD students for creating an environment that so inspired me.

I want to thank Annette Andresen and Henriette Melchiorsen for your great collaborations in the materials courses and for allowing me to integrate and test my ideas. Your designerly inputs and visions for materials courses have improved the focus of the project and given me insights I wouldn't have found myself.

In the project I have experienced great support from other (primarily Danish) design educational institutions that have provided insight in their way of conducting materials teaching. I especially want to thank Annette Kjær from The Royal Danish Academy of Fine Arts, School of Design for helping me test tools in materials courses and in general helping in many other ways. To all my extended colleagues and people involved in the relatively small field of materials and textiles in Denmark. This especially include Elisabeth Heimdal for clearing the way for textile engineers at DTU, Astrid Mody for fruitful discussions and great travels, Louise Ravnløkke for being a textile soulmate and Erik Müller for always providing answers, when I or students have material inquiries or questions.

I want to thank my family and friends for always standing behind and support me. I am still not sure you really understand what this project is about, but hopefully this dissertation can clarify some things. I want to thank my parents (all three) for encouraging me to always follow my dreams and my sister for boosting my interest in materials, albeit from a very different scale and discipline. I also want to thank Susanne and Peter Laszlo for proofreading and giving comments on my dissertation in the final revised version.

I want to thank all the lovely people at RumOs and Tranevej20 for making the intense writing process a pleasurable and memorable time. I also want to thank all the people who stopped by to bring supplies, photocopies or just to say 'hi' during the process. You know who you are.

And last, but definitely not the least, I want to thank all the students that have been part of the project through courses, interviews and informal supervisions and discussions on materials. I have often been thanked for the time I spent helping and discussing material concerns. I just want to say that thanking should go in both directions. My work is not meaningful until I experience that what I can offer makes a difference for someone.

OUTLINE OF THE DISSERTATION

The dissertation has been divided into four main parts: Part I_ Introduction, Part II_ Material perspectives and learning, Part III_ Materials exploration methods in practice and Part IV_ Concluding discussion. Each part consists of a number of chapters. It should be possible to read each part and chapter individually without reading the previous or the following part or chapter. Each chapter is introduced with its aim and content and ended with a chapter summary that highlights a number of important aspects from the chapter. In addition the dissertation consists of a prelude (which you have started reading), a postlude, appendices and dissemination activities being papers and posters.

In the summary, table of contents only the primary headings are included. On the front page of each part a table of contents with primary and secondary headings is provided and a full table of contents can be found in Appendix [A10].

Part I_ Introduction presents the fundamental premises for the project in three chapters. 'Chapter 1. Background' introduces the initial motivation and the premises from which the project has been developed. 'Chapter 2. Design practice, education and research' presents the design field and design as a discipline focusing on practicing designers, design teachers and design research. The chapter serves to establish a contextual frame for the project. 'Chapter 3. Design methodology' discusses the approach applied in the project based on a research model to structure and develop experiments, the role of research objects and subjects and how experiments have been analyzed.

Part II_ Material perspectives and learning establishes the theoretical foundation for the project and is divided into three chapters. 'Chapter 4. Understanding materials' introduces materials as objects approached as physical and societal entities. It leads to material value systems based on physical, experiential and sustainable aspects of materials. 'Chapter 5. Learning and materials' discusses learning as a social practice and the role of materials in a reflective design practice, where material meanings can embed both physical and experiential attributes. The chapter further introduces sustainble design as a design frame. 'Chapter 6. Materials communication and methods' provides an overview of state of the art materials for design literature, materials collections and databases and material exploration and selection methods.

Part III_ Materials exploration methods in practice contains the empirical foundation for the project and is divided into four chapters. 'Chapter 7. Materials teaching – past, present and future' presents the learning environment and the pedagogical tradition the empirical studies have been conducted in. It introduces initial experiences with the materials selection matrix looking at previous and prospective uses and presents a study on how students approach and express materials. ‘Chapter 8. Material exploration – first iteration’ documents the first iteration of the materials selection matrix putting emphasis on structures and trends and presents four supporting teaching tools that strengthen the use of the matrix. ‘Chapter 9. Material exploration – second iteration’ documents the study of the materials selection matrix in a different learning environment and with a different setup. Emphasis is put on how these influence the use and need for the materials selection matrix. ‘Chapter 10 – Towards a methodology for teaching materials’ proposes a methodology that builds on ‘materials accessibility’, ‘materials transparency’ and ‘materials approachability’.

Part IV_ Concluding discussion presents the findings of the project in five sections. The ‘Discussion’ answers the research questions and hypothesis are answered linking to findings from conducted experiments, discusses learning and teaching and reevaluates the methodological frame of the project. ‘Contributions’ positions the projects’ findings in education, practice and research. ‘Future work’ elaborates on how the project could be further developed.

The postlude contains References, Index of keywords, Summary (English) and Resumé (Danish).

The appendices contain eight appendices. [A1] presents selected materials for design literature, [A2] provides a list of material attributes identified from material libraries, [A3] offers an overview of the development of the Materials & Sustainability course at Design School Kolding, [A4] contains transcripts from student interview, [A5] provides three examples of presentation content from the Materials & Sustainability course in the fall 2012, [A6] is a list of material attributes extracted from conducted experiments, [A7] is a study on matrix topologies, [A8] provides guidelines for the presented learning tools, [A9] illustrates components of the newest version of the materials selection matrix and [A10] is a full table of contents.

The papers and posters section includes papers and posters produced during the project. For more details, see table of contents and the specific section.

For practical reasons, the dissertation comes in one book, while appendices, papers and posters have been compiled in separate book.

Unless otherwise indicated, the photos and illustrations used have been taken or drawn by me.

Photo by Diana Lovring

PART I_ INTRODUCTION

Contents_

1. BACKGROUND

This dissertation with the title 'Learning through Materials' is a contribution to materials teaching in design education focusing on interactions between physical, experiential and sustainable aspects of materials used in product design. Here physical aspects correspond to objective properties defined by composition and processing of the material, while experiential aspects correspond to the subjective experiences users have with a material based on sensations, associations and emotions.

The project serves to bridge artistic and engineering understanding of materials to establish a common base for present and future tools and methods used in materials teaching. The project builds on long-established traditions and experience in teaching materials at Design School Kolding and has aimed to prepare future materials teaching for changes in the material landscape, in design courses and in the role of sustainable product design (such as fashion, textiles and industrial design).

The content of the project and the dissertation has been established on the hypothesis that

> *"a stronger emphasis on materials teaching in design education can strengthen awareness of materials among (product) design students and enable students to make stronger and better-founded materials choices in a sustainable perspective".*

The project has thus aimed to understand how design students approach materials and to propose, how materials teaching can be modified to accommodate a stronger focus on materials in (educational) design practice.

In the dissertation different perspectives that challenge the hypothesis are introduced and discussed. Based on experiences and discoveries in the project, a methodology for teaching materials in design education that corresponds to the hypothesis is proposed. The methodology is built on identified prospects and challenges that can be summarized in three categories: how materials are accessed and used (materials accessibility), how materials are understood and mediated (materials transparency) and how material knowledge is transferred (materials approachability) (see figure 1). The categorization will be discussed further in Chapter 10.

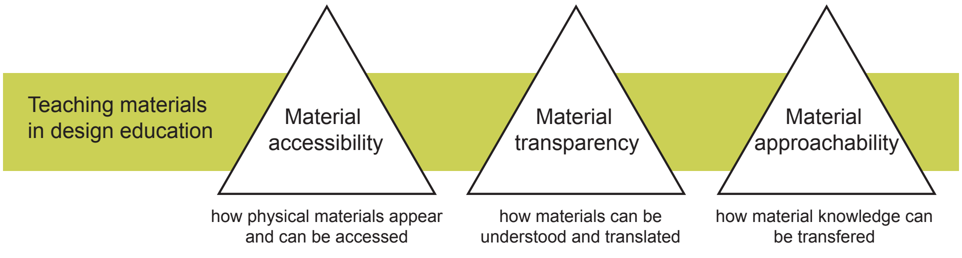


Figure 1. The identified three main focus areas in the dissertation: materials access, materials transparence and materials approach.

LEARNING THROUGH MATERIALS

The title 'Learning through Materials' stresses the emphasis on learning, on materials and how they interact. The project has been motivated particularly by three challenges: a changing material landscape, a progressing design education and the challenge of more sustainable product design. The challenges are introduced in depth in Chapter 4 and Chapter 5, and will just be summarized here.

The material landscape

The traditional material landscape consisting of material families with significant material attributes is slowly dissolving (Vannini, 2009). New kinds of emerging materials that are either crossovers of already well-known materials or newly developed materials appear and well-known materials are refined and customized to fit special applications. This means that the number of materials is rapidly increasing and embedded material meanings, physical as well as social, are decomposed. Within the last hundred years, the number of materials has increased from a few hundred to more than 150.000 and this number continues to grow (Ashby et al., 2007).

Design education

Design practice is developing and design education has to try to anticipate its needs and requirements. In this dissertation there is a special focus on artistic design education in Denmark with some influence from industrial design engineering education in the Netherlands.

The modern design practice that started with the industrial revolution to help industry create products and information changed subsequently to include emphasis on products' appearance and interactions, and, in recent years, needs (The DesignX Collaborative, 2014). Teaching has continually been influenced by societal and industrial theory including gestalt and visual perception theories (Wertheimer, 1938), methods and systems thinking (Buchanan, 1992), affordance and emotional design (Desmet, 2003; Norman, 2004, 1988), design semiotics (Krampen, 1995) and experiential design (Schifferstein and Hekkert, 2008) among others. The influences bounce back and forth, which means that design education is in constant flux. Research based in design schools is relatively newly founded and has been established as part of the academization of (artistic) design schools (Hansen, 2014). Thus even though knowledge has been generated through many years of teaching, academic literature and documentation is limited.

Design practice, and thus education, has further developed due to the concurrent technological developments and the increased use of digital tools in the design as well as in the production process. The increased use of digital tools has partly shifted the emphasis from hands-on work to computer-work, where it is easier and faster to produce drawings and renderings. Furthermore, due to globalization, communicating intentions and descriptions is increasingly important. The digital 'revolution' is also supporting designers with information on materials, for example focusing on environmental impacts.

Sustainability

In product design sustainability considerations are increasingly required as part of the design process. The concept of sustainable development most often referred to today, is that such development strives towards a sustainable society, where future generations can maintain the same quality of life as present generations, putting emphasis on environmental, economical and social sustainability (UN - WCED, 1987).

The focus on sustainable development in product design has developed and changed design practice through trends that increasingly acknowledge holistic design and circular processes such as 'Cradle-to-Cradle' and 'circular economies' (Ellen McArthur Foundation, 2012; McDonough and Braungart, 2002) as well as 'service design' and 'product-service systems' (for example Osterwalder et al., 2014; Stickdorn and Schneider, 2012). Consequently an increasing number of books on sustainable design as a design approach, and with examples of sustainable solutions, are available (for example Bhamra and Lofthouse, 2007; Fletcher, 2008; Fletcher and Grose, 2012; Fletcher and Tham, 2015; Krüger et al., 2013; Thorpe, 2007).

Implications

These above-described extra dimensions influencing the design field have developed in tandem. Consequently they interact and intertwine and have shifted the focus of design practice and the breadth of areas in which design is useful (The DesignX Collaborative, 2014). Both the material landscape and design practice have developed into increasing complexity and the combination of the two is not less complex. In design education it has resulted in the necessity to rethink materials teaching that to a larger extent incorporates design practice in which materials are used and contains approaches to explore materials in new ways. The considerations for sustainability have added an extra dimension to the complexity not only related to the choice of materials but increasingly also include users and their actions with the product, hence incorporating a dual focus on physical and experiential values.

CONTRIBUTIONS

The project is a contribution to a materials teaching methodology for design education. It has been based on the learning environment and materials courses at Design School Kolding, but the issues it has been developed to answer are generic for design courses, design practice and industry. Thereby it addresses stakeholders in the design field, but in particular lecturers and students in materials courses and in design education in general. The methodology provides a structure for materials teaching based on progression of cognitive learning and includes five tools and methods that individually and collectively increase the overall output of students' material meaning creation and work with sustainable design.

The project also seeks to contribute to an expanded approach to understanding materials based on value systems that highlight physical, experiential and sustainable material attributes. In design, value systems can elicit and identify user needs and experiences. A three-legged model to communicate values can thereby facilitate considerations for sustainability in the design process. The approach contributes to an increased understanding of materials that are valuable for design education as well as design and production companies when exploring and developing materials.

CORE NOTIONS

In the thesis a number of notions will be used repeatedly. Because the theoretical foundation of the work has been collected from various academic traditions, the conceptions of the notions may differ.

The two core notions **'materials meanings'** (or meanings of materials) and **'materials understanding'** (or understanding of materials) are often used (for example Desmet and Hekkert, 2007; Karana, 2010; Krippendorff and Butter, 2008). They describe meanings of materials as the associations and experiences humans have with a given material constructed through any kind of interaction with the material. Materials meanings are influenced by humans' set of values, being individual as well as social. **'Materials meaning creation'**, being the cognitive process in which material meanings are established, is a fundamental part of materials teaching. Material meaning creation is based on **'sense making'** and **'sense giving'** mechanisms (Weick et al., 2005; Klein et al., 2006). They describe sense making as the meaning construction and reconstruction in the attempt to develop a meaningful framework for understanding.

In this thesis the set of values ascribed to materials depends on individual human's understanding of the society. This is described with the concepts of **'mindsets'** (Person et al., 2012; Andreasen, 2003) and **'communities of practice'** (Wenger, 2010, 1998). Person et al. describe mindsets as the attitudes or beliefs a human have about a specific entity (Person et al., 2012) while Wenger describes communities of practice as the communities of humans that share practices in established or free constitutions (Wenger, 2010, 1998).

The thesis further applies a number of different taxonomies to label materials meanings based on the depth of subjectivity or objectivity in a given materials attribute. Here the dominant division is between **'physical'** attributes that relate to materials as physical objects with properties defined by the materials' composition and construction and **'experiential'** attributes that relate to materials as social object and humans' experience with a material (Ashby and Johnson, 2014; Karana et al., 2014; Vannini, 2009). The duality is expanded with an aspect that relates to **'sustainable design'** here understood as initiatives of any kind (such as materials, processes, services, strategies and experiences) aiming at minimizing the sustainable impact of product design by considering environmental, economic and social sustainability in the design process.

The primary context of the studies can be characterized as an **'active'** or '**interactive'** learning environment that stresses **'practice-based'** and '**experiential learning'** (Illeris, 1999; Kolb, 1984). Kolb considers experience the central role of learning and suggest an integrative learning perspective that combines experience, perception, cognition and behavior (Kolb, 1984).

POSITIONING THE PROJECT IN THE RESEARCH LANDSCAPE

The project has derived inspiration from different research fields, but it is predominantly a design research project. It has been conducted in an artistic design school, using design students as research subjects and the learning environment as the context.

In (design) practice research, Frayling has identified three modes being: 'research in design', 'research through design' and 'research for design' (Frayling, 1993: 5). The design field has developed since the publication of Frayling's article, but its notions are still often referred to when labeling design research, such as in Bang et al. (2012) and Koskinen et al. (2012). The project is constituted of all three modes that dominate different aspects of the project. The project is a 'research in design' as it departs from an design learning environment, where both the research context, objects and subjects are inherently related to design; it is a 'research through design', as it has used design methods and mindsets to investigate, analyze and develop the proposed methodology and tools and it is a 'research for design', as its outcome is directly targeting design students and thereby future designers. Looking into design research the project can be positioned between artistic and engineering design. It corresponds to design engineering research such as in its use of structures and models and it corresponds to artistic design research such as in its appreciation of reflection and experiential values.

The project does not label the interactive role of research subjects, but it can be positioned within 'User Interaction research' in some way (Sanders, 2002; Sanders and Stappers, 2008; Sanders and Westerlund, 2011). As previously mentioned, the materials meaning theories and notions, which have been introduced, draw links to research on 'design experience' and 'meanings of materials' and the recognition of sustainability as part of the design practice. This indicates that the project can be perceived as an example of integrating sustainable design in materials teaching. The learning and meaning creation theories and notions, which have been presented, establish links to research on 'learning processes' and 'learning strategies' (Jonassen and Land, 2000; Kolb and Kolb, 2005; Schunk, 2012).

PROJECT FRAME

This project was conducted at Design School Kolding from March 2012 until August 2015 with economic support from the Danish Ministry of Culture. The project was initially associated with Department of Product Design and since the school changed its organizational structure, the project has referred to the educational disciplines of fashion, textiles and industrial design as well as the research department. Two materials courses at Design School Kolding for respectively fashion textiles and industrial design students have served as the primary source of empirical data and other inputs.

Scope of the project

In Chapter 4, an actor-network-oriented approach has been used to describe the relationship between design students and materials, being the two primary actors in the project. Nevertheless a larger network of involved and peripheral actors can be identified that played a role in the execution and findings of the project.

In figure 2, an actor-network of the problem area is included. In the network relevant actors (human as well as non-human (see p. 49 ff. in Chapter 4)) have been identified. It could have been larger, but it has been tried to balance the inclusion of actors to keep it simple while still providing a comprehensive overview.

This network has been used to frame the scope of the project and to highlight other important interactions of actors. In the network 'ordinary' connections are indicated with a straight line, such as 'Educational institution'-'Industry' and 'Materials courses'-'Societal trends and streams'. The dotted lines are connections between actors and subcategories of the actors such as 'Teachers'-'with Technical background', -'with Design background', -'with Commercial background' and -'Workshop managers' and 'Adjacent disciplines/institutions'-'Engineering', -'Sociology' and -'Anthropology'. The primary focus has been on the relations indicated with full straight lines, but it is acknowledged that due to a diversity of actors, it is necessary to also consider different actor subgroups. The key relations discussed in the project are indicated with bold green lines.

The network shows that the key actors have been 'Students', 'Materials', 'Learning', 'Teaching', 'Materials courses', 'Methods/tools', 'Material understandings', 'Sustainability', 'Physical properties' and 'Experiential characteristics'. The interactions of these consider '*how students learn about materials in materials courses*', '*how students develop understanding of materials based on physical properties, experiential characteristics and sustainability attributes*' and '*how methods and tools can facilitate the learning process*'. The network also identifies secondary and tertiary actors. Secondary actors are regarded as actors that have influenced the premises of the project and that will be referred to in the dissertation.

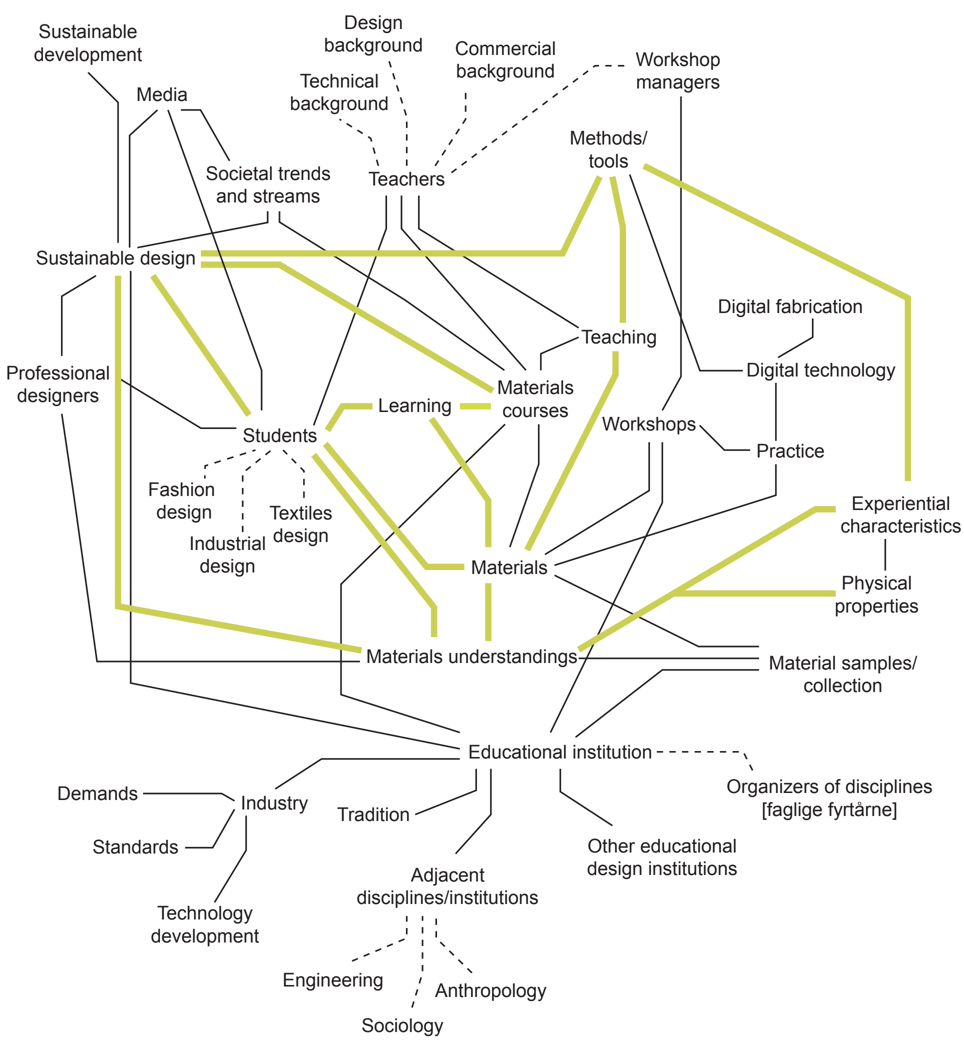


Figure 2. Actor network of the problem area that has been used to define the scope and vital actor interactions. The bold green lines are the actor relations that have got special focus in the dissertation.

Secondary actors include Design School Kolding as an educational institution (including the physical environment, the administration, the board, the discipline organizers and other employees) and the teachers involved in the materials courses. The teachers in the materials courses are essential, but the dissertation does not discuss in detail how different teachers influence the learning outcome. Adjacent disciplines and institutions such as engineering, sociology and anthropology have influenced the theoretical framework of the dissertation and have thus functioned more as sources than active actors in the development of the methodology.

Similarly tertiary actors are regarded as actors that exist as parts of the network, but have been discarded due to the necessity to focus on a limited number of relationships. It means that actors such as professional designers and industry have been eliminated. It will leave many unanswered questions, but as Part IV will discuss, the methodology primarily addresses students with no or limited materials experience. Professional designers and the industry would therefore in any case approach the methodology differently.

Design School Kolding

This project has been performed at Design School Kolding and being the primary context and target user, the school and its students have played vital roles in the project. Design School Kolding is an artistic design school rooted in an art and craft tradition inspired by the pedagogic visions from the Bauhaus Design School. From it was established in 1967 until it changed its name in 1998, it was called School of Arts and Crafts [Kunsthåndværkerskolen]. Design School Kolding has around 380 students specializing in five disciplines: fashion, textiles, industrial, accessories (from summer 2014) and communication design at bachelor's and master's level ("DSKD - information" 2014).

The school has three overall strategic areas: 'Design for sustainability', 'Design for play' and 'Design for well being' integrated in the curriculum as a whole and into individual courses. Materials and sustainability, being one of the central points of the project, therefore fit well into the school's overall strategy.

In the call for the PhD position, Design School Kolding wanted a project that put emphasis on "New materials within a design professional and sustainable frame of reference" ("PhD call," 2011) that should "contribute to building knowledge of new materials in a broad design sense (…)" (Ibid.). It was further stated that knowledge from the project should "strengthen creativity and innovation in terms of education and practice, contribute to renewed self-understanding, and support design solutions to the many future challenges of product design" (Ibid.). The quotes are included to highlight the institutional motivation and the preliminary premises for the project. Design School Kolding wanted to explore the role of emerging materials and sustainability for the product design discipline and especially in the design education building on the work and legacy of textile engineer, Joy Boutrup and textile designer, Annette Andresen from more than a decade of materials courses. The project should provide knowledge to strengthen creativity and promote the self-understanding for future designers based on actively learning about subjective and objectives of materials in a sustainable context.

Personal motivation, roles and competences

In the preface I stated that I'm a 'material girl' and materials have fascinated me as long as I remember. My courses have primarily developed my understanding of materials, and especially textiles, as physical objects. This resulted in a BSc in Textile Technology from the Swedish School of Textiles followed by an MSc in Design & Innovation from the Technical University of Denmark.

My textile technical background has been fundamental in the project. Being responsible for and teaching in materials courses have helped me to identify the problem area, to get a context and to collect valuable data. My driver in the courses has been, and will remain, the students' appreciation of the efforts I make.

I chose to study Design and Innovation to widen my understanding of textiles as materials useful for more than clothing but I graduated with wider knowledge on the design discipline. Design engineers, of whom I am one, concentrate on structures and methods. Jan-Pieter Stappers has suggested a topology of meta-levels that describes the roles humans take (reflecting or using methods) ranging from a philosophical role that applies methods to organize thoughts to the role of methods in life as a way to structure experiences and act from them (Stappers, 2009). Building on Stappers, I have applied different approaches to methods in the projects:

- On a philosophical level I have reflected on the roles of methods in materials teaching and for future development of materials understanding among product designers (philosophical level cf. Stappers (Ibid.)).
- On a methodological level, I have designed the research method used in the project to be able to extract information and generate knowledge to create a greater understanding of the field (methodological level cf. Stappers (Ibid.)).
- On the level of applied methods/tools, I have developed methods and tools for students to access materials, translate material meanings and evaluate materials (tool designer level cf. Stappers (Ibid.)).

The topology highlights that methods have had different roles and they are therefore approached in different ways. The methodological level is primary applied in Chapter 3 where the research approach is presented; the tool designer level is predominantly applied in Chapter 7, 8, 9 and 10, where methods are tested and evaluated; and the philosophical level is applied throughout the dissertation when the roles of methods in materials practice are discussed.

In addition to the competences I have from my educational background, I have had the privilege of working with something that truly interests me. I have deliberately chosen to write this dissertation as a first-person narrator. I have done this to emphasize that this dissertation documents the approach I have taken in the materials in design education field. I have conducted the study based on the competences I had and have acquired during the last three years. Nevertheless, I also acknowledge that I'm not an expert in all the fields I have considered.

I am aware that the dual role of being the researcher responsible for collecting and analyzing data and the lecturer responsible for teaching and discussing with students may seem as problematic to some. I have tried to split these roles and exploit the project to gain valuable insights into the student's practice. A discussion on this dual role is found in the discussion (p. 235ff).

Research exchange and collaborations

From October to December 2013, I had my daily employment at the Construction & Product Development section (Konstruktion & Produktudvikling), Department of Mechanical Engineering at the Technical University of Denmark under supervision of associate professor Torben Lenau. I did my master's in the department and it was a reunion with familiar faces and with the design engineering mindset I was schooled in. The temporary relocation provided peace to analyze empirical data and a reintroduction to the more structured aspects of the project.

From February to July 2014 I was affiliated with the Reliability & Durability section at Department of Design Engineering, Faculty of Industrial Design Engineering at Delft University of Technology. With supervision of assistant professor, Dr. Elvin Karana I was given the opportunity to be a guest researcher in an institution that positions itself between industrial design and engineering and with focus on experiential aspects of products. In a 'Materials for Design' course a workshop on the use and appreciation of the materials selection matrix was conducted.

Translations and language use

The majority of the experiments have been conducted in Danish. To strengthen the connection to the course curriculum and to the theory taught in design schools, some Danish terms have been included [in square brackets]. This arises especially for materials' attributes and how they relate to the argument and to the context. I have been responsible for the translations and I'm aware that even though translations have been made as objective and direct as possible, some English terms are more technically oriented than their Danish counterparts, because I have adapted them to a technical vocabulary. The workshop in the Materials for Design course at Delft University of Technology was conducted in English. Therefore most of the matrices and sketches were filled in and described in English.

In Appendix [A6], a list of attributes in Danish and English is provided. The properties and characteristics have been extracted from comparative material scales and material selection matrices made in the materials courses at Design School Kolding. The list demonstrates the variety of material properties and characteristics students have to navigate, and provides a basic dictionary for students to be used and developed in their future material practices.

CHAPTER SUMMARY

This first chapter of the thesis introduces briefly the motivation and premises for the project. The project motivation stems from the increasing complexity of meanings of materials, changes in design education and a focus on sustainability in product design. This calls for rethinking material teaching in design courses. The premises establish frames for the project by means of core concepts, scope, motivation, roles and competences and collaborations. Finally it deals with working in both Danish and English and how it has been manifested in the dissertation.

Summary

- The project contributes a materials teaching methodology building on materials access, transparency and approachability and is relevant due to a changing material landscape, developing material educations and the need to consider sustainability in product design.
- Core notions are 'materials meaning', 'materials understanding', 'sense making' and 'sensegiving', 'mindsets' and 'communities of practice', 'physical and 'experiential' material attributes, 'sustainable design' and 'practice-based' and 'experiential' learning.
- Key actors are 'Students', 'Materials', 'Learning', 'Teaching', 'Materials courses', 'Methods/tools', 'Material understandings', 'Sustainability', 'Physical properties' and 'Experiential characteristics'.

2. DESIGN PRACTICE, EDUCATION AND RESEARCH

The following chapter provides a short introduction to different approaches within design practice, education and research. The introduction is made to establish an understanding of the field in which the project has been conducted. Even though the introduction by no means is comprehensive, it should create an overview of, how the design field differentiates from other, adjacent fields.

DESIGN PRACTICE

The product design profession arose from the industrial revolution in the 18th and 19th centuries to provide products optimized for industrial machinery. Later design shifted focus as a response to the streamlining of products in the industrial revolution putting more emphasis on crafts as a discipline. This means that design as a discipline and profession is rooted in different needs that put emphasis on various things. Consequently this created design disciplines with focus on arts and craft as well as engineering and industrial production.

This project primarily focuses on three disciplines that all work with products, being fashion, textiles and industrial design. In Denmark, the design schools that educate fashion and textiles designers are grounded in arts and craft design practices, while industrial design can be rooted in both disciplines, thereby emphasizing on both arts and craft and more technically oriented practices and understanding.

Design as a cultural category is situated in an often undefined and ambiguous position between arts, production and commercialism (Jensen, 2005: 26). Nevertheless, even though the design profession is multifaceted, it is evident that there is a strong and shared identity of being a designer. It may correspond to a tendency that designers often link what they do with what they are and therefore the profession goes beyond professional service and identity to also include personal identity (Jensen, 2005: 27). The design profession can be regarded as a community of practice (Wenger, 1998) (see Chapter 5), where the relations between actors in the community are dynamic and changeable. Because the professional design discipline is not clearly defined, it is necessary for the designer to work continually on her/his identity and position her/himself in the tension between different oppositions in the design field such as arts and commercialism, crafts and industry and self-realization and social benefit (Jensen, 2005: 26).

For the last 20-30 years, the identities of designers are being challenged further by what could be called a new paradigm in design practice and a transition from ‘Old design’ to ‘New design’ (Wasserman, 2009). The notion of design seems to be moving away from a narrow artistic-aesthetic and product-oriented understanding, where design implies an 'object' towards a more spatial notion of design as a 'methodology', a strategic tool to innovate and develop across disciplines and on all levels of development processes (Center for Designforskning, 2005: 9). This calls for a new mindset that increasingly integrates and merges the two mindsets and practices. As part of this, it has been relevant to understand the design discipline, in what Cross calls in 'Studies of Design' (Cross, 2006: 99), to "establish appropriate structures for the design process, the development and application of new design methods, techniques and procedures, and reflection on the nature and extent of design knowledge and its application to design problems" (Cross, 1984). Even though "there are forms of knowledge peculiar to the awareness and ability of a designer, independent of the different professional domains of design practice" (Cross, 2006: 100), design is still often communicated as a multidisciplinary discipline that draws from traditions in arts and craft, humanities, social sciences, natural sciences and engineering.

While formalized methods increasingly become parts of design practice, it is vital to remember, that 'designerly thinking' is just as much about the decisions and reflections that are in-between or embedded in the methods themselves. These can be difficult to comprehend, articulate and thereby include in formalized processes. Based on interviews with designers, Cross suggests that designers find some aspects of their work natural, perhaps almost unconscious, ways of thinking and because they feel relaxed about making decisions and generating proposals in the design process, they feel no need to seek rational explanations or justifications (Cross, 2011). Chapter 5 will return to Schön's 'the reflective practitioner' (Schön, 1983), that can be used to understand the distinctiveness of design practice.

DESIGN EDUCATION

Design education has developed with the transformation of the design field and can now be found in many different variations. The dissertation will return to these, but for now it will focus on the course based on arts and crafts, as this has been the primary learning environment studied in this project.

The first design school, School of Design was founded in London in 1837 to support new needs from the industry and to strengthen competitiveness (Forty, 1992). At the end of the 19th century, the first arts and craft courses were founded in England as a critique of the industrial revolution where traditional crafts were replaced by industrial manufacturing (Pye, 1968). The courses wanted to reestablish aesthetic and decorative qualities in consumer goods that had been suppressed in the search for low cost products.

Present artistic design courses often refer to the German Bauhaus school that operated from 1919 to 1933 (Fiedler and Feierabend, 1999). That school's pedagogic and aesthetic visions were ahead of its time and were influenced by the period's pedagogical trends (among these the writings of John Dewey) (Díaz, 2008: 260), based on political streams and cultural changes. The school built on practice-based knowledge creation with basic courses (In German: Vorkurs) and follow-up specialization courses in practical workshops taught by Itten, Moholy-Nagy and Albers (Fiedler and Feierabend, 1999; Moholy-Nagy, 1947) among others. Here materials and practices were vital components of the didactics applied. In figure 3, the Bauhaus Educative Scheme from 1922 shows the course structure with the basic course (outer shell) followed by 'study of materials and tools', 'study of nature', 'study of materials', 'space study - color study - composition study' (second outer shell) and 'study of construction and representation' in first and the 'clay', 'stone', 'wood', 'metal', 'textiles', 'glass' and 'color' (third shell).

Figure 3. The Bauhaus Educative Scheme (Schema zum Aufbau der Lehre) by Walter Gropius, 1922. The scheme shows, how the courses progress from the basic course to further specialization.

Johannes Itten, who developed the basic course in 1919, formulated a 'theory of contrasts', building on senses and expressions that became fundamental for the course. The theory and the exercises that were built on it allowed students to explore basic and special material characteristics based on hands-on exploration (Wick, 2000) in what today could be called active or interactive learning. The learning approach facilitated students' further education in practice based materials-oriented workshop courses.

Before the industrial revolution arts and crafts were learned through apprenticeships, where apprentices were observing, imitating, copying and developing the practice of the master. Generation after generation the practice was handed down by hands-on work and 'doing' with little written communication. In the established arts and craft education systems, the former apprenticeships were re-established and formalized. The apprenticeship was moved from industrial workshops to learning environments that offered different opportunities and challenges. In the Bauhaus school, teachers formulated their ideologies and methods in a number of seminal writings (Gropius, 1925a, 1925b; Kandinsky, 1926; Klee, 1923; Meyer, 1924; Moholy-Nagy, 1929). Since design education has developed and progressed in accordance with the trends and tendencies in the design field and in the society in general, however still building on many of the same principles as the Bauhaus School.

The use of methods and systems thinking as part of design originates from mechanical engineering. The first technically oriented industrial design program worldwide was established in 1969 at Delft University of Technology at the Faculty of Architecture ("TU Delft - IO," 2015). The program stressed topics such as ergonomics, technical subjects, market research and management. Building on traditional engineering but focusing on design, product development and manufacturing, the technical industrial design or industrial design engineering programs that have emerged since, put much weight on transparent processes using methods and systems thinking for exploration and development.

Interaction design and human-computer interaction studies occurred at the end of the 1970s due to the increased use of computers and technology in society (Card et al., 1983). Since then, interaction design has developed into user experience as a broad term to understand, how users (humans) experience products, services and phenomena. It has resulted in stronger links to anthropology, sociology and psychology as these can be used as theoretical foundations to understand the interaction between users and artifacts (for example Schifferstein and Hekkert, 2008; Shove et al., 2008).

Eco-design and environmental design emerged in the 1970s (Papanek, 1971) and has evolved from the increasing concerns of the global condition and our future on the planet, while service design (for example Stickdorn and Schneider, 2012), product-service systems (for example Osterwalder et al., 2014) and strategic design combine all the above-mentioned trends to create holistic sustainable systems where users, products, services and business models interact and function together (Lindahl et al., 2013; Robèrt, 2012).

The role of design education on designers' professional identities

From a report published by the Danish Center for Design Research, it appears that designers appoint educational institutions as the places where design idealism is founded and where it can be practiced (Jensen, 2005: 31). This means that design education is the breeding ground for how future designers identify themselves and their work, which emphasizes the importance of establishing strong and coherent self-understanding from the beginning. From the report, it also appeared that the designers felt restricted by their educational design discipline. In the artistic design courses, educational differentiations are rooted in practical specializations in traditional apprenticeship situations (Jensen, 2005: 33). It is however evident that specializations and thus also characteristics of the disciplines are softened and graduating designers are increasingly considering themselves as 'designers' more than designers in a specific discipline. This chapter does not concern materials, but it is relevant to mention that the changing identities of designers entail a different methodology for introducing and discussing materials in design education that increasingly embrace ways to explore a broad selection of materials rather than focusing on specific material categories.

Different kinds of design courses

Very simplistically, three approaches to design education can be identified: one rooted in arts and craft (figure 4), one in business and industry and one in engineering and technology (figure 5). The approaches have further defined learning philosophies and methods used, meaning that arts and craft design courses emphasize practice; business and industry emphasize application and sales, while engineering and technology design courses emphasize methods and structures. The gap between different design courses becomes smaller as the educators learn from, interact and inspire each other. The different approaches have been illustrated using a triangle with the extremes 'arts and craft', 'business and industry' and 'engineering and technology'. The design educations in Denmark that are presented in the following overview correspond to this triangle.

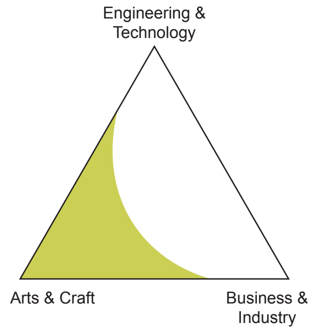


Figure 4. Philosophical orientation at artistic design educations.

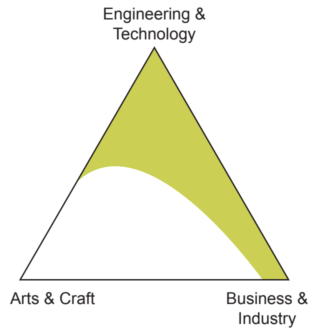


Figure 5. Philosophical approach at engineering oriented design disciplines.

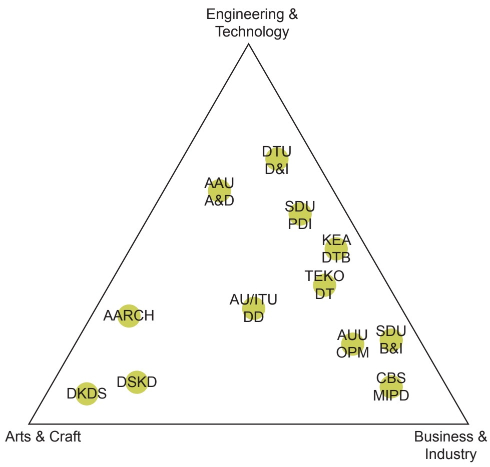
Design courses in Denmark

In Denmark design courses are found in different learning environments. Design School Kolding and The Royal Danish Academy of Fine Arts, School of Design are rooted in artistic design and educate designers through practice-based training. The institutions offer 3 years BA and 2 years MA programs focusing on material-based learning in well equipped workshops, where students obtain the academic title 'Cand. Design' ("KADK - School of Design," 2014). In addition also Aarhus School of Architecture educates industrial designers ("AARCH - ID," 2015).

The Technical University of Denmark (DTU), the Southern University of Denmark (SDU) and Aalborg University (AAU) educate engineering and industrial designers in 5 year programs ("AAU A&D," 2014, "DTU D&I," 2014, "SDU PDI," 2014), where graduates obtain Master of Science in engineering degrees within their specialties [civilingeniør]. The Southern University of Denmark, Aalborg University and Copenhagen Business School (CBS) educate graduates in business and entrepreneur-oriented design ("AAU OPM," 2014, "CBS MIBD," 2014, "SDU B&I," 2014), the IT University and Aarhus University educate graduates in digital design and communication programs that emphasize on user experience and interactive design ("AU Digital Design," 2015, "ITU Digital Design," 2015) and industrial education institutions such as Copenhagen School of Design and Technology (KEA) and the VIA Colleges (e.g. TEKO) offer shorter programs (2 years to 3.5 years) in Design, Technology and Business ("KEA DTB," 2015), Design Technology ("KEA DT," 2015, "TEKO," 2015) and Textile Design, Crafts and Communication ("TEKO - Textile," 2015).

In figure 6, the Danish design courses have been tentatively positioned according to orientation towards 'engineering & technology', 'arts & craft' and 'business

Figure 6. Positioning of the Danish design educations according to orientation towards Engineering & Technology, Arts & Craft and Business & Industry.



& industry'. The mapping serves to show that working with design has many different entrance points, which also means that designers have various identities creating a broad and diverse design field. The positioning has been made as a tentative mapping based on subjective interpretations of the courses extracted from the curriculum, objects and learning goals of the respective courses.

DESIGN RESEARCH

Research in design is still in its infancy. The increasing complexity of modern technologies in products has led to the establishment of design as an academic discipline, and a rapid growth in the connections between science, engineering and design (Stappers, 2007: 81).

Stappers has compared the disciplines of research and design (Stappers, 2007). He argues that whereas "research is perceived as seeking to understand of the past or present state of the world, and to establish explanations of why it must be so (…) based on validity and proof, by logical reasoning and empirical measurement (…) design is seen as being concerned with establishing a working effect in a possible future, realizing successful instantiations in a world that does not yet exist and is not yet known based on methods and manifestations that emphasize inspiration realization in-the-world, and proof by demonstration" (Stappers, 2007: 82). With this Stappers says that, while research tends to put emphasis on structuring the past and the present, design looks forward and wants to construct better futures. This difference in time and scope for design and research or design and science has previously been highlighted by Buchanan (1992) and Simon (1996) among others. The different emphasis and cultures means, that combining the two disciplines often leads to conflicts. However, design and research also share commonalities. They both exist to improve the understanding or control over the human condition and are methodologically characterized by iterative cycles of generating ideas and confronting them with the world (Stappers, 2007: 82). Design and research can benefit from each other; design skills can be used in research to enhance the exploration space through creative processes and methods and research in design can create understanding of, what design is and how it can be used.

Different scholars have discussed, how research from established disciplines can be positioned towards each other (for example Feyerabend, 1993; Harré, 1981; Stoke, 1997). Horváth has looked at, how design research can be positioned in the research landscape and writes that design research takes a middle ground between disciplinary 'basic' research and practical application and is found in three states that translate and transport knowledge between former (traditional and ontological extremes) (Horváth, 2007). The three states are 'research in a design context', 'design-inclusive research' and 'practice-based design research', which also can be labeled 'research on design', 'research in design' and 'research through design' (Frayling, 1993).

I have hesitated to label the research approach in this project, as it has been influenced by different traditions and disciplines. Instead, it is positioned as a constructive design research project, with reference to Koskinen et al.'s use of constructive design (Koskinen et al., 2012). It is stated that "design researchers can explore new materials and actively participate in intentionally constructing the future (…) instead of limiting their research to an analysis of the present and the past" (Zimmerman and Forlizzi, 2008). This establishes constructive design research as "design research in which construction – be it product, system, space, or media – takes center place and becomes the key means in constructing knowledge" (Koskinen et al., 2012: 5). In constructive design research, the research objects are thus the product, systems, spaces or media that are investigated and the research subjects are the intended users. Constructive design research is multidisciplinary and includes disciplines such as sociology, anthropology and computer sciences (Ibid: 29), and acknowledges the need for approaching a problem from different angles.

This project has predominantly been influenced by four disciplines: 'artistic design', 'engineering design', 'learning and pedagogics' and 'science and technology studies'. The four disciplines have influenced the theoretical framing of the project, especially based on science and technology studies and learning theories and the procedural frame based on artistic and engineering design. The theoretical angles are covered in Chapter 4 and Chapter 5 and the methodology is presented in Chapter 3. To establish the premises for the methodological approach, two research approaches from respectively artistic and engineering design are presented now.

Methodologies in design research

Based on constructive design research, Bang et al. have proposed a research model called the Entrance Level-model (Bang et al., 2012). The model describes links and interactions between motivation, hypothesis, research questions, experiment, evaluation and knowledge creation metaphorically illustrated in a cogwheel. In the Entrance Level-model experiments have the central place, stressing the role of experiments to create strong and relevant knowledge of the subjects or objects investigated. The Entrance Level-model is shown in figure 7. According to the figure, it is evident that design research processes are non-linear, interactive and iterative processes.

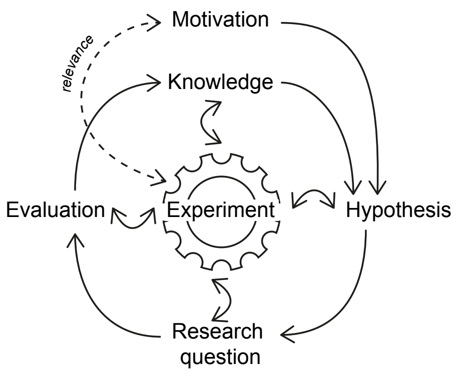


Figure 7. Entrance Level-model (after Bang et al., 2012).

Based on engineering design research, Blessing and Chakrabarti have proposed a Design Research Methodology (Blessing and Chakrabarti, 2009) structured in four stages: 'research clarification', 'descriptive study 1', 'prescriptive study' and 'descriptive study 2' (Ibid.: 39) (see figure 8). The structure serves to answer two objectives of design research namely to (1) formulate and validate models and theories about the phenomenon of design and to (2) develop and validate support

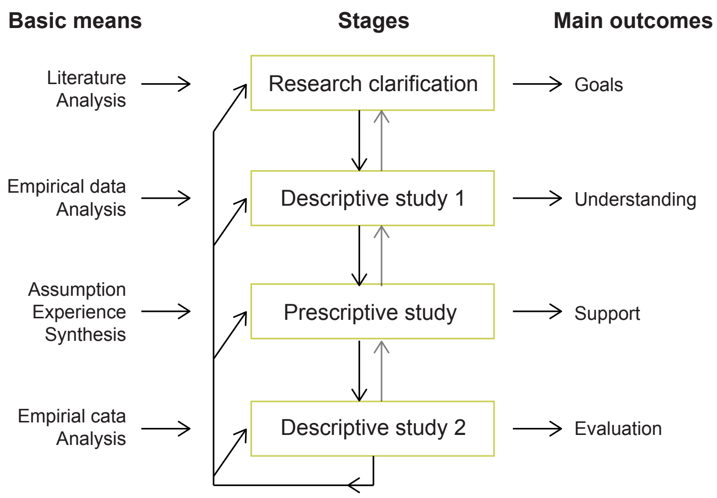


Figure 8. Design Research Methodology (DRM) (after Blessing and Chakrabarti, 2009).

founded on these models and theories, in order to improve design practice.

Both methodological proposals include different but relevant components. The Entrance Level-model provides a means to create coherence and to reflect on design research as a mental process, whilst the Design Research Methodology provides a model to structure and overview a methodology. While the Entrance Level-model and other experimental design research methodologies such as the programmatic diagram suggested by Brandt and Binder (2007) establish conditions for using a methodology, the Design Research Methodology and other structural methodologies such as the Stage Gate model (Ulrich and Eppinger, 2011) systematize the process and describe basic means and main outcomes of each of the stages.

The applied research methodology has found inspiration in both of the above-described methodologies. The constructive design methodologies have influenced the dynamics and interactions between components of the methodology, while the structured methodologies have inspired systematic and controlled structures for the conducted experiments, by means of the purposes of the experiments, experiment evaluations and how knowledge from the experiments fit into the overall knowledge generation.

CHAPTER SUMMARY

The chapter has introduced three dimensions of design namely design practice, education and research. The design discipline interacts with adjacent disciplines such as arts, engineering, social sciences and humanities and therefore design can be found in many different variations and interpretations. In recent years, design has become increasingly focused on 'methods' rather than 'objects'.

Summary

- The design practice positions itself between arts, production and commercialism in a strong community of practice and shared identity.
- Design courses are typically oriented towards arts & craft, engineering & technology and/or business & industry.
- Methodologies in design research aim to understand processes and build on reflection and coherence as well as structures and analysis.

3. DESIGN METHODOLOGY

This chapter presents the project's research method. The underlying mindset can be traced back to the two methods that were introduced in the previous section: the Entrance Level-model (Bang et al., 2012) from constructive design research and the engineering-inspired Design Research Methodology (DRM) (Blessing and Chakrabarti, 2009).

PROCESS

The first element concerns the process and describes the framing of the overall methodology by means of motivation, hypothesis and research questions and how these interact.

In Bang et al.'s Entrance Level-model (2012) motivation is one of the components of the research process and can act as a catalyst to multiple other steps in the process as well as be the result of them. Motivation exists on several layers: 'individual motivation' from the person that conducts the projects and perform procedural decisions that is here being me, 'organizational motivation' from the institutional and political interests in a project and 'societal motivation' influenced by social agendas and streams. The organizational and social motivations were presented as three challenges in Chapter 1. Background stressing a changing material landscape, developing material education and increasing sustainability concerns in product design.

Project hypothesis and research questions

The three challenges identified in the background have been condensed into a hypothesis. Rienecker and Jørgensen have defined a hypothesis as '(…) a prediction of an answer to a question or a problem that it is expected to be found (…)' (Rienecker and Jørgensen, 2012). To me the statement clarifies the motivation and acts as an initiator and catalyst that helps to guide and set up overall frames for a project. A hypothesis should therefore grasp the essential features the project consists of, and be fixed at some point, enabling you to return to the hypothesis, if research questions, experiments or results become unfocused. Furthermore, the hypothesis should be clear and straightforward, but also leave room for exploration and modification. Based on these considerations, the hypothesis for this project has been that:

> *"A stronger emphasis on* ***materials teaching*** *in* ***design education*** *can strengthen* **awareness of materials** *among [product] design students and help students make stronger and better-founded* ***choices of materials*** *in a* ***sustainable perspective****".*

The hypothesis stresses that creating better-founded material choices in the end create better products, as suitable and non-suitable materials have been explored and reflected on.

The hypothesis highlights five dimensions that have functioned as guidelines to frame the theory use, empirical studies and analyses. They have operationalized the agenda, defined directions in which the experiments should go, provided a context to evaluate and discuss the findings of the experiments and functioned as bridge-builders to external stakeholders to whom relevant knowledge generated in the project could be communicated. Each dimension has been clarified and qualified in research questions equivalent to design questions or problem statements if using design terminologies.

The research questions have been divided into one primary and five secondary questions. The primary research question links directly to the hypothesis, while five secondary questions link to the dimensions.

The primary research question is:

> *"How can a renewed understanding of materials in design education help students to develop well-founded material choices supporting more sustainable decisions?"*

Secondary research questions are:

Design education [RQ1]

> *"How can a stronger focus on material understanding in design education help students to use new materials as a more integral part of the design process?"*

Materials teaching [RQ2]

> *"Which tools and methods are used and needed for the material education to satisfy the requirements from stakeholders such as students, the educational institutions, and industry?"*

Material meanings [RQ3]

> *"What kinds of material meanings are essential for design students to strengthen their material awareness and how do they communicate materials?"*

Material choices [RQ4]

> *"How do design students choose materials? - And if the process can be improved, how can it be approached?"*

Sustainable perspective [RQ5]

> *"How can a stronger materials awareness improve the sustainable impact in product design?"*

Methodological hierarchies

In the Entrance Level-model (Bang et al. 2012) the experiment takes a central place surrounded by a hypothesis, research question(s), evaluation and knowledge. The model leaves room for a non-linear (and even circular) development process as opposed to the linear design research methodology proposed by Blessing and Chakrabarti (2009). However the lower degree of structure makes the detailing of the model less significant. The methodological approach applied in the project has been inspired by both a designerly and an engineering approach to its methodology. The overall methodology has been framed by a designerly approach, similar to the Entrance Level-model, while the detailing has stressed a higher degree of structure, similar to the Design Research Methodology. The combination makes the frame simultaneously dynamic and static.

The hypotheses and research questions challenge and create overall frameworks for the project to maneuver in. To activate the hypothesis and research questions an underlying level of the two concepts has been applied for in-depth investigations. Here they are called subordinated hypotheses and subordinated research questions and are analogue to Bang's 'dynamics guides' used in her PhD dissertation (Bang, 2010: 243). The subordinated hypothesis and research questions operationalize the hypothesis and primary research questions in specific experiments and for specific modes of enquiry.

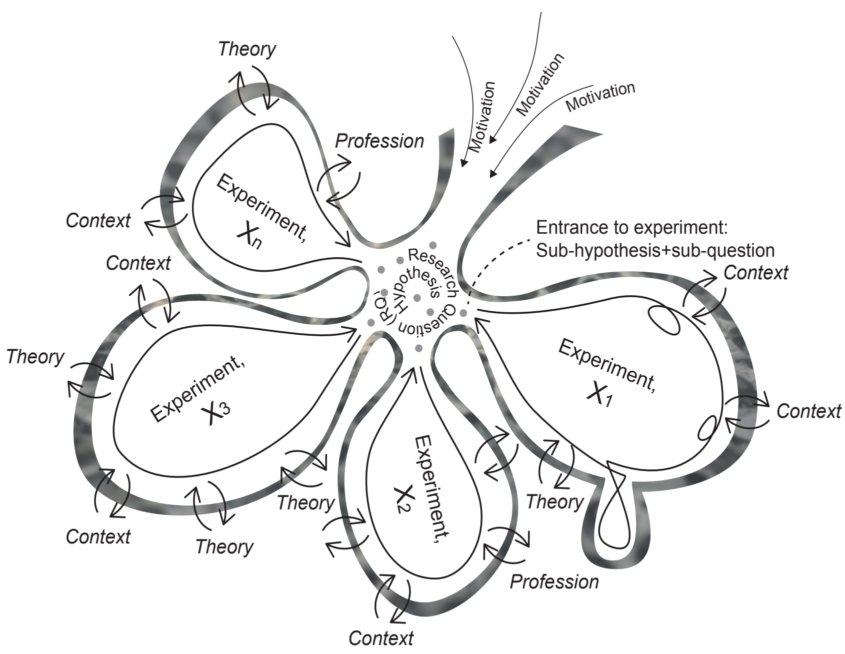


Figure 9. The Jellyfish-model used as the research approach in the project. The Jellyfish-model puts the hypothesis and the research question as the center place. From links to experiments, the hypothesis is fed with generated knowledge to support the hypothesis.

The Jellyfish-model

The methodological approach applied in project has been named the 'Jellyfish model' mainly after its flexible nature and shape and is illustrated in figure 9. In contrast to the Entrance Level-model (Bang et al., 2012), where the experiment is in the center, the Jellyfish-model centers on an imaginary 'soup' containing the hypothesis and research questions as well as the knowledge generated during the project - being defined or undefined, standing alone or being united.

The knowledge soup is linked to experiments through gateways that define the purpose of the experiments based on the hypothesis, research questions and existing generated knowledge. The gateways further serve to define and structure the knowledge extracted and generated from the experiments. The experiments are connected to the context they are conducted in, relevant theories and experience through dynamic membranes that allow continuous interaction between the two sides of the membrane. Hence experiment gateways are figuratively used to formalize experiments and to describe their contributions to the project.

Due to the context of the studies conducted, it was a challenge to predetermine and structure most experiments thoroughly beforehand, as the specific courses and the participating students influenced the execution of experiments. However the further the project developed, the easier it was to set up specific goals for experiments. The protocols have therefore helped to systematize experiments in iterations (within the same bubble) and to combine experiments (different bubbles).

With inspiration in natural science, the knowledge generation and the use of gateways can be abstractly described by chemical reactions. A reaction consists of three components: reactants, products and catalysts. The reactants are what you put into the reaction, the products are what you get out the reaction and the catalysts are what initiate or keep the reaction going. Subordinated hypotheses and research questions are used to prepare experiments and consider premises such as the context and time. This part reaction is shown in Equation 1, where the subordinated hypotheses and research questions have been denoted h_i and rq_i corresponding to the experiment, x_i.

$$h_i + rq_i \xrightarrow{\text{Premises[I]}} x_i$$

[Equation 1]

The desired product in the reaction is knowledge. The knowledge output (extracted knowledge) from the experiment is dependent on the experiment itself and its premises. The product of the reaction is influenced by evaluation and analysis. In the part reaction shown in Equation 2, knowledge is denoted k_i.

$$x_i \xrightarrow{\text{Premises [II]}} k_i$$

[Equation 2]

The knowledge generated in each experiment had to be collected and assembled to relate and interact to become coherent knowledge. Knowledge generation and experiences acquired are not necessarily tangible and useful at first and they need to consolidate and mature. Experience from experiments has to connect and interplay with impressions and experiences from other experiments, from theory or other external sources such as talking to people. Knowledge strings and a knowledge pool have been used as metaphors to describe the immature and unconnected state of knowledge from individual experiments and the shared space for knowledge to grow, connect and mature. In Equation 3, knowledge strings from individual experiments are connected into a shared and collective knowledge output.

$$\sum k_i \xrightarrow{\text{premises}} K$$

[Equation 3]

Different premises rule in the different parts of the experiment. Premise[I] relates to the construction and setup of the experiment, Premise[II] relates to the evaluation and analysis of the experiment, while Premise[III] relates to the collection of knowledge components. The premises describe adjustable variables that allow experiments to be modified and improved. The premises allow experiments to be descriptive or prescriptive (cf. the Design Research Methodology as proposed by Blessing and Chakrabarti (2012)), as they define the orientation of the respective experiments and how restrictive or explorative their setups are.

EXPERIMENTS

The experiments in the project have been conducted to illuminate research questions and have been related to the learning environments they were conducted in. Learning environments are subject to continuous changes and modifications, which meant that it was a challenge to keep strict protocols and to predict the nature of the data that could be extracted from the experiments. The structured and yet flexible research methodology helped to establish dynamic experiments.

In a simplistic interpretation the common understanding of experiments corresponds to a clear procedure that is easy to extract data from and to reproduce and that is independent of the context it is executed in. Experiments are also used in design research, but here the term has a broader meaning than when it is used in natural scientific disciplines. Bang et al. suggest that the experiment serves as the drive wheel of constructive design research and can as such inform at (and be informed by) every level in the research process (Bang et al., 2012), Binder and Redström argue that design experiments must engage with a reality of designing outside the research setting (2006) and Koskinen et al. talk about constructive design research as strings of actions that construct knowledge, but do not elaborate further (2012).

Here an experiment is interpreted as a systematic action to collect knowledge or experience. Whether it is spoken or tacit, an experiment can answer or clarify a hypothesis or an unresolved question. Thus experiments can provide wide as well as specific and supplementing answers. In contrary to quantitative research, in design research and other predominantly qualitative research disciplines, output from experiments are not always clear-cut, which makes the interpretation and further development of experiments more complex. Hence combinations and iterations of experiments can provide a multifaceted and holistic understanding of the investigated field.

Experiment settings

The relative novelty of the design research field means that different research approaches seek to position and define the field. A basis to discuss the characteristics of experiments has been proposed in Koskinen et al. (2012) by means of the notions the ‘lab’, ‘field’ and ‘showroom’. The ‘lab’ draws from the natural scientific tradition of laboratory experiments, the field from the social scientific tradition of fieldwork and observations, and the showroom from the arts tradition of exhibitions and exploratory showpieces. In this project, a combination of ‘lab’ and ‘field’ is applied called the ‘field experiment’ (Ibid.: 51ff).

Field experiments

In the distinction of approaches proposed in Koskinen et al. (2012), the risk is to create an artificial gap between the ‘lab’ and the ‘field’ (or between the experiment and the fieldwork, terminologies used by Brewer and Hunter (2006)). Field experiments combine these otherwise traditional distinctive and opposing settings and can be described as controlled and constructed experiments conducted in the field, i.e. in a ‘real’ world situation. The methodological approach combines methods and reasoning from both natural and social sciences respectively and corresponds to subjective as well as objective analyses within the domains the experiments are framed in.

Gerber and Green state that field experiments should invoke several criteria, such as (1) whether the treatment used in the study resembles the intervention of interest of the world, (2) whether the participants resemble the actors who ordinarily encounter these interventions, (3) whether the context within which subjects receive the treatment resembles the context of interest, and (4) whether the outcome resembles the actual outcomes of theoretical and/or practical interest (Gerber and 2012: 11).

Materials courses are used as the frames of the project and are defined by course descriptions and the institutional culture. The materials courses provide controlled settings, but because students are familiar with the learning environment, they do not experience the boundaries of the experiments as being more limiting and restrictive. To this Harrison and List write that “(…) In the sense that one is able to observe a subject in a controlled setting but where the subject does not perceive any of the controls as being unnatural and there is no deception being practiced" (Harrison and List, 2004: 1010). Field experiments cover the entire range of experiments in controlled or uncontrolled settings and the experiments conducted in this project show similarities to what Harrison and List call 'artefactual' or 'framed' field experiments (Ibid.). An artefactual experiment employs a standard non-subject pool, an abstract framing, and an imposed set of rules, while a framed field experiment employs a standard non-subject pool, an abstract framing, an imposed set of rules and with field context in either the commodity, task, or information set that the subjects can use (Ibid.: 1013-1014). Here artefactual means that the studies are based on specific tools to explore materials and framed means that the experiments have been framed by for example the course settings.

The field experiment as a way to unravel the reality

Latour has pinpointed that in order to ensure a successful translation between different settings, such as between controlled and uncontrolled settings, it is essential to understand the actors involved (Latour, 1983). He has written that "they (scientists) learn from the field, translating each item of science into their own terms so that working on their terms is also working on the field" (Ibid.). Put in another way, traditionally (natural) scientists dealt with real-life problems that were converted into controlled settings and then adapted to help the problems. As a result, a successful translation was dependent on the translators' ability to create their own meaning, but also to communicate this newly created meaning to others. It is thus vital that translation is considered not only in one way, such as from 'field' to 'lab', but with knowledge translation from 'lab' experiments that can be extended to and applied in the field. Any translation process influenced by the action of translation and meanings is distorted (Ibid.). Field experiments operate on a meta-level between the 'lab' and the 'field' and can facilitate the translation process, as it is not specifically oriented towards one of them. It has been acknowledged that in this thesis, translation processes are subjective, which is in line with overall understanding that people and objects create and influence each other, for example by means of material meanings. As a result the taxonomy introduced by Harrison and List can refine the terminology of 'lab', 'field' and 'showrooms' and create a common ground for experiments that allows bridging experiment characteristics.

Domains of experiments

In the attempt to structure experiments, the concept of domains of experiments is introduced. Domains describe a territory over which rule or control is exercised, a field or a space that share conditions ("Domain," 2015). In this research methodology they frame the conditions and the significance in which experiments have been conducted, for example in terms of context, participants (discipline and amount), and time and educational frame. In that sense domains share features with 'arenas of development' as used by for example Jørgensen and Sørensen (1999). They describe an arena of development as "a cognitive space that holds together settings and relations that comprise the context for product or product development (...)" (Ibid.: 410). Both domains and arenas of development consider contextual relevance and acknowledge the necessity of having a shared setting or 'space' to act in. The concept of the domain enables researchers to expose and identify potentials and obstacles that are significant for a specific domain across all experiments. Furthermore experiments generate more information than can be directly extracted and using domains allows this to be collected as supplementary and intangible knowledge.

In Table 1 below an overview of domains is provided. Domains will be further described as background for the empirical studies in Part III.

Table 1. Overview of four domains that describe kinds of experiments.

Domain	Characteristics
Course: Material introduction	Compulsory courses at Design School Kolding for 2nd semester fashion, textiles and industrial design. Duration 1+3 weeks with material theory lectures, part assignments and final assignment
Course: Materials & Sustainability	Compulsory courses at Design School Kolding for 3rd and 4th semester fashion, textiles and industrial design. Duration 3 weeks with material theory lectures and design project. Special focus: sustainability
Workshop: Materials and Design	2-hour workshop at Faculty of Industrial Design Engieering at Delft University of Technology for postgraduate students.
Educational workshops	Shorter workshops and assignments given in materials courses at other educational institutions
Miscellaneous	Relevant, but less structured activities such as student supervision, interviews and observations in other courses

It is however important to stress that fundamental insights also have been available just by being part of the learning environment at Design School Kolding such as through informal corridor chatting, discussions with students in other courses than the two materials courses and supervising students on miscellaneous projects.

RESEARCH OBJECTS AND SUBJECTS

The experiments have been based on students' use of educational tools and methods in materials teaching. The primary studies have focused on the materials selection matrix, while secondary studies have focused on tools and methods to support the matrix and to create an overall materials teaching methodology. The section provides an overview of tools and methods and discusses the role of the research objects in the overall research methodology.

- The materials selection matrix is a structural materials exploration and evaluation method introduced in the Materials and Sustainability courses at Design School Kolding. The method has been developed to explore material requirements, structure materials and to perform elaborate material decisions.

The supporting tools form a collection of educational tools either already used in the materials courses or introduced due to the scope and findings of the project to support to the materials selection matrix. The supporting tools include:

- The personal materials collection initiative: an initiative to encourage students to collect and index materials.
- Materials descriptions: collections of material information sheets made by students for students.
- The comparative material scale: a tool to explore materials' attributes by means of personal constructs and interaction between subjective and objective material aspects.
- The Hanger-model: a tool to overview and approach sustainability aspect and to create a sustainability vocabulary.

The role of the research objects

The experiments have been a means to study the use of different tools. The tools have had dual roles; they have served as facilitating tools in materials courses to explore and communicate materials and they have served as research objects to examine, how students approach materials in the courses. Thus they have also functioned as meta-products that have aimed to extract and make knowledge more accessible.

Some call such meta-products tools used for epistemic artefacts (Biggs, 2002; Richter and Allert, 2011; Tvede Hansen, 2009). Episteme relates to knowledge and epistemic artefacts can be described artefacts that generate knowledge. Tvede Hansen describes the use and need for epistemic artefacts as "(…) the creation of the artefact and the artefact itself can be seen as tools or means to develop theory in interplay with a verbal reflection and discussion" (Tvede Hansen, 2009: 6). In contrast to other epistemic artefacts that are developed specifically for the sake of the experiment and do not have to make sense outside the experimental setting

(Ibid.: 6) the tools in the project have multiple functions. According to Tvede Hansen, one of the advantages with epistemic artefacts is that it "enables the design researcher to ignore the design context, which usually is about the relationship the artefact and the user" (Ibid.: 6). However, because the tools have been developed and introduced specifically for the materials teaching at Design School Kolding, they are strongly connected to this context.

Students as users

In the beginning of the project it was not clear that teaching and students would become such important parts. Consequently it took some time to realize that this is a user-oriented project. By nature user-oriented design focuses on users' needs. The users here are not potential end-users of a commercial physical product as seen in many design projects, but design students.

Because the project was not framed as a user-oriented study it has not been labeled in terms of user-oriented design traditions such as user-centered, participatory and co-design (such as Brandt et al., 2011; Sanders and Stappers, 2008; Sanders and Westerlund, 2011; Sanders, 2002). The thesis will not go in depth with a distinct branch of user-oriented design approaches to prevent the restrictions and delimitations that could occur if doing so. Furthermore, because the user-orientation perspective in the project is somewhat retrospective, it has not been a conscious part of developing the project. In essence, students are the users of the investigated tools and methods and they have functioned both as research subjects and as research partners. They have not taken part in developing tools and methods, but their uses and outputs of and comments on the tools have guided the development of the studies.

Research in education

Teaching as the empirical basis has potentials and challenges. The project concerns learning and studying a learning environment is therefore an obvious place to conduct experiments. The atmosphere has been relaxed and natural, as students are not taken out of their normal environment. The two materials courses most experiments have been conducted in are mandatory, which means that not only students with prior interests in materials have participated in the experiments providing a complete representation of students.

It can be argued that education-based research can be of ethical concern, as research interests can influence the course curriculum and that students do not have the opportunity not to participate. In the project, my role as the teacher has been prioritized over my role as a researcher. It means that teaching has been the most important and that experiments have had to be fitted into the already often-compact course curriculum. Control groups have therefore not been used much to validate experimental data, as this could give students different learning outcomes.

Being both the teacher and researcher gives mixed roles. As a teacher, one role has been to ask questions and facilitate discussions, while as a researcher, one role has been to secure valid data for further analysis. There has been a strong but sensitive balance between subjectivity and objectivity for my part in the project. However, one of the strengths has been that I have been able to add another dimension of observations to my analysis, as I have taken part of the learning environment not only when specific exercises there conducted. The benefits and challenges of the dual role in the project are further debated in the Discussion.

THEORIES AND NOTIONS

The use of theory in the dissertation is not segregated in specific sections, but has been integrated and merged with practice-based findings. Thus the experience acquired and observations made have determined the directions the project has taken. The project has progressed due to practice-based findings supported by theory and theoretical inputs that have been empirically tested in experiments. In that sense, the project has shifted between inductive and deductive reasoning, where practice and theory have developed the project in a continuous interplay. Theory has helped to frame boundaries and to understand the relevance of the topic. It has served to motivate, develop and mature research approaches as well as to strengthen and validate experimentally induced findings. It has served as a connection between findings and as inspiration for new and alternative approaches. Due to the multiple aspects in the project, different kinds of theory have been integrated and merged.

The choice of theories and notions in the project

The choice of theory has been framed by the different approaches to the scope and has aimed to grasp both technical and experiential understandings of materials and learning with roots in engineering as well as artistic design. Even though the theories have been collected from different research disciplines, the underlying ontological understanding of the world correlates and builds on keywords such as contextuality and interaction in an overall social constructivist epistemology (Piaget, 1967).

The theories used in the project can be grouped in three overall clusters that interact and overlap. Components from materiality studies, science and technology studies and grounded theory have been used to understand relations and interactions between involved actors; components from social learning theories and sense making have established an understanding of the contextual learning environment; and systems theory has been used to explore dimensions of values and to develop tools and methods for the proposed materials teaching methodology.

I have allowed myself to use theories and notions from a wide variety of research disciplines, as the project has comprised many aspects. It has therefore been a challenge to ensure that the theories cohered and supported each other.

The use of theories and notions

In the diagram in figure 10 relations between the theoretical notions used in the dissertation are illustrated. The diagram serves to demonstrate, how the notions build on and supplement each other. As the diagram unravels the network of concepts, it also contains notions that are left out in the dissertation, but are central in adjacent research disciplines and/or function as basic frameworks. In the diagram, (ordinary) lines are direct relations, while dotted lines are notions from different frameworks that share characteristics.

The two following chapters, 'Chapter 4. Understanding materials' and 'Chapter 5. Learning and materials' are based on different and yet overlapping theoretical frameworks. The content of the two chapters are illustrated with two enclosures. The theories or notions that are written in grey are not explicitly touched upon in the thesis.

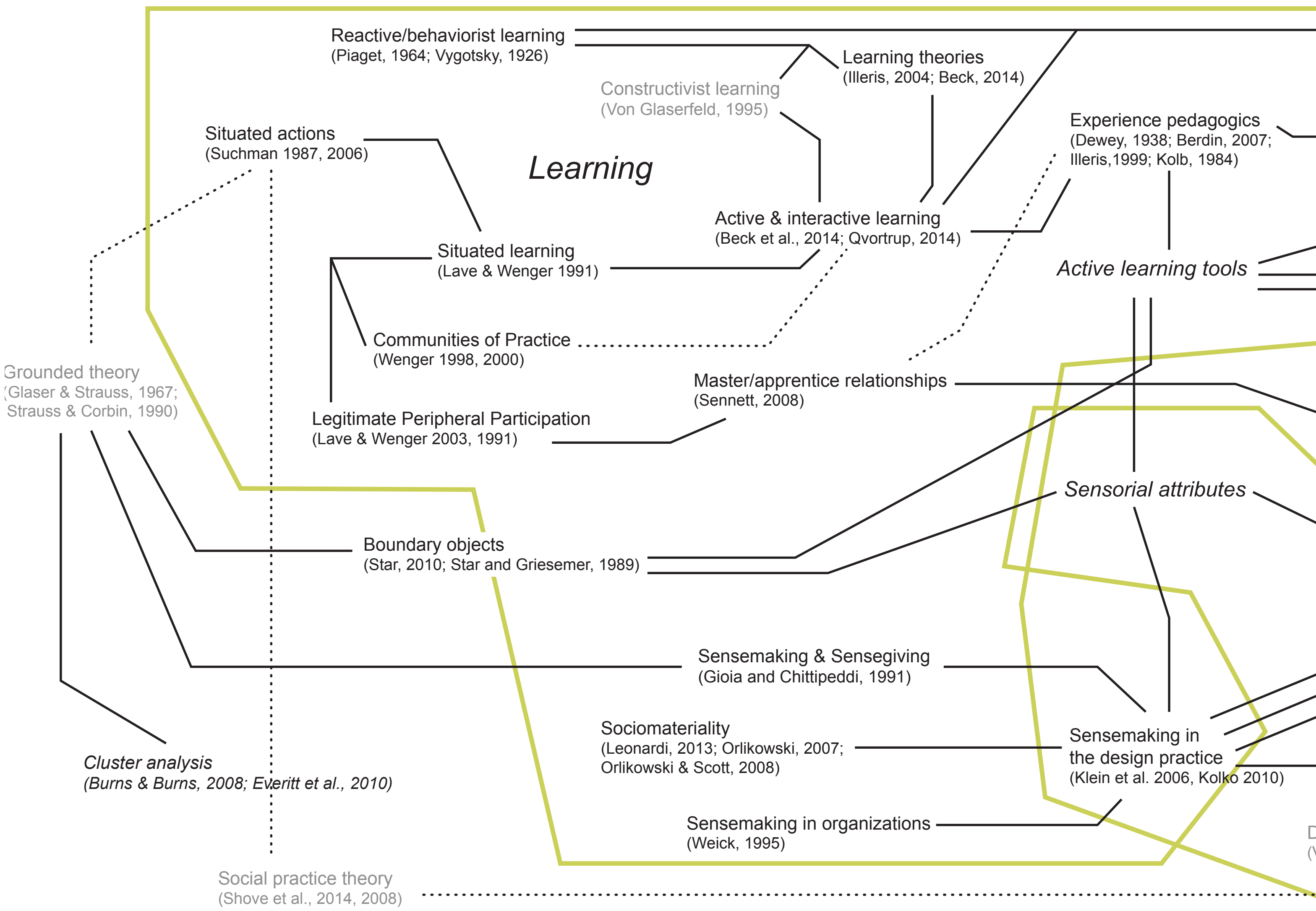
Understanding materials

Chapter 4. Understanding materials serves to unravel dimensions of material meaning creation based on **'translations'** (Latour, 1988, 1983) and **'descriptions'** (Akrich, 1994) with origin in **'actor network theory'** (Kien, 2009; Law and Hassard, 1999) and '**science and technology studies'** (STS) and '**social practices'** (Shove et al., 2012, 2008). The notions describe, how meanings are and become embedded in objects through interaction and mediation. The concepts are used to explore, how materials can be used even when being prescribed by the society it takes part of and to create an awareness of the role of human and non-human actors when talking about materials use.

The chapter further introduces a '**value systems theory**' (Graves, 1970; Vickers, 1968) and a '**domain theory**' (Andreasen, 1980; Andreasen et al., 2014; Hansen and Andreasen, 2002) that serves to establish a structured frame for considering material attributes based on values. Value systems build on a systemic understanding of the world and society, and through appreciations the systems acknowledge the role of subjective values. The domain theory has been developed from the **'Theory of Technical Systems'** (Hubka and Eder, 1984) and thus represents a systemic approach rooted in technical design and with emphasis on objective values. This combined systemic approach in the thesis allows room for both subjective and objective value and creates an appropriate space for discussing the broad range of material meanings and integrating sustainability considerations.

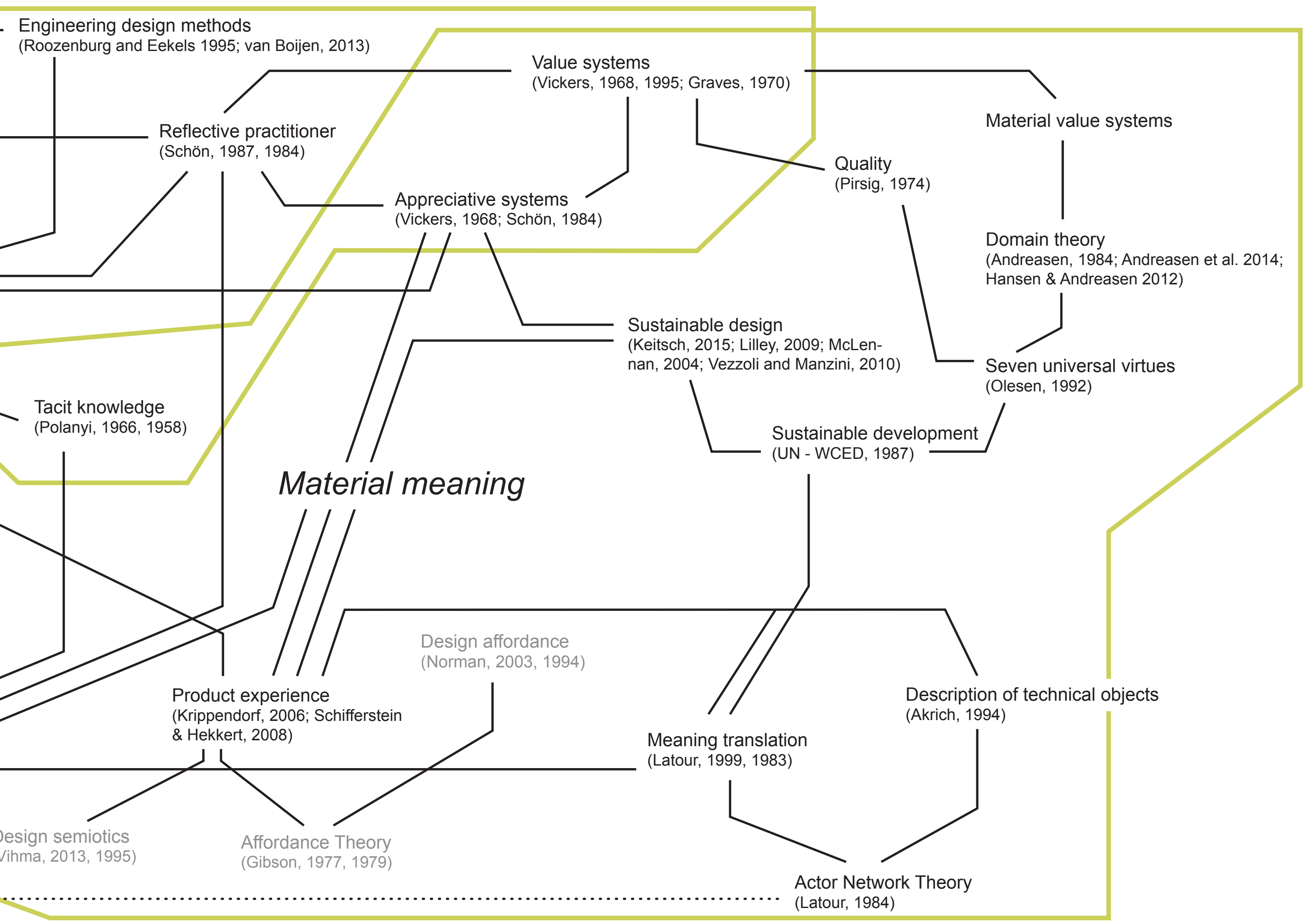
The above theories and notions provide space for the concept of **'sustainable design'** that considers '**sustainable development'** (Ellen McArthur Foundation, 2012; Keitsch, 2012; UN - WCED, 1987) in product design with emphasis on a different models and perspectives such as the **'Triple Bottom Line'** (Elkington, 1997), **'Four beginnings of sustainable design'** (McLennan, 2004) and **'Six beginnings of sustainable design'** (Ibid.) as well as **'industrial ecology'** (Frosch and Gallopoulos, 1989), **'circular economy'** (Ellen McArthur Foundation, 2012) and **'Cradle-to-Cradle'** (McDonough and Braungart, 2002).

Figure 10. Theory and concept mapping. The lines between theories and notions mark connections and relations, and the two big enclosures show theories related to respectively 'material meaning' and 'learning'.



Learning and materials

Chapter 5. Learning and materials discusses learning traditions and establishes a foundation for materials learning based on **‘active’** and **‘interactive’** learning (in opposition to ‘reactive’ learning’) that are rooted in constructivist learning theories (such as von Glasersfeld, 1995) and related to **‘situated actions’** (Suchman, 1987) and thereby share characteristics with **‘communities of practice’** (Lave and Wenger, 1991). The discussion on meaning creation in the design practice departs in **‘sense making’** and **‘sense giving’** mechanisms (Fachin, 2013, Klein et al. 2010) with inputs from Grounded Theory (Gioia and Chittipeddi, 1991), Organizational Theory (Weick, 2005) and sociomateriality studies (Leonardi, 2013; Orlikowski, 2007; Orlikowski and Scott, 2008).



Across chapters

As it can be seen on the diagram (figure 10) multiple theories and notions cross-over. **'Appreciative systems'**, a concept first used to elaborate on value systems for materials meaning (Vickers, 1968), also relate to Schön's concept of **'the reflective practitioner'** (Schön, 1987, 1983) as well as **'active learning tools'** derived from **'experience pedagogics'** (Berdin, 2007; Dewey, 1938) and functioning as a **'boundary object'** (Star and Griesemer, 1989). **'Sensorial attributes'** being attributes that comprise both objective and subjective dimensions and derived from **'product experience'** (Schifferstein and Hekkert, 2008), are essential for the material meaning mediation in the design education, through experience pedagogics and thereby also function as a boundary objects (Star and Griesemer, 1989).

Analytical theories and notions

In addition to the theories and notions used to develop the understanding of the topic, a collection of analytical theories and notions has been applied. Analytical theories and notions here correspond to theoretical fundamentals for tools and methods used in extracting and analyzing information in the project.

Analytical theories thus include 'content analysis strategies' used to make **'cluster analyses'** (Everitt et al., 2010; Hsieh and Shannon, 2005) and **'Likert-scales'** (Likert, 1932, Tullis and Albert, 2008) that are shortly described on page 37-38. The theories also include the **'Semantic Differential Technique'** (Osgood, 1964; Osgood et al., 1975) and the **'Personal Construct Theory'** (Bang, 2010; Bang and Nissen, 2009; Fransella et al., 2004; Kelly, 1955) that are further discussed in Chapter 9.

A discussion on the use of theory follows in Part IV_ Concluding discussion (p. 234).

ANALYSIS

Experiments have been analyzed in an ethnomethodology-inspired approach that provides a degree of experimental free space necessary to extract valuable data and offers a structure that allows data to be analyzed and grow. Ethnomethodology concerns "studying the relationship between sociological practice and everyday language and attempts to understand the methods people deploy" (Jensen and Andreasen, 2010) and "how people behave in given (often structural) situations and explores the nature of methods that take part of human reasoning within everyday life" (Andersen and Kaspersen, 2005: 210). Without going into detail it has been used to understand, how design students approach, use and internalize the materials selection matrix and other supporting tools to create material understandings.

Basis for findings

The empirical findings are based on relatively small data sample sizes. The findings are therefore not based on quantitatively validated data, but on mixed inputs from many different sources. As the studies have been based on materials courses, the sample sizes have not been larger than the number of students in each course.

In the courses conducted at Design School Kolding between 12 and 36 students have participated from respectively fashion, textiles and industrial design. Even though the students show many similarities, some of the part studies also revealed that it is important to differentiate between the disciplines. It has not been possible to increase the sample size, as this would change the conditions for the experiment setup in the domains. It is thus important to stress that project findings are tendencies that have occurred in the experiments. Furthermore, as the experiments are so strongly linked to the contextual frame, the same tendencies are not necessarily occurring if the domain is changed for example if the same experiments were conducted in a different learning environment.

Quantification of qualitative data

The research knowledge generation has had many different inputs. One has been to quantify otherwise qualitative data using analytical approaches such as cluster analyses and Likert scales. In mixed methods research the fundamental belief is that analyses do not have to be either quantitative or qualitative to give meaning (Creswell, 2013; Johnson and Onwuegbuzie, 2004). However quantifiable qualitative data can be considered as a grey zone between quantitative and qualitative data and objective and subjective means, as the translation and coding of qualitative data will be influenced by the subjective preferences of the person who has performed the translation. In the project, I have been the 'translator' of the quantification while most translations have been assessed by one or more colleagues to improve the objectiveness of the findings.

Cluster analysis

A cluster analysis is a qualitative content analysis, where data strings are clustered by means of similar characteristics (Everitt et al., 2010). Hsieh and Shannon have described qualitative content analyses using written texts (Hsieh and Shannon, 2005). They state that "(…) typically a study using a summary approach to qualitative content analysis starts with identifying and quantifying certain words or content in text with the purpose of understanding the contextual use of the word or content. This quantification is an attempt not to infer meaning but rather to explore meaning” (Ibid.: 1283). Hence content analyses can be used as methods to extract essential meaning from data samples. Cluster analyses have been used in Chapter 7, 8 and 9.

Likert-scales

In the experiment conducted at Delft University of Technology and documented in Chapter 9 Likert-scale were used to measure the satisfaction of using the materials selection matrix. The Likert-scale is a means to quantify an experience or meaning based on a linear numerical scale usually ranging from a negative to a positive extreme and can function as basis for statistical analyses (Likert, 1932).

In the original version the Likert provided terms for each point of the scale being ‘strongly agree’, ‘agree’, ‘neither’, ‘disagree’ and ‘strongly disagree’, but it is now common to only label the two extremes (Tullis and Albert, 2008). The scale can be even or odd numbered dependent on whether the respondent should be forced to have an opinion about the mid-point. If only the two extremes are indicated, it is up to the respondent to interpret the remaining scale.

Conducted experiments

In table 2, an overview of experiments is provided. The overview aims to show the development, structure and contexts of conducted experiments. The table-format probably makes the experiments seem well organized and elaborated. Neverthe-less, the experiments have developed as the project has formed and progressed. Some activities have become interesting in a retrospective and have been stream-lined afterwards.

Interviews

As a supplement to the more structured and elaborated experiments, eight student interviews were conducted in the fall of 2014. The interviews were framed as short and semi-structured dialogues that aimed to demonstrate and clarify some of the challenges experienced with materials and methods as part of their education. The interviews did not serve to provide a comprehensive view, but to illuminate some students’ materials and methods approaches.

RESEARCH DESIGN

Experiments have been combined and related to allow interactions between qual-itative and quantitative approaches and inductive and deductive reasoning in a mixed methods approach. Mixed-methods research describes effects of combi-nations of methods (Creswell, 2013; Frederiksen et al., 2014) and is “a class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study" (Johnson and Onwuegbuzie, 2004: 17). Mixing methods has been a means to create a methodological platform for knowledge generation from different experiments and under different premises. Combining methods forces traditional scientific paradigms to un-loose, to create pragmatic rather than ontological-founded and restricting paradigms (Morgan 2007: 65) that build on logic and human behavior.

Research-wise multiple reasons for mixed-methods can be identified. Moran-Ellis et al. (2006) identify five: (1) increasing the accuracy, (2) generating new knowledge, (3) hearing different voices, (4) reflecting on the complexity, or (5) logically implementing a theoretical framework (2006: 46). This project mixed-methods were predominantly used to generate new knowledge (2) and reflecting on the complexity of the research topic (3) through successive, territorial, comparative and accumulative studies (Krogh et al., 2015). Iterations of the materials selection matrix and the comparative material scale have generated accumulative knowledge within the same domain (at Design School Kolding) and comparative knowledge

Table 2. Overview of conducted experiments.

When?	What?	Who?	Where?	How?	Why?
Fall 2012	Material selection matrix – nature of material criteria identified	3rd semester students from Design School Kolding - fashion, textiles and industrial design together	Materials and sustainability course	Extracting and clustering material criteria from material selection matrices	Relevant to RQ2, RQ4, RQ5
Spring 2013	Comparative material attributes – how did students react on the assignment and what kinds of attributes were considered?	2nd semester students from Design School Kolding – industrial design and fashion textile design in two concurrent courses	Materials introduction course	Observing the material comparison process and analyzing the used attributes	Relevant to RQ1, RQ2, RQ3
Fall 2013	Material selection matrix – the nature of the criteria identified and degree of structure applied	3rd semester students from Design School Kolding - fashion, textiles and industrial design in two sequential courses	Materials and sustainability courses	Extracting and clustering material criteria from material selection matrices	Relevant to RQ2, RQ4, RQ5
Spring 2014	Material ideation material – how was a more restricted edition of the tool received and used?	Master students from Faculty of Industrial Design Engineering, Delft University of Technology	Workshop in an elective materials and design course	Analyzing approaches on use, attributes were identified and comments on use given	Relevant to RQ2, RQ4, RQ5
Spring 2014	Associative material meanings - how did students translate meanings to materirlas	2nd semester students from Design School Kolding – fashion and textile design	Materials introduction course	Analyzing the correspondence between key-phrases and textile samples made	Relevant to RQ1, RQ3
Spring 2014	Comparative material attributes	2nd semester students from Design School Kolding – fashion and textile design	Materials introduction course	Analyzing chosen material attributes and how materials were ordered	Relevant to RQ1, RQ2, RQ3
January 2015	Comparative material attributes	2nd semester students from Design School Kolding	Materials introduction course	Analyzing how students ranked materials and assessed materials using different senses	Relevant to RQ1, RQ2, RQ3

in different domains (at Design School Kolding and Delft University of Technology), knowledge from different tools has generated territorial knowledge, and the personal materials collection initiative and materials descriptions have generated successive knowledge.

Using the research methodology

The methodology was influenced by two research methodologies; the linear Design Research Methodology proposed by Blessing and Chakrabarti (2012) and the cyclic and interactive Entrance Level-model proposed by Bang et al. (2012).

It has provided a structure for conducting and combining experiments with flexibility to adjust and modify, how experiments have been planned and analyzed to better answer the research questions. The Jellyfish-model has established a methodological frame to ensure that generated knowledge was relevant to the hypothesis and research questions as well as could interact with strings of knowledge from previous or parallel experiments. The model has also made it possible to combine experiments that were highly structured and more explorative and dynamic, all within a joint frame where the hypothesis, research questions and preliminary knowledge have guided the directions of the project.

Compared to Blessing and Chakrabarti's Design Research Methodology that applies four stages ('Research classification', 'Descriptive study 1, 'Prescriptive Study' and 'Descriptive study 2') the proposed model applies a higher degree of circularity. The structure of the Design Research Methodology has inspired the structure applied in 'experiment gateways' that establish premises for creating coherence between the conducted experiments and have helped to overview how experiments have supported each other. The four outcomes in the Design Research Methodology (Goals', 'Understanding', 'Support' and 'Evaluation') have had substantial roles in the methodology, but have not been significantly separated between different studies in the project as a result to the circular methodological approach. However, as the project has developed, the experiments have increasingly shifted from focusing on understanding the field to supporting findings and evaluating on the previous experiments.

Compared to Bang et al.'s Entrance Level-model, that has the 'experiment' as the center phase surrounded by the 'hypothesis', the 'research question(s)', 'evaluation' and 'knowledge', the methodology stresses that the 'motivation', the 'research question(s)' and 'generated knowledge' should have center positions rather than the experiment. In the applied methodology experiments are more used as investigative processes to gain insights that can justify the hypothesis and help answer the research questions. This also means multiple activities have functioned as experiment-like activities in the project and that activities have been acknowledged as experiments if it was possible to identify or create a certain structure before or after conducting them.

Dynamics in the methodology

The following section reflects on the dynamics in the methodology with focus on the relations between the motivation, hypothesis, primary research question and five subordinated research questions, and the roles of experiments and theory in methodology. Figure 11 provides a structural overview of the relations between the above-mentioned notions according to the research methodology.

The project has departed in a motivation based on personal, institutional and societal observations, insights and values within this specific topic dealing with materials, design education and sustainable issues. The inputs have been condensed into a hypothesis, as a statement that identifies variables and relationships between variables that are of special interest. The hypothesis here has been:

> *"A stronger emphasis on materials teaching in design education can strengthen awareness of materials among [product] design students and help students make stronger and better-founded choices of materials in a sustainable perspective".*

In this case variables have been identified as 'materials teaching', 'education', 'awareness of materials', 'choice of materials' and 'sustainable perspective'. They have been linked through words such as 'stronger emphasis', 'strengthen', 'help 'make stronger and better-founded' that all relate to an action or process towards something different and 'design students' as research subjects.

Being statements, hypotheses are often related to deductive research disciplines verified with quantitative measures that support or reject the truth content of the statement (Fuglsang and Olsen, 2004). This project is not a deductive study and experiments are not conducted to verify the hypothesis, but to create an exploration space that can gain insights into the topic. Consequently the hypothesis more gets a function of a guiding principle that refers to the motivation and forward to the experiments.

The inductive counterpart to the hypothesis is the research question (Ibid.). A research question is the question that a research projects sets out to answer and thus provides investigative and explorative inquires to gain knowledge in the problem area. As a result in this project the hypothesis and the primary research question have been regarded as two sides of the same coin but having different approaches and modes of inquiry. It also means that the variables are very similar. In the re-

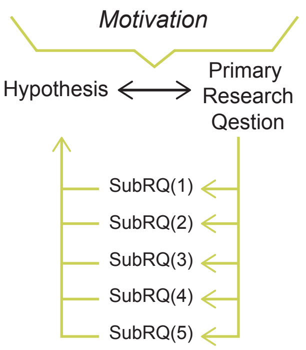


Figure 11. Hierarchical relations between the motivation-level, the hypothesis/research question-level and the five subordinated resesearch questions in the research methodology.

search question the variables are ‘understanding of materials’, ‘design education’, ‘material choices’ and ‘sustainable decisions’.

> *“How can a renewed understanding of materials in design education help students to develop well-founded materials choices supporting more sustainable decisions?”*

The dynamics between a deductive hypothesis and an inductive research questions allow for reflection of different kinds. A question format automatically generates new questions that here have been formalized as subordinated research questions that each consider one of the variables in the primary research question. The hierarchical structure provides attention towards all the variables in the hypothesis, but it does not take into account that some of the variables are more complex than others. Furthermore they poorly integrate the interactions between the variables and therefore the subordinated research questions become entangled in each other and difficult to answer individually. In the discussion each subordinated research question is debated individually, but as it will show in the theory and analyses the variables point at each other and take part of larger and more holistic understanding of the problem area. Therefore focusing on only one subordinated research question at a time inadequately justifies for the insights that are generated in between the questions and in their synergic contributions to each other.

The subordinated research questions consider a present condition, or an action towards a different future, or both. Present conditions are for example formulated as (methods and tools) ‘use’ in RQ2, ‘communicate’ (materials) in RQ3 and ‘perform’ (material choices) in RQ4. Actions are for example formulated as ‘stronger focus’ and ‘more integral’ in RQ1, (tools and methods) ‘needed’ in RQ2, ‘strengthen’ (material awareness) in RQ3, ‘improve’ (material choices) in RQ4 and ‘stronger’ (material awareness) and ‘improve’ (sustainable impact) in RQ5. It means that the conditions for relating to the research questions differ and answers become ambiguous and less specific. This is for example the case for the research question that includes both a present condition and an action.

Abductive thinking as a way to combine inductive and deductive reasoning

Even though the experiment as an investigative component is not perceived as the center point in the applied research methodology, it has applied an experimental mode of enquiry and mindset. Design research is in its core an experimental discipline (Buchanan, 1992; Eneberg, 2011) where abductive modes of thinking are highlighted (Coyne, 1988; Dunne and Martin, 2006; Kolko, 2010a). Abductive modes of thinking navigate in the space between deductive and inductive thinking and create a dialogue between the hypothesis and the research question(s). The exploratory outset of abductive modes of thinking often creates several points of departure that each work as arguments or enquiries in the exploration of multiple contexts, objects or subjects. From this it can be concluded that the research design has applied an abductive research strategy. The use of abductive thinking in the design practice is further elaborated in the discussion.

CHAPTER SUMMARY

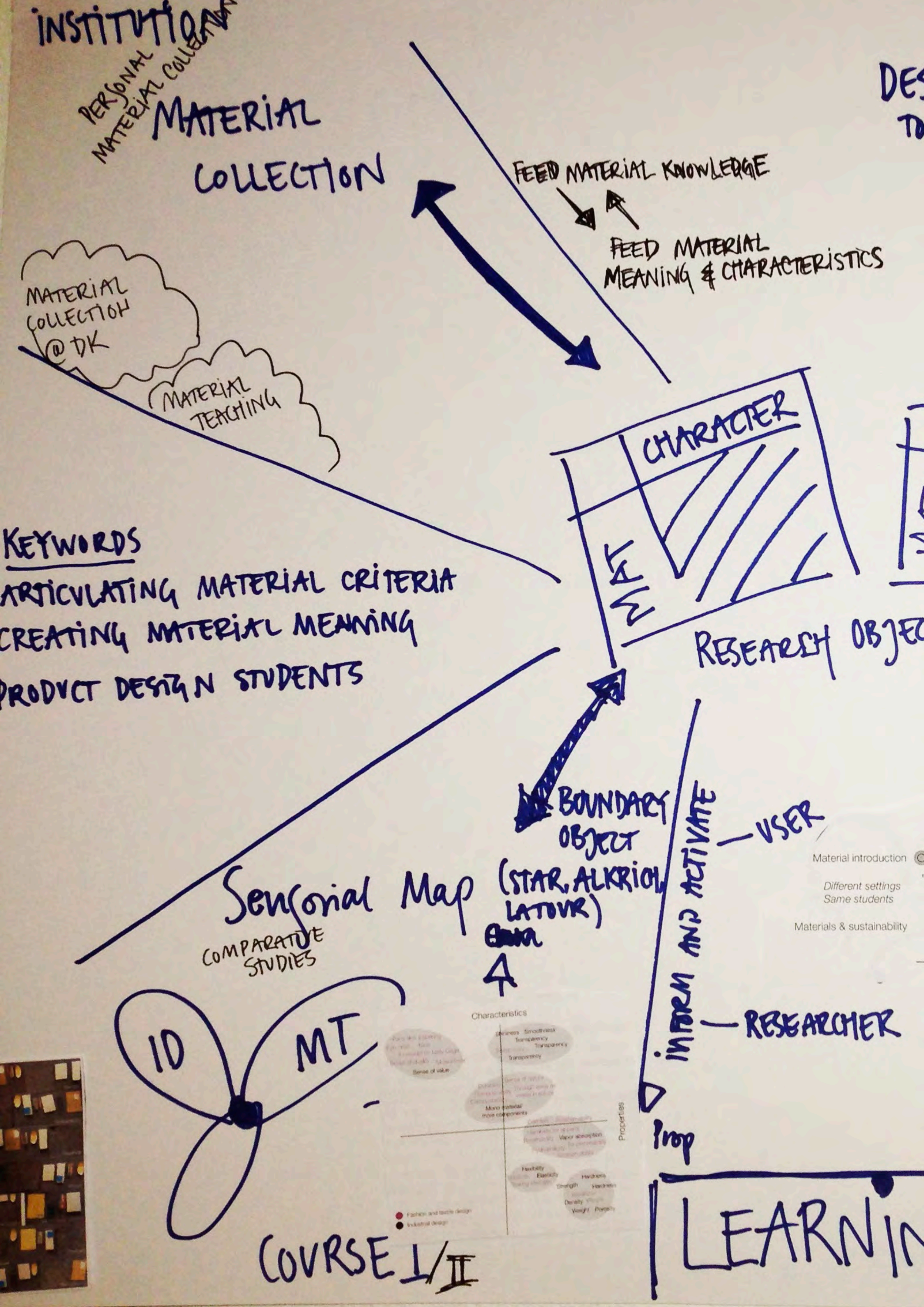
The chapter has introduced the methodological approach of the project, based on a model named the 'Jellyfish model'. The model combines mindsets from artistic and engineering design research to provide a methodology that allows flexibility and structure simultaneously. The experiments have been based on the use and appreciation of educational tools and methods in design educational learning environments, where experiments have been framed as field experiments drawing from both 'lab' experiments and 'field' studies.

The chapter has further introduced the theories and notions used to unravel the scope and entries of the project. This includes theories and notions that elaborate on materials understanding and learning strategies in design education within a frame of sustainable design. It also includes analytical theories and notions used to extract and analyze information from the empirical studies.

Finally the chapter provides a critical reflection of the research design that puts emphasis on navigating the research methodology.

Summary

- The research methodology applied in the project has combined mindsets from engineering and artistic design research.
- Experiments have been conducted in materials courses in design educational learning environments and in studies exploring how students use methods and tools developed for materials teaching. The research methodology shifts between inductive and explorative and deductive and structural reasoning.
- The findings are based on qualitative studies and should be regarded as contextual tendencies rather than exact knowledge.



INSTITUTIONAL
PERSONAL MATERIAL COLLECTION
MATERIAL COLLECTION
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FEED MATERIAL MEANING & CHARACTERISTICS
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CREATING MATERIAL MEANING
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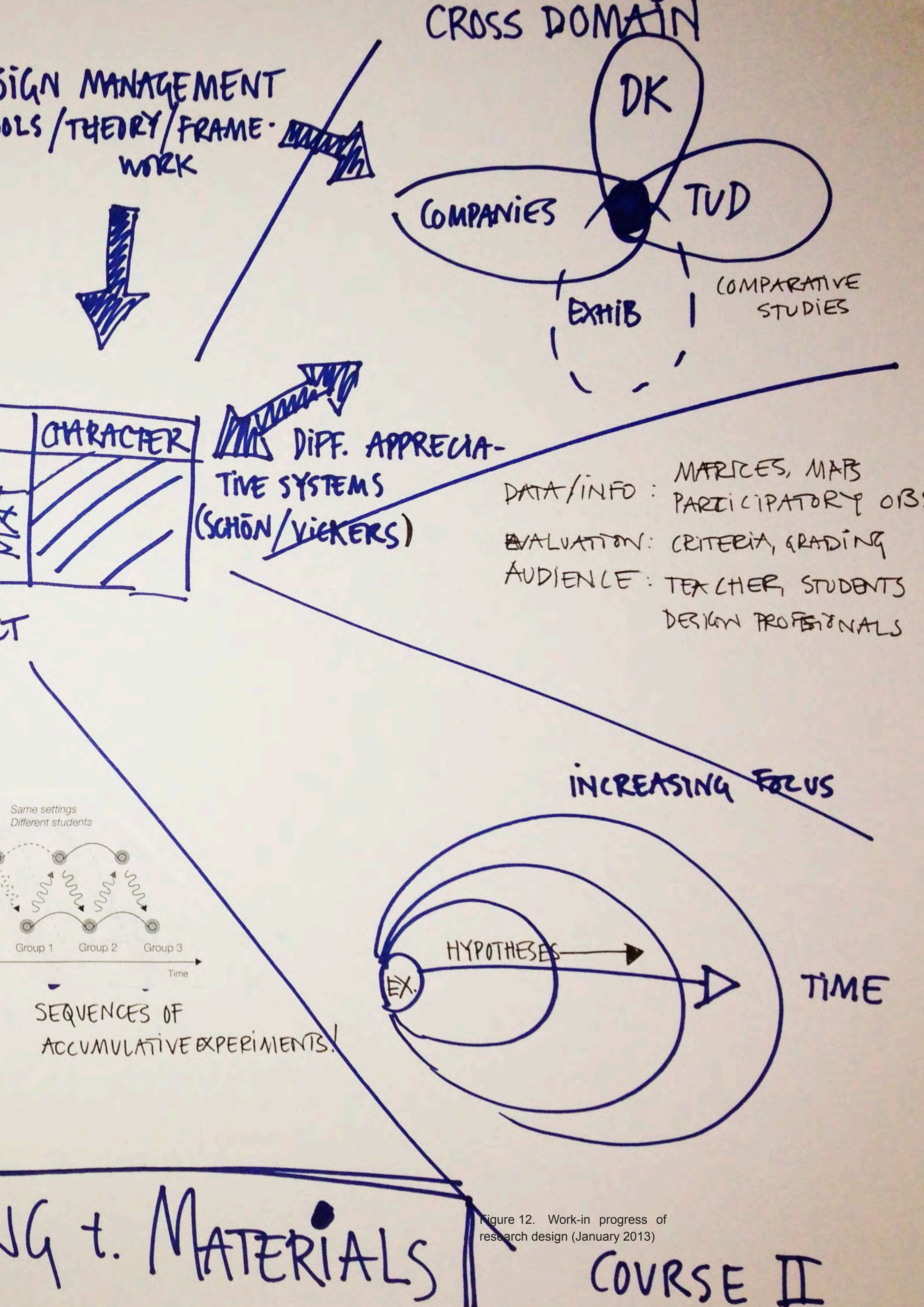


Figure 12. Work-in progress of research design (January 2013)

PART II_ MATERIAL PERSPECTIVES AND LEARNING

Contents_

4. UNDERSTANDING MATERIALS

This chapter presents the concept of 'materials' and how materials can be understood and considered based on material meanings and experience. The relationship between designers, users and materials is presented in terms of actor network theory. The chapter establishes an approach that acknowledges that material understanding is based on the appreciation and values users have and associate with the materials. It is here argued that it is necessary to consider materials for their technical, experiential and sustainable attributes. Finally it is discussed how material value parameters apply in practice with emphasis and 'quality' and 'sustainable design'.

WHAT IS A MATERIAL?

Materials are physical objects that consist of matter. The matter has a certain composition that defines the matter's performance and a shape that defines its physical appearance. Materials are also social entities that can provoke sensorial, associative and emotional user experiences. Experiential attributes that refer to the group of sensorial, associative and emotional material attributes can be difficult to grasp and articulate to others than yourself.

When a material is chosen for an artifact (such as a product), it should be based on its external performance, being physical and technical properties, as well as in its internal and contextual performance, being experiential characteristics. Only considering physical properties could mean using materials in a product that are not socially suited for the product's purpose. Only considering experiential characteristics produces materials that do not follow functional requirements on for example production and durability. This antithesis creates a dichotomist approach to the materials field (Vannini, 2009: 3). Human and social sciences use materiality and material studies to explore, how materials and the objects they embody influence the lives of their users, while natural sciences and engineering use materials science to explore, how materials perform and function. This means that human and social sciences typically consider materials when they have been embodied in products, while natural sciences and engineering typically consider materials in their entire life cycle from being a raw material, to production, use and disposal. When different disciplines approach materials it means that the degree of application and maturity of the materials differ. In figure 13, three examples of degree of application are provided. The three materials are plastics, metals and phosphorescent pigments ranging from raw or unapplied materials to the left to applied materials to the right.

Chris Tilley, professor of archeology and anthropology at University College, London has described materiality as "all about going beyond the stone (the object) itself and situating it in relation to other stones, landscapes, persons and their doings – in other words developing a holistic and conceptual, theoretical and interpretative framework" (Tilley, 2007: 18). This means that understanding a material, as an object with a physical substance also involves acknowledging the world the material is part of.

As a result of the diverse approaches used to define materials and materiality, materials do not possess a specific language. Instead they constantly have to be adapted and translated to fit the involved actors in given situations. This accounts for divergence in, how professionals, as opposed to laymen, regard materials as well as individual professionals from material related disciplines. Additionally it accounts for cultural differences in using materials, potentially creating strong asymmetries in the perception and use of materials across regions.

Natural and man-made materials

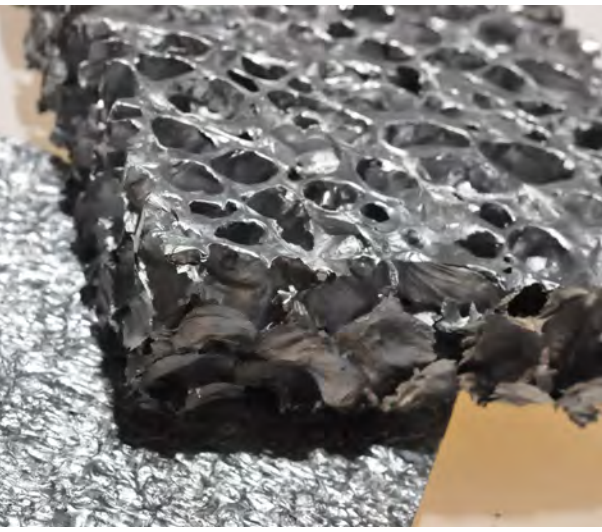
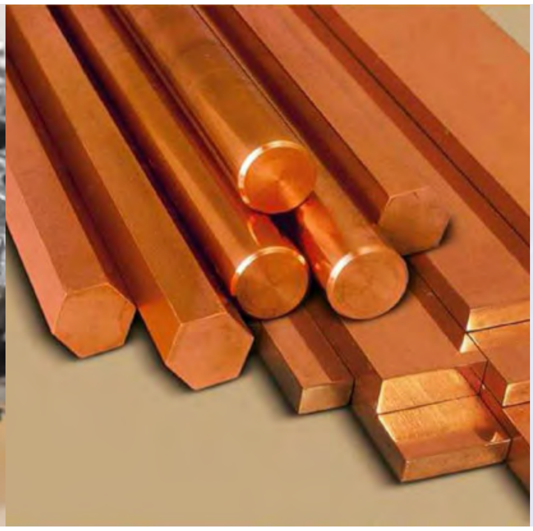
According to David Miller, also professor of archeology and anthropology at University College, London, the shift is the result of a change of materials use of consumer goods from natural and virgin materials such as wood and stone to synthetic or semi-synthetic materials that undergo a dramatic change in composition and appearance from its original material (Miller, 2007: 26). Whereas natural materials can tell a story, for example by growth rings or signs after branches in woods or fossils embedded in stones, synthetics such as plastics lack identity. According to Manzini there has been a 'loss of recognition' of materials since the introduction of plastics in 1940s and 1950s (Manzini, 1989). Plastics that may seem identical to the normal eye have different properties and can be customized for specific applications, which thus challenge the traditional understanding of materiality in these materials. In that sense the term 'man-made' used for synthetic materials is striking, as it stresses a paradigm shift in how these materials are manufactured. From making products that embrace the properties of the materials used for it, materials are now selected and designed to qualify for partly or already fully developed product designs. It marks a transition of power, as the conditions for 'nature-made' and 'man-made' material use are remarkably different. As a concept, materiality is challenged by this paradigmatic shift, as a breakdown in meanings inherently embodied in traditional materials is occurring.

MATERIAL MEANINGS AND EXPERIENCE

The breakdown of the transparency of meanings of materials calls for alternative ways to understand materials. This section introduces a sociological view on materials based on an actor network theory-inspired approach applying especially






coated phosphorescent pigment

For use on
Most Fabrics
& Other
Surfaces
NIGHT GLO™
Screen Printing Ink
Speedball.

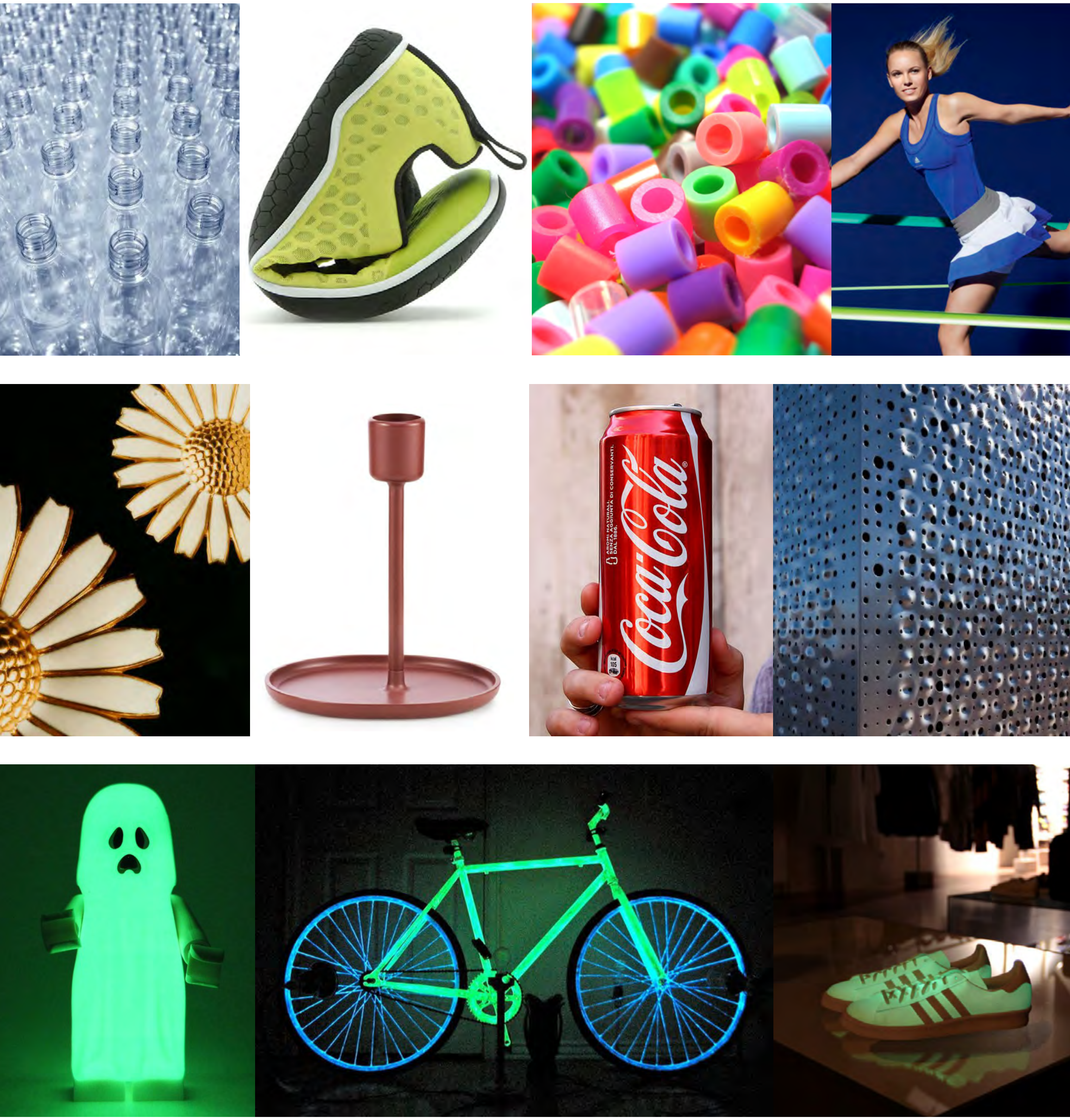



Figure 13. Examples of degree of application for three materials - top: plastics, middle: metals, bottom: phosphorescent pigments. The materials are increasingly applied and matured going from left to right (all photos have been found on Google).

Latour's use of translation (Latour, 1999, 1983) and Akrich's use of descriptions (Akrich, 1994). Both terms are used to understand, how users can and often have different understandings of what a material is and what it can be used for. The two terms are strongly intertwined, but slightly differ in their focus of the process in which meanings are mediated. The approach does not aim to offer a complete actor network analysis of, how material meanings are established, but to provide examples of factors that influence them, and why as well as how. The two main actors in this project are 'materials' and 'design students' and the discussion will stress how these act separately and how they affect each other. Here translations are used to elaborate on the role of design students, while descriptions are used to elaborate on material specific meaning creation.

Actor network theory to untangle meanings

Actor network theory can be used to understand the interactions and interconnections between human and non-human actors in the translation of material meanings in design practice and in the design education.

The fundamental concepts in actor network theory are actors, networks and the roles of actors in networks. An actor has been clarified as being autonomous figures, but besides that they can be anything - individual or collective, figurative or nonfigurative' (Latour, 1988b: 158). In other words, actors are autonomous entities, meaning that they can be differentiated from others and they can be human as well as non-human. Actors interact and interfere with each other in networks and it is the position and power relations in the networks that define the actor. This further means that in order to maintain power and position, actors must constantly build relationships with other actors. The more and stronger relations an actor has, the more stable an actor appears to be. Hence strength is gained by "associating with other actors, by speaking on behalf of all other actants, and in effect, by translating the voices of the multitude of other actants" (Kien, 2009: 34).

Dominant human actors in the design field are for example design practitioners and students, end-users and material teachers and lecturers. Dominant non-human actors are for example the material itself, what it is composed of, the product the material constitutes, manufacturing techniques and properties. Actor network theory is further used to understand, why it is essential to appreciate the role of material meanings when considering and selecting materials.

The actor network-inspired approach is used as a theoretical frame in the discussions of material meaning and material cultures that previously have occurred within materials for design (for example Ashby and Johnson (2014), Karana (2010), Karana et al. (2014), van Kesteren (2008) and among others) and product meanings and experience (for example Desmet (2003), Lenau and Boelskifte (2004), Lenau and Lindegaard (2008) and Schifferstein and Hekkert (2008)). However, whereas actor network theory often has a tendency to apply a retrospective view, in this dissertation I have wanted to use the actor network theory constructively to create 'prospective' perspectives, which, in line with design research, provide solutions for the future.

By tradition there is a great diversity in, how materials are understood across different disciplines, which makes it a complex environment to navigate and interact in for designers. To this, Karana has written that "designers, who aim to select a material that will contribute to the meaning they intend to convey in a product, are confronted with the difficulty that the materials universe is immense" (Karana 2010: 271). This is understood as not only referring to the increasing availability of physical materials, but just as much how materials are communicated within a profession and across professions. Understanding materials in more technically and natural scientifically oriented disciplines has been established by means of standardized and quantitative measures, such as physical and technical properties for centuries. This language for communicating about materials makes sense for actors that have learned the terminology and the underlying theory. It can however be difficult, and, in reality, often impossible for others to relate to.

Materials are active players in the product design process, and as Karana states "(…) materials can stimulate designers to create new shapes, new solutions and new mechanisms for existing needs" (Karana, 2010: 272). To a certain degree designers consider technical material properties, but just as much, designers use their perception and their cognitive experience to create material meanings. In design education it is therefore essential to provide materials teaching that encourages students to consider materials and create personal material understandings based on multiple variables within technical and experiential material domains.

Materials and actor network theory

Questions that could arise in a materials-designer network are:

> *'Do non-human actors have meanings?'* and *'How do non-human actors affect other actors' meanings such as human actors?'*

The questions point back to one of the central aspects of the project being the differentiation and power relationships between humans and objects. Thereby it relates back to a fundamental dichotomist approach to understanding the society and the world we live in. Latour has used the relation between human and non-human actors to equalize the society and provide actors and non-actors with the same power (Latour, 1999). He argues that if humans and non-humans have the same value in an actor network, actors are affecting and displacing the scripts, goals and meanings of each other (Ibid.: 177). To describe the power relationship and the mediation between a human and a non-human actor, Latour has used a gunman and a gun (Latour, 1994). The gun enables the gunman to shoot, but the gun is of no use with out the gunman. Hence both the human actor (the gunman) and the non-human actor (the gun) have equal power in the action.

Within design a similar relationship can be described between designers and materials. Materials enable designers to design, to construct new artefacts, but the materials themselves have no value if no designers use them. Getting to know a new material can make the designer act differently and designers can use materials in different ways that explore new facets of the material. This means that humans can embed scripts in materials; they can assign a meaning or a use, but materials also force designers to develop and open up for exploration and reflection. Materials make it possible for designers to act and experience, while working with the material. As a result, both the designer and the material are mediated and redefined when they meet.

Meaning translation

Displacement of meaning, as exemplified in the previous section is called translation. Translation has been defined in different ways and here two theorists' definitions have been included. One definition is that translation is the "mechanism by which the social and the natural world progressively take form" (Kien, 2009: 30). Another is that translation is "the process of any script from one repertoire to a more durable one" (Latour, 1988a: 305) and "the displacement, drift, invention, mediation and the creation of a link that did not exist before and that to some degree modifies the two" (Latour, 1999: 179). Theorists agree that translation entails processes where actors relate to one another, and because actors change from situation to situation they are "transformed in their movement between practices" (Gad and Jensen, 2010: 57).

An important aspect of the translation process is symmetry (Latour, 1999: 177). Symmetry means that even though it may not always appear so, actors interfere with the scripts or with the identity of one another in an equal manner. The relation between the designer and the material is again used to demonstrate symmetry and that both actors affect each other equally. The material affects, how the designer perceives the material, but so do similar materials, relevant manufacturing processes, potential products and so on. Similary the designer can affect the materials visually by changing and its physical appearance, but more importantly, by embodying meanings and open up for new applications.

Materials as actors

Inscriptions were originally introduced by Akrich as a means to explain interactions between humans and technology through inscribed meanings and intentions embedded in an object through its network (Akrich, 1994). Scripts are connected to the anthropological understanding of materiality, as used by for example Miller (2005) and Tilley (2007).

In meaning creation and translation inscriptions elaborate on the creation of meaning displacement. Described by Akrich, scripts are "the assumed actions and assumptions of use for a given object (…)" and "inscribed entities that make up the world in which the object is to be inserted" (Akrich, 1994: 208). Based on translation processes, scripts can thus be regarded as intentions of actions of an actor by another actor. Accordingly, in materials-designer interactions, materials are both 'inscribed' by the designer's material practice and 'inscribers' of the product the materials have been used on. Thereby designers strongly influence the inscription of material meaning that defines and illustrates the materials' place in the social world.

It means that a material will never occur as a single entity with a fixed identity. Its meanings are created by the products it has composed, the human actors that apply and embed inscriptions in it, and the surroundings of its use. The same virgin wood can be used for a range of different applications from tables, chairs, wood chips, and even as the raw material for rayon (textile) production. Similarly copper can be used for jewelry, cables, coatings, and alloys among many other things. Without reference to actor network theory, Ashby and Johnson have interestingly compared materials to actors, because they can assume so many different personalities dependent on the role they are asked to play (Ashby and Johnson, 2014: 73).

Stability of power relations

Stability of power relations is created by the actor's interaction with its surrounding network. The more the network agrees on the actor's inscribed meanings, the more power it gets and the more stable it becomes. A material obtains power through manufacturers and suppliers that shape the representation of the material, through designers that use the material in products, through users that customize and domesticate the material in the products it is used, and through existing material applications and similar products that acknowledge, translate and interact with the material into meaning given and value adding uses. Present materials have been influenced on their way from being a raw material to a commercial material or applied in a commercial product, where meanings have been translated numerous times by involved actors in the process. Therefore commercial materials are hybrids of actors that have embodied intentions that influence the script of the material. A material is stabilized, if its network agrees on and 'black-boxes' the role of the materials, for example in terms of potential applications. Many existing and commercial materials have already been black-boxed as a result of the actors that have influenced the materials and hence there often exists a prior understanding, as to which materials are appropriate for which products.

The traditional use of material families is an appropriate example to describe, how materials are stabilized. Traditional material families possess strong inscribed meanings based on the origin and the general chemical composition of the individual families that determine the materials' physical and technical properties. For nature-made materials, material properties are transparent and throughout history material families have served as instinctive guidelines for material applications. With man-made and superior technology, traditional material families and thereby transparent families are slowly decreasing and formerly strong material inscriptions weaken. It is a paradox that access to more materials make meanings inscribed in materials weaker. Nevertheless the breakdown of meanings, in what Latour would call 'reversible black-boxing' (Latour, 1999), can open up to new applications and material meanings. Therefore the challenge is that when material meanings weaken, it becomes more difficult to find the right material, because performance is less transparent.

MATERIAL VALUE SYSTEMS

In the previous section the understanding of materials (and designers) as part of social systems was introduced using an actor network theory inspired approach. The section did not further elaborate on how material value systems are created, what they include and how they influence material meanings. This section introduces material value systems as a means to frame which material aspects are appropriate and relevant to consider in material selection in design education.

It has previously been stressed that materials have no value without a network of actors that appreciate and mediate the meanings of the material. A value system can be described as the collection of values human beings and communities they belong to have developed through cultural affiliation, profession, experiences and so on. Value systems, used to describe socio-cultural behaviors of individuals and collectives, were first used in the beginning of the 1970s by for example Graves (1970) and Vickers (1968). Value systems and especially appreciative systems (the term that Vickers predominantly used for similar systems) were used to understand collective decision-making. Appreciative systems describe the normative frame in which actors with similar appreciations share values and meanings and thus form a community with shared appreciations. According to Vickers, collective decision-making is determined by collective appreciation in a three-step process including: (1) 'reality judgments about what is', (2) 'value judgments about what ought to be' and (3) 'instrumental judgment about what can be done to reconcile the difference between the observed and the expected standard' (Vickers, 1995). With this three-step process appreciative systems can be used to differentiate for example how different professions act and approach tasks differently. The next chapter will introduce Donald Schön and his work with understanding the reflective practitioner (Schön, 1983). Schön has also used appreciative systems to describe, how reflective practitioners, especially designers and architects, work. From design engineering mindsets models also build on shared values and appreciative systems (see for example Andreasen, 2003; Person et al., 2012).

The following introduces an approach to consider material value parameters originating in a model developed for design engineering, but embracing both artistic and engineering design research. The model has been modified and enlarged with parameters that consider some of the values that are highlighted in this project. Furthermore, we can hope that by merging and uniting different approaches, bridges can be built and varying attitudes in design research reconciled.

Domain theory and universal virtues

The domain theory is a model that aims to understand artefacts based on analysis and synthesis (Andreasen et al., 2014). The model is built upon Hubka and Eder's Theory of Technical Systems that describes a transformation system with inputs from human systems (HuS), technical object systems (TS), information systems (IS) and management systems (MS) (Hubka and Eder, 1984). The domain theory provides a taxonomic subdivision to understand artefacts from different perspectives of design in systems model that includes three domains: an 'activity/transformation domain' that considers how products are used, an 'organ domain' that considers how product function and a 'part domain' that considers how they are constructed (Andreasen, 1980; Andreasen et al., 2014; Hansen and Andreasen, 2002). The organ and part domains consider structural elements that define functionalities and that are the results of, how the product is materialized and produced while the activity/transformation domain considers product-user interaction. The domain theory suggests that product attributes can be split into two classes, namely 'properties' that correspond to the anatomy and structure of the product and 'characteristics' that correspond to the means used to realize the object synthesis, when it is brought into a context and utilized (Andreasen et al., 2014: 176). In figure 14, the domain theory model is illustrated with basis in Andreasen et al. (2014: 173ff) and Hansen and Andresen (2002: 101). It is demonstrated that the activity/transformation domain interacts with the organ domain and the organ domain interacts with the part domain.

In other design engineering approaches similar concepts have been proposed. In Simon's 'the nature of artefacts', it is proposed to use goal (purpose), inner environment (physical structure) and outer environment (surroundings) (Simon,

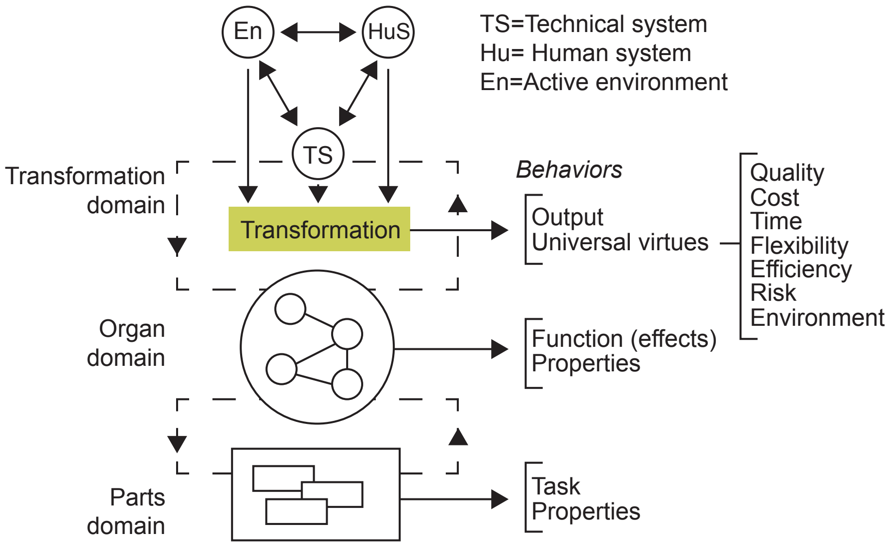


Figure 14. Schematic model of the domain theory (after Andreasen et al. (2014)). The model contains three parts: the transformation domain, the organ domain and the parts domain. In the model the seven universal virtues as proposed by Olesen has been included (Olesen, 1992).

1996), while Kroes' 'the dual nature of artefacts' differentiates in function, physical structure and context of human action (Kroes, 2012, 2002).

Olesen has added the appreciation of universal virtues to the original domain theory model (Olesen, 1992). Universal virtues characterize the 'goodness' of an activity and can be used as means to influence the appreciation of a product intent (Ibid.). The seven virtues being 'quality', 'cost', 'time', 'efficiency', 'flexibility', 'risk' and 'environment' are considered as universal. It means that they can be related to any product development process in the efforts to create an integral product that optimize the supply, production and delivery to the transformation activities and to fit the products to the user's life phase activities such as use, maintenance and disposal/recycling (Andreasen et al., 2006). When Olesen introduced the seven universal virtues, he did not go into detail in the meanings of the individual virtues and therefore it is not clear, how these could be approached. But he writes that "(…) if somebody responsible for a functional area is asked to say which measures should be taken into consideration in a renewal project, he or she would probably mention measures such as (the universal virtues)" (Olesen, 1992: 41). It is here interpreted that he primarily considers the virtues of being of functional or anatomic origin and with limited interest in product behavior and interactive characteristics.

Based on this presumption, the thesis will highlight two of the universal virtues that are specifically relevant to this project - 'quality' and 'environment' – as these, from my understanding, are as much influenced by human factors than by anatomy of the product. This is elaborated in the following sections.

'QUALITY' AS A MATERIAL VALUE PARAMETER

In product design in general and when communicating materials 'quality' is a commonly used value parameter and products of good quality are usually preferred over products of bad quality. Quality often corresponds to components that break, such as in plastics or products that change visual appearance, for example due to surface changes such as degradation or abrasion. These views on quality relate predominantly to changes in the physical appearance of a material. It is however relevant to ask:

'What is quality really?'

The notion itself has the same origin as 'qualitative', which corresponds to understanding human behavior and subjective interpretations of a matter. Hence in its origin, quality should not be linked to the physical dimension of an object, but be associated with the relationship between the subject and object based on the user's appreciation of the material and the experience it partakes of. This means that quality is a highly contextual virtue (and thus not really universal). It also means that in relation to materials, it is only fully correct to consider quality, when the material is used by itself or applied in a product that is used.

Quality as a concept is here based on Robert Pirsig's Metaphysics of Quality (MOQ) framework (Pirsig, 1974). Pirsig describes quality as "the continuing stimulus, which our environment puts upon us to create the world in which we live" (Ibid.). This puts Pirsig's framework into the same epistemological and philosophical tradition as theories of social constructions, such as actor network theory and to sense making models (such as Klein et al. 2006; Kolko, 2010b; Weick, 2005), mindset models (such as Andreasen, 2003) and appreciative systems (such as Vickers, 1995 and Schön, 1983).

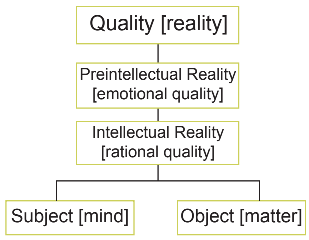


Figure 15. Bartneck's Process of Quality model (Bartneck 2009)

With origin in Pirsig's MOQ framework, Bartneck has proposed a process of quality, where quality is created in the interaction between the subject and the reality [or the object] as a pre-intellectual reality based on emotional qualities and then further developed into an intellectual reality based on rational qualities (Bartneck, 2009). The process is illustrated in figure 15. Here the process of quality is regarded as a maturing process of the mental consciousness where people will create an intellectual (spoken/aware) reality through structuring and articulating mental images from the pre-intellectual (unspoken/unaware) reality. The process of quality creation thus provides a schematic model for the mental and cognitive recognition and appreciation of materials that can translate emotional impressions to cognitive understandings.

Because quality depends on the prior images (and experiences), we have accumulated in our memory (Pirsig, 1974), material qualities can be regarded as 'black-boxed' non-human actors through products and cultures that have domesticated the products. Quality and how materials are appraised are linked to demographic differences such as gender, age, education, income and cultural background among others (Desmet and Hekkert, 2007, Karana, 2009; Ljungberg and Edwards, 2003). This means that different cultures often perceive the value of a material differently, as studied by for example Karana and Hekkert (2008) and Dormer (1990).

Accordingly there are strong preconceptions of materials and products of good and bad quality. In reality pre-understandings are results of bad or insufficient material choices or compromises on material attributes such as price and mechanical properties. To many, plastic products have a reputation of being bad quality. However, it is not the plastic itself, but the use of plastic in the products in question that is inappropriate. In many applications plastics are chosen because they are inexpensive, which means that price becomes one of the primary decision parameters and overrules functional parameters such as mechanical strength and resilience. The result is that products do not live up to their requirements and thus appear as bad quality.

Unraveling quality as a material value parameter

The elaboration of the understanding of quality is continued by asking:

> *'How does quality arise?'* and *'How can quality be measured?'*

These questions can help to explore the interface between experiential and physical material attributes and their interchangeability between irrational and rational mental states in the appreciation of materials' qualities. The questions can further build a bridge between this project and the existing 'materials for design' community and help to establish a shared terminology that covers variations of attitudes within the community.

Material performance in the physical and social worlds should be considered on equal terms (Shove et al., 2012; Vannini, 2009). A material's physical world corresponds to physical performance established by its composition embracing chemical, physical and mechanical properties as well as engineered properties based on the processes and technologies it has undergone. A material's social world corresponds to the human meanings and experiences evoked through social interaction with the material (Dant, 2008; Schifferstein and Hekkert, 2008). Even though multiple measures can be assigned to describe fundamental differences in the outlooks of the two material worlds (such as quantitative/qualitative or objective/subjective), the two worlds also overlap. Therefore it is essential to breakdown the dichotomous understanding and regard material performance parameters equally.

Natural sciences have established a shared platform for valuing materials based on quantitative and standardized measures from centuries-long research established in natural scientific laws and models such as Newton's three physical laws (1687), Maxwell's four laws on electromagnetism (1865), Einstein's Theory of Relativity (1916, 1905) and Bohr's Model of Atoms (1913). Social embedded material meanings have not gained as much attention and do not stand as strong, which make it necessary to consider alternative ways to unravel the societal aspects of materials and how physical and societal aspects interact.

Material values in materials for design

The following introduce different articulations and categorizations of material attributes from 'materials for design' research. This has founded the basis for the categorization of material attributes applied in the dissertation. For the majority of the categorizations, the material attributes cover both physical and societal aspects and vary continually in their level of abstraction.

Ashby and Johnson use four terms to describe material aspects (Ashby and Johnson, 2014). 'Aesthetic attributes' relate directly to the senses and include touch, taste, smell, form, color and texture of a material or products; 'attributes of association' connect to time, place, event, person or culture; 'perceived attributes' describe a reaction to a material or product influenced by context and experience; and 'emotional attributes' describe how a material or product makes you feel (Ibid.: 36-37). In an earlier study, co-authored by Johnson and Ashby, the 'perceived attributes' are further differentiated in 'symbolic attributes', such as formal/informal or masculine/feminine and 'stylistic attributes' such as 'rococo' and 'art deco' (Johnson et al., 2003).

Rognoli divides material attributes into 'physical', 'mechanical', 'chemical' and 'technological' aspects, and 'phenomenological' aspects that cover 'tactile' and 'photometric' aspects (Rognoli, 2004).

Van Kesteren differentiates into 'material properties' that include 'physical' and 'sensorial' properties and 'user-interaction' aspects of materials that include 'use' and 'personality'. 'Personality' aspects are further dissected in 'perceptive', 'associative' or 'emotional' aspects (van Kesteren, 2008: 25).

Karana works with five dimensions of material meanings being 'meaning from physical properties', 'meaning from product aspects', 'meaning from user characteristics', 'meaning from interaction and use' and 'meaning affected by the context' (Karana, 2009).

Taking [emotional] textile design as a point of departure Bang uses the notions of 'formal qualities', 'expressive qualities' and 'symbolic qualities' to describe aesthetic experience (Bang, 2010: 109). The notions have been inspired by Fiore and Kimle's work on understanding aesthetic experience in textiles and apparels (Fiore and Kimle, 1997). Bang further elaborates on emotional design using Norman's three levels of information processing, being the 'visceral', the 'behavioral' and the 'reflective' level (Norman, 2004). The three levels of information processing correspond to the cognitive processes that will be introduced in Chapter 5. Here they serve to illustrate hierarchical layers, such as the depth of the conscious cognition and link to the levels of experience.

In figure 16 the above-introduced taxonomies are included. The attributes (or meanings generated by the attributes) are structured by means of their degree of

Figure 16. Overview of materials for design taxonomies of material attributes and meanings.

Author	**Material attributes and meanings** (← *Level of abstraction* →)
Ashby & Johnson (2003/2014)	Aesthetic attributes; Attributes of association; Perceived attributes; Emotional attributes
Johnson et al. (2003)	Aesthetic attributes; Perceived attributes: *Symbolic attributes*, *Stylistic attributes*
Rognoli (2004)	Physical aspects; Chemical aspects; Mechnical aspects; Technological aspects; Phenomenological aspects: *Tactile aspects*, *Photometric aspects*
Van Kesteren (2008)	Material properties: Physical attributes, Sensorial attributes; User-interaction: Use, Personality (*Perceptive*, *Assocative*, *Emotional*)
Karana (2009)	Material properties; Product aspects; User characteristics; Interaction and use; Affected by context
Bang (2010)	Formal qualities; Expressive qualities; Symbolic qualities

abstraction ranging from tangible attributes to the left and intangible attributes to the right. Even though different terminologies are used, there appears to be a consensus on how to deal with material attributes in the design for materials community.

The taxonomies have inspired a hierarchical model of material attributes that is illustrated in figure 17. The model comprises two overall material categories that correlate to the two traditional material perspectives, physical and social, and four subordinated categories. The two categories have been called 'physical properties' and 'experiential characteristics'. Physical properties correspond to material performance embedded in the physical and chemical composition of the material and include technical and sensorial properties. Experiential qualities correspond to experience-oriented and user-driven material attributes and include sensorial, associative and emotional characteristics. The model further puts emphasis on the relations, interactions and mobility between categories of material attributes that is essential to describe how technical properties influence emotional characteristics and vice versa. The physical composition of a material and how it has been processed influence the sensorial perception of materials, for example by means of its touch, its smell and its visual appearance. The sensorial perception then again creates associations with previous experiences with references to for example similar sensorial stimuli and associative meanings can create and evoke emotions that can

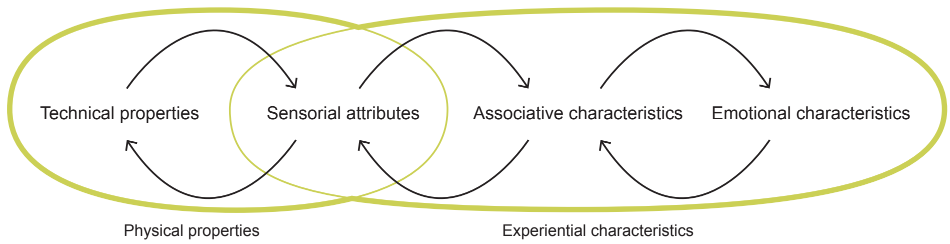


Figure 17. Material attribute taxonomy with emphasis on respectively physical and experiential attributes and the interrelation and mobility between categories of attributes.

be difficult for people to comprehend and articulate.

Properties and characteristics

In the model and in the continuing work, 'properties' and 'characteristics' are applied to differentiate between physical (and objective) attributes and social (and subjective) attributes. Characteristics could also have been called qualities (as opposed to properties as quantities), but because 'quality' is widely used as means to describe value this could cause confusion and misinterpretations. Therefore 'quality' is used for any kind of value or aspect that an actor takes into consideration. The quality itself can thus be both objective and subjective.

Properties relate to the physical world of materials, for example by means of mechanical, chemical, thermal properties etc. These properties are based on quantitative measures and could therefore also be denoted quantities; it has however not been the tradition.

Characteristics relate to the social world of materials, for example by means of meanings and emotions. These characteristics are individual interpretations and perceptions based on qualitative experiences.

Sensorial attributes as bridge builders

According to the model in figure 17 sensorial attributes can be regarded as both physical properties and as experiential characteristics. The physical object generating human stimuli is well-defined by means of for example shape, dimensions and surface, but how humans interpret the stimuli is subjective and therefore the same object can and will be perceived differently by humans. As sensorial attributes relate to both worlds, they function as boundary objects that link and strengthen the connection between physical and social understandings of the world.

In Grounded Theory, boundary objects [grænseobjekter] are defined as objects that are adaptable to different viewpoints while still being robust enough to maintain identity across them (Star and Griesemer, 1989). Boundary objects build on the belief that actors, when creating stability in networks, translate and negotiate meanings (for example Callon and Law, 1986, 1982; Latour, 1983). When great imbalances exist in the intersection between different actors, opposing meanings can arise that restrict both individual actors and the networks they take part in. Boundary objects thus serve to provide coherence in the translation of meaning and to negotiate power relations. When it comes to products and materials, meanings and attributes have long been divided and approached from two adversative epistemological traditions that (still) find it difficult to establish a common ground. As sensorial attributes can function as bridge builders and as frames to improve the interaction of meanings between physical and social material dimensions appear.

Quantifying sensorial attributes

In natural sciences, material properties are quantified and therefore materials can be quantitatively compared using standardized test methods. The ability to quantify materials based on for example mechanical, thermal and conductive performance is vital for designing products that live up to functional requirements and it improves the functional 'quality'. Even though standards are decontextualized and simplified, they help to predict how a material functions physically in use.

Experiential material values are more complicated to measure, as they depend on the appreciation of the individual user. However, as sensorial attributes are linked to associative and emotional attributes (in accordance to the model), the ability to quantify sensorial attributes is a step towards deeper understanding material dependent appreciations. The five human senses (seeing, hearing, touching, smelling and tasting) behave differently and on different levels of complexity, which means that some senses are relatively easier to quantify than others.

Many material test standards build on objectively assessing sensorial aspects. For textiles that includes light fastness tests such as ISO 105-B02:2014 (color change due to an artificial light source) (ISO, 2014) and ISO 105-C06:2010 (color change due to laundry) (ISO, 2010), mechanical tests such as such as ISO 12945-2:1999 (abrasion on textile surface) (ISO, 1999) and ISO 12947-2: 2000 (fuzzing and pilling) (ISO, 2000). Quantitative data provides little information on aesthetic materials, however experiential characteristics are of interest in the materials for design community to link physical properties and experiential characteristics).

Similar to the standardized tests, a group of cross-disciplinary researchers have explored how taste is influenced by the chemical composition of a material (Laughlin et al., 2011; Piqueras-Fiszman et al., 2012). Based on different solid metals, a metallic taste has been assessed using standard electrode potentials and subjective perceptions. The metals have been assessed based on subjective ratings of bitterness, strength, unpleasantness, saltiness, sweetness, coolness and hardness showing a dependency of the subjective perceptions and objective measures of chemical composition of the spoons (Ibid.).

Last many material meaning creation tools and methods function as boundary objects to create coherence between physical and experiential material aspects. The Expressive-Sensorial atlas (Rognoli, 2004), explores experiential material characteristics using relational semantic scales. The characteristics correlate to quantitative properties, which create a joint understanding for subjective and objective material aspects. The Expressive-Sensorial atlas and other material meaning creation tools are introduced in Chapter 6 and the Expressive-Sensorial atlas been used as inspiration for the comparative material scale that is introduced and discussed in Part III.

SUSTAINABILITY AS A MATERIAL VALUE PARAMETER

In Olesen's dissertation (Olesen, 1992) 'environment' is used as a universal virtue to describe environmental effects in product development. Today more than 20 years after Olesen proposed his seven universal virtues ('quality', 'cost', 'time', ‘efficiency’, ‘flexibility’, ‘risk’ and ‘environment’) ‘environment’ has been broadened and it is probably more correct to substitute it with ‘sustainability’. Sustainability covers a broader span of issues, including those relating to the environment, but a common understanding of sustainability (or sustainable development) is still in progress. Different terminologies and taxonomies to describe and operationalize sustainability are used, which may cause ambiguous definitions. Here a selection of taxonomies is presented as a basis for discussion. The taxonomies build on chronological progressions, holistic worldviews as well as specific methods.

The following sections derive from three concepts, being ‘sustainable development’, ‘sustainable design’ and (the role of) ‘sustainable materials in design’. The first two concepts are based on thoughts, theories and methods within sustainable thinking, whereas the last concept is based on a model proposed in the thesis to unravel relationships between small- and large-scale understandings of materials. The three concepts are strongly intertwined and have grown out and with each other.

Sustainable development as a philosophy and holistic worldview

Sustainable development is an overall philosophy that strives towards a sustainable society where future generations can maintain the same quality of life as present generations (UN - WCED, 1987). It does not target specific actors or institutions, but want to improve dynamics and systems on a societal level, which involve actors such as policy makers, economists, philosopher, engineers and also designers. As a result sustainable development has different meanings for different people.

Even though sustainability issues had been on the agenda and discussed before, for example in Schumacher’s ‘Small is beautiful’ (Schumacher, 1974) and Papanek’s ‘Design for the Real World – Human Ecology and Social Change’ (Papanek, 1971) the publication of Our Common Nation report in 1987 (UN - WCED, 1987) and its

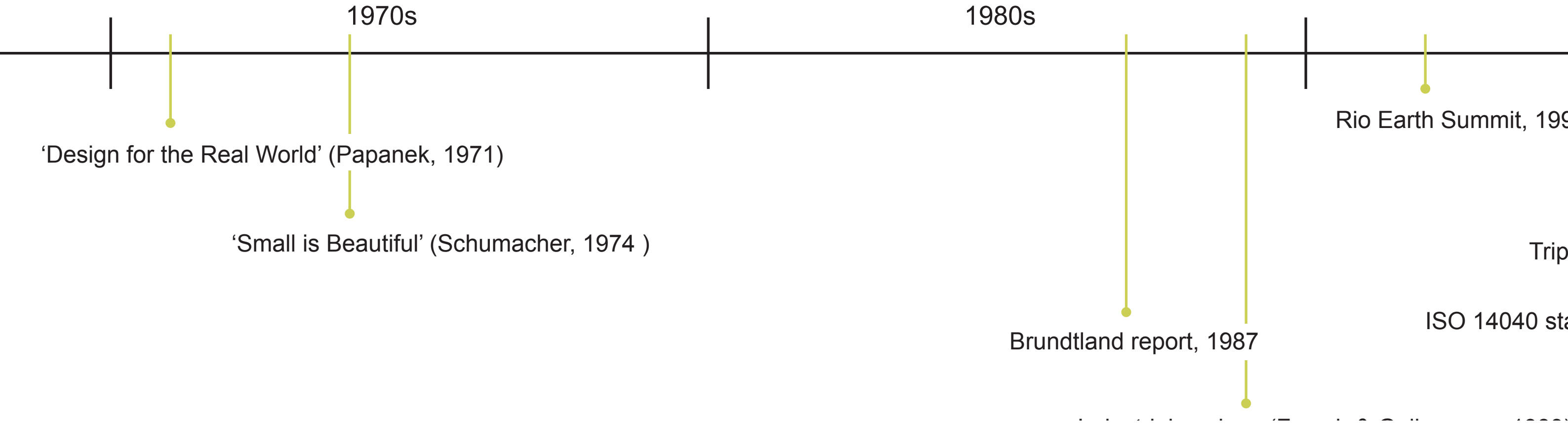


Figure 18. Timeline of some lpublications, concepts and methods related to sustainable development.

definition of sustainable development was seen as a milestone in the acknowledgment of the need for a new order of business and society. As a result it has played a vital role in the growth of sustainable awareness in industry as well as among consumers. One of its most highlighted phrases states that:

> *"Sustainable development is the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (UN - WCED, 1987).*

The report established a philosophical frame for sustainable development and ever since people involved in sustainability discussions have used it as a universal framework in their works but pointing in multiple directions. However, as development is a process, meaning something in flux, there is a common agreement that sustainability should put emphasis on the evolution on initiatives towards better solutions and not on the final solution itself. Figure 18 shows a timeline of some publications, concepts and methods that have been part of framing sustainable development.

Since the environmental movements in the 1960s and 1970s, it has been acknowledged that sustainable development has to be more than (but also encompass) concerns on efficiency improvements in the industrial and agricultural sectors, such as rising pollution, increasing oil consumption, continuous oils spills and the depletion of nature's resources, but also embrace related economic systems and the surrounding society. The Triple Bottom Line manifested by Elkington (1997) and more recently the Three P's proposed by Fisk (2010), put emphasis on interactive systems containing 'environmental sustainability' (Planet), 'economic sustainability' (Profit) and 'social sustainability' (People). The triangular understanding has proved to be a supportive framework for people wanting to give weight to sustainable development, especially in innovative business and management contexts

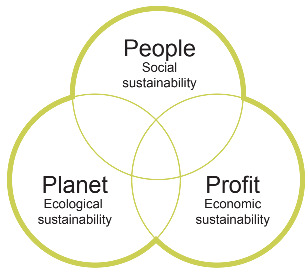
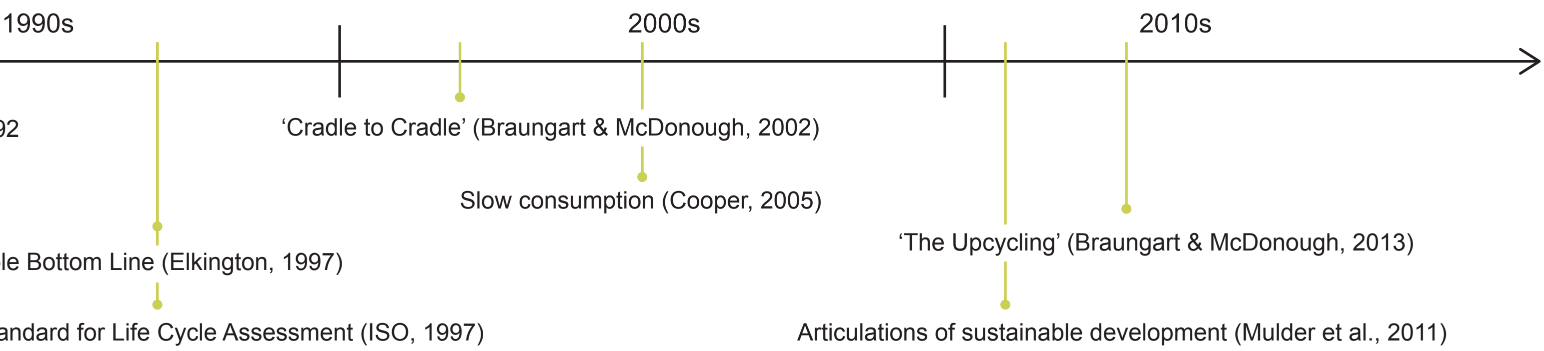


Figure 19. The three P's when discussing sustainabilility: 'People' that refers to social sustainability, 'Planet' that refers to ecological sustainability and 'Profit' that refers to economic sustainability (Elkington, J., 1994).



(for example Ashby and Johnson, 2014).

The triangular models have become dominant ways to comprehend sustainable development, but they fail to elaborate how the pillars should be interpreted, how they should be operationalized and not least, how the pillars interact and influence each other. Figure 19 demonstrates the thoughts behind the Triple Bottom Line and the Three P's, where each pillar is represented as a circle and the circles overlap to show how pillars (can) interact. This illustrates that the model serves as a means to interpret sustainable development as a holistic system.

Sustainable product design

Sustainable design can be described as the dimensions of sustainable development that refer to design in all its facets and with design solutions that are "good" for all species at all times (McLennan, 2004).

Different scholars have described the development of sustainable design and the interaction and influence with sustainable development. Keitsch applies a 'micro', 'meso' and 'macro' levels approach with the assisting labels 'Design for Environment', 'Industrial ecology/ecodesign' and 'Design for Sustainability' (Keitsch, 2015); Vezzoli and Manzini describe it through four interventions being 'Environmental redesign of existing systems', 'Designing new products and services', 'Designing new production-consumption systems' and 'Creating new scenarios for sustainable life style' (Vezzoli and Manzini, 2010); Bhamra and Lofthouse explain it with two waves: the first wave emerging in the late 1960s in the critique of modern and sustainable development and the second wave emerging in the late 1980s as part of the green consumer revolution that became more widespread and appreciated even though difficult to manifest in the commercial design industry (Bhamra and Lofthouse, 2007) and McLennan proposes four 'beginnings of sustainable design' labeled 'the biological beginning', the 'indigenous beginning', the industrial beginning' and 'the modern beginning' and six principles of sustainable design being 'respect for the wisdom of natural systems', 'respect for people', 'respect for place', 'respect for the cycle of life', 'respect for energy and natural resources' and 'respect for processes' (McLennan, 2004: 38). Similarly the commercial design company SustainAbility describes their commitment within sustainable development first as 'risk and engagement' (from 1987 to 1999), then 'value and collaboration' (from 2000-2009) and finally 'transformation' (from 2010 and onwards) ("SustainAbility," 2015). However no matter the terminologies used, all approaches describe a journey from predominantly focusing on raw materials and consumption of production resources to product use and user involvement to larger strategic systems and further towards cultural interventions.

In this journey the value system has shifted from being mainly objective to increasingly acknowledging subjective dimensions. It has also shifted from perceiving sustainable initiatives as primarily singular and non-interactive entities to large and complex systems with constant interactions between human and non-human actors. The broadening of the scope of sustainable development means that more disciplines take part in a collection of mindsets, methodologies and traditions that both strengthen and dilute the concept of sustainable development.

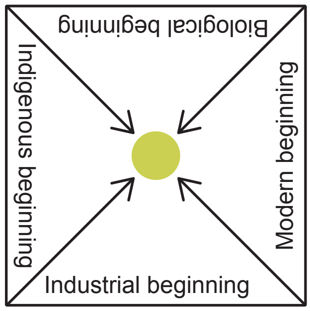


Figure 20. The four beginnings of sustainable design according to McLennan (2004)

McLennan bases his work on sustainable design in architecture and not product design, but it has inspired this project's understanding of sustainable design. Specific eras of the human development can be linked to his four beginnings and they take as the point of departure certain constant phenomena that keep them relevant and provide an interesting and different take on sustainable design. In the following the four beginnings are briefly summarized:

_ The biological beginning corresponds to the evolution of our planet and nature's balance of the eco-system and self-regulation and considers how species have adjusted their living conditions based on their habitat (McLennan, 2004: 11ff).

_ The indigenous vernacular beginning refers to design and systems developed by ancient civilizations, exploiting well-known materials and duplicating nature's own systems to meet occurring needs (Ibid.: 16ff).

As McLennan also reflects, former civilizations worked with principles that are now considered as sustainable, but their incentives were not to be sustainable. They used available materials and developed techniques for generations creating optimized solutions for essential functions simply to survive, satisfying 'needs' rather than 'wants' and 'desires'. However decoration has at all times been part of cultural heritage and in the making of clothing and products (Brett, 2005). This suggests that aesthetic means of creating a sense of connection between human beings and objects have always been part of society.

_ The industrial beginning departs in societal changes lead by the industrial revolution and driven by new availability of materials and technologies. It changed the relationship between humans and nature and between humans and objects, believing that nature's systems could be controlled and tamed and that all arising problems could be fixed using newly invented technologies. Accordingly the industrial beginning of sustainability can be regarded as the conscious reaction against the unsustainable consequences of human intervention with nature's systems, the environmental movements were fighting for (McLennan, 2004: 20ff).

_ The modern beginning assigns the modern environmental movements

> that acknowledged the necessity to change our ways of living in order to save our own species with a code of responsibility and a structure to guide a change in behavior. The modern beginning also recognizes that our lifestyles, technologies and increasing population rates have a negative impact on the environment and that “we have a responsibility as caretakers of the earth to craft our societies and the technologies for the continued survival of our species and those that we share it with” (Ibid.: 24ff).

A paradigm shift between indigenous vernacular and industrial beginning can be observed relating to the construction of society and the interpretation of design. This corresponds to the previously mentioned authors, Schumacher and Papanek, who criticized modern society’s oblivious consumption of nonrenewable resources (Schumacher, 1974) and pinpointed the necessity of designers to consider real needs rather than wants and desires (Papanek, 1971).

In Chapter 1. Background it was emphasized that the ‘modern’ design practice is a result of the industrial revolution and that sustainable development is a necessary consequence of the industrial or modern society consumption. Consequently modern design practice is strongly connected to sustainable development philosophy.

According to Manzini, no matter how sustainable design is approached, it deals with reducing the environmental impact on the existing and future societies by simplifying things and doing things differently (Manzini, 2006) and seeks to connect technologically possible and ecologically necessary initiatives with socio-cultural propositions (Vezzoli and Manzini, 2010: x). Therefore it makes sense to talk about sustainable design as environmental design, as the environment is the main driver for sustainable products ranging from pollution treatments, to interventions of clean tech technologies to redesigning products or services to reorienting social behaviors though sustainable consumption (Ibid.).

The scope of sustainable design has evolved since the environmental movements in the 1960’s and 1970’s and there is a tendency that the newest arrived ‘trend’ is considered as the superior, which causes formerly applied and more established trends to lose attention. In recent years concepts such as interaction design, service design and strategic design (in more or less chronological order) have been used as means to develop the sustainable design field. This corresponds to the trend in sustainable development that subjective means are increasingly acknowledged and that sustainability initiatives should be regarded as systems rather than singular achievements.

The following sections describe sustainable design with a hierarchical taxonomy departing from materials. However before doing that, McLennan’s ‘six principles for sustainable design' is briefly introduced. The six principles break with the aforementioned hierarchical taxonomy; when examined, it becomes clear that sustainable design concepts, old as well as new, can be supported by at least one of these.

Figure 21 shows graphic interpretation of the six principles of sustainable design. The interpretation has deliberately been made as a hexagonal 'clock' where each principle points towards the center to eliminate a hierarchical order of principles. 'Respect for the wisdom of natural systems' is the principle of biomimicry meaning mimicking nature's own systems to obtain the most efficient solutions (McLennan, 2004: 39), 'respect for people' is the principle of human vitality meaning designing for the people that use a product (or service or system) (Ibid.: 46), 'respect for place' is the principle of ecosystems and bioregion meaning to acknowledge and respect the environment in which a products is used (Ibid.: 52), 'respect for the cycle of life' is the principle of 'seven generations' meaning that a design should be sustainable not only now with present conditions, but also in seven generations (Ibid.: 64), 'respect for energy and natural resources' is the principle of conservation and using renewable resources meaning that designs should consider, how resources (such as materials) can be either conserved or renewed as parts of closed loops (Ibid.: 74), and finally 'respect for processes' is the principle of holistic thinking meaning that designs should take part of larger integrative systems (Ibid:. 83).

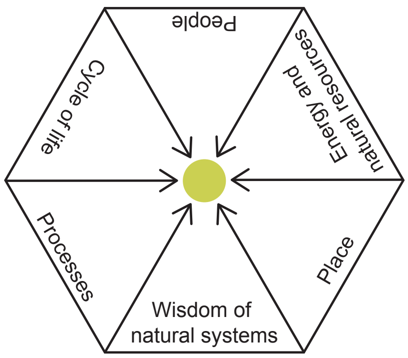


Figure 21. Interpretation of McLennan's 'six principles of sustainable design' (based on McLennan, 2004).

Materials in sustainable design

The next section discusses sustainable design and how it has evolved with sustainable development but with specific focus on the role of materials. In product design materials play a great role in general, as all (physical) products are composed of materials. Thus materials as promoters for sustainable design are relevant to debate. This is framed with a model designed to unravel impacts of materials from five perspectives and to provide an overview and hierarchy of the increasing complexity of concepts and notions used in sustainable design. The model has been developed for this project and with inspiration in aforementioned taxonomies such as Keitsch (2015), Bhamra and Lofthouse (2007), Vezzoli and Manzini (2010) and McLennan (2004).

The five perspectives being: ‘processes’, ‘products’, ‘services and use’, ‘strategies’ and ‘culture and experiences’ are hierarchically structured in a shell like box arrangement as illustrated in figure 22. In that sense the perspectives build on and supplement each other in the depth of working with sustainable design. Here each perspective is described based on content, origin, value set and correlation to previous perspectives as well as with examples of relevant material-driven or material-influenced approaches.

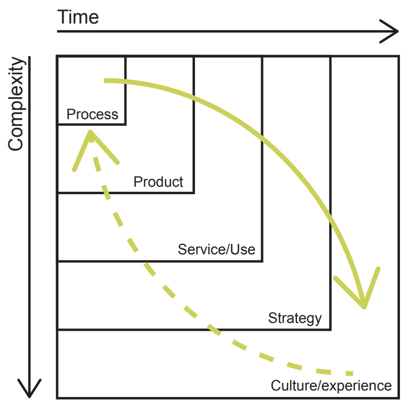


Figure 22. The hierarchical perspectives model that is used to illustrate the emergence of sustainable design through ‘processes’, ‘products’, ‘services and use’, strategy’ and ‘culture and experience’.

Perspective 1: Processes

The first perspective, ‘processes’ refers to the environmental impacts of extraction and production of raw materials during pre-consumption and waste generation processes during post-consumption that were gaining increased momentum with the 1970s environmental movements. With impacts predominantly assessed by quantitative measures such as water, energy and chemical consumption, industry started to investigate how these processes could be improved to lower the environmental impact of existing processes rather than finding more environmental profitable alternatives.

The fundamental philosophy behind clean technologies (‘Clean Techs’) is derived from this perspective and deals with environmental preferable technologies of different kinds. The perspective also incorporates considerations for use of artificial substances thus promoting ‘natural resources’ and ‘organic materials’ as well as ‘renewable’ and ‘bio-degradable’ materials to lower the consumption of non-renewable materials and renewable energy such as ‘wind power’ and ‘bio-fuel’.

Among relevant political initiatives REACH (Regulation on Registration, Evaluation, Authorization and Restriction of Chemicals), a European Union regulative to prevent harmful chemicals (“REACH,” 2015) can be mentioned.

Perspective 2: Products and use

The second perspective, 'products and use' broadens the scope of 'processes' to include the environmental impacts of the consumption phase in a 'cradle-to-grave' (C2G) or life cycle approach. It means that in addition to pre- and post-consumption, transportation and use of products are included in the assessment of impacts. With the incorporation of the use phase it becomes relevant to know, how consumers use their products and thereby their environmental impact.

In a report from UNEP, the United Nation's Environmental Program in a life cycle approach it is stated that: "we recognize how our choices influence what happens at each of these points so we can balance trade-offs (…)" and "(…) is a way of thinking which helps us recognize how our selections – such as buying electricity or a new t-shirt – are one part of a whole system of events" (UNEP, 2004: 6).

The life cycle approach has been formalized with Life Cycle Assessment tools (LCAs) (for example ISO, 2010a, 2010b, 2010c) and derivatives from it such as the Ecodesign Strategy Wheel (van Boeijen et al., 2013: 63) also called the Eco design-web (Andresen, 2010) and the (Danish) MEKA analysis (McAloone and Bey, 2009).

A sustainable design 'trend' that corresponds to products and use is 'ecodesign', a design approach that seeks to limit the environmental impact throughout a products life cycle (Ibid.). Ecodesign products typically emphasize using materials from renewable resources such as wood and natural fibers or from recycled or upcycled materials that in new products have different shapes and aesthetic expressions (Block and Quella, 2012; Wimmer et al., 2010).

Perspective 3: Services and systems

The third perspective, 'services and systems' moves the focus from single products and individual consumers to larger systems of material and product flows that can be interchanged and reused between multiple actors. Still with focus on environmental impacts, services and systems introduce ways to share products and streamline consumption. A relevant concept here is 'product service systems' (or PSS), a strategic business model that through larger integration of products and services serves to reduce resource consumption among consumers and companies (Ceschin, 2013; Sakao and Lindahl, 2009; Vezzoli et al., 2014).

An example of a PSS in the Danish hospital sector is the rental services of industrial garments provided by Berendsen. This company was previously mainly laundering garments owned by the hospitals, but now it owns the garments and provides a more efficient service, including laundering and transport ("Berendsen," 2015). In a similar manner on a consumer level, leasing products from washing machines to cars such as Danish company Vigga that provides a subscription service of babies' clothes, where subscription holders received a packet with new clothes as the baby grows ("Vigga," 2015). The perspective also covers products that are privately owned, but that can be shared or rented out via platforms (often internet-based) such as the Danish MinBilDinBil [MyCarYourCar], where private car owners can rent out their cars to other privates ("MinBilDinBil," 2015), Jepti, where people can rent out common goods such as cameras, plates and tents when not needed ("Jepti," 2015) and DinnerSurfer where people having left over food can sell it ("DinnerSurfer," 2015).

In the search for prolonged product life, consumption patterns become increasingly important. Consequently understanding consumers' everyday practices has become essential to sustainable design, with concepts from sociology and anthropology (Shove et al., 2012, 2008). In the fashion industry, known as one of the most polluting global industries, attention to reducing environmental impact is high (Fletcher, 2008; Fletcher and Grose, 2012; Fletcher and Tham, 2015). Here Fletcher argues that "the more radical innovations focus on consumption patterns bring the biggest benefits, because they are based on cultural change and shifts in consumer consciousness" (Fletcher, 2008: 28). However, the challenge is that the stronger the beneficial impacts, the longer it takes and the more difficult is the implementation, which has been illustrated in a 'time/difficulty of implementation' versus 'sustainability improvements' graph in figure 23.

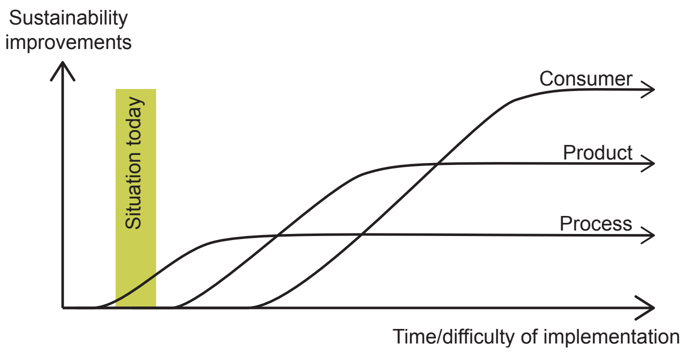


Figure 23. The sustainability improvements of 'processes', 'products' and 'consumers' elicited in difficulty of implementation (based on Fletcher, 2008: 80 from Brezet, 1997).

Perspective 4: Strategies

The fourth perspective, 'strategies', embraces the three inner perspectives in a holistic understanding, emphasizing economic, environmental and social sustainability, as proposed by Elkington (1994), and Fisk (2010). This perspective also builds on a 'circular economy', where circular material flows can be used to establish a restorative economy (Ellen McArthur Foundation, 2012). It can be traced back to the concept of 'industrial ecology' as used by Frosch and Gallopoulos (1989), highlighting the incentives for recycling and conservation (of materials) and proposing an industrial ecosystem, in which the consumption of energy and materials

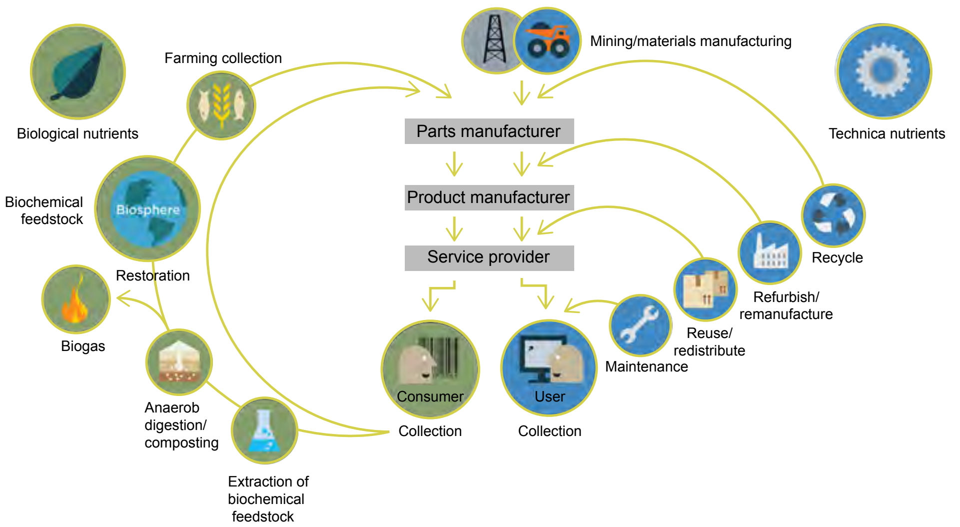


Figure 24. The two circuits according to the circular economy model being the biological and the technical circuits (after Ellen McArthur Foundation, 2012).

is optimized, waste generation is minimized, and effluents of one process serve as the raw material for another process (Ibid.: 44). The circular economy builds on two material circuits: a 'biological' circuit with materials that can be renewed and degraded as substance and nutrients for growing new materials and a 'technical' circuit with materials that can be reused, remanufactured or redistributed. When separating the two circuits it is possible to utilize materials optimally and thereby lower the overall environmental impact. The concept of 'Cradle-to-Cradle' as used by McDonough and Baumgart (2002) also describes a circular economy.

A relevant aspect of the strategies perspective is that it focuses on the interaction

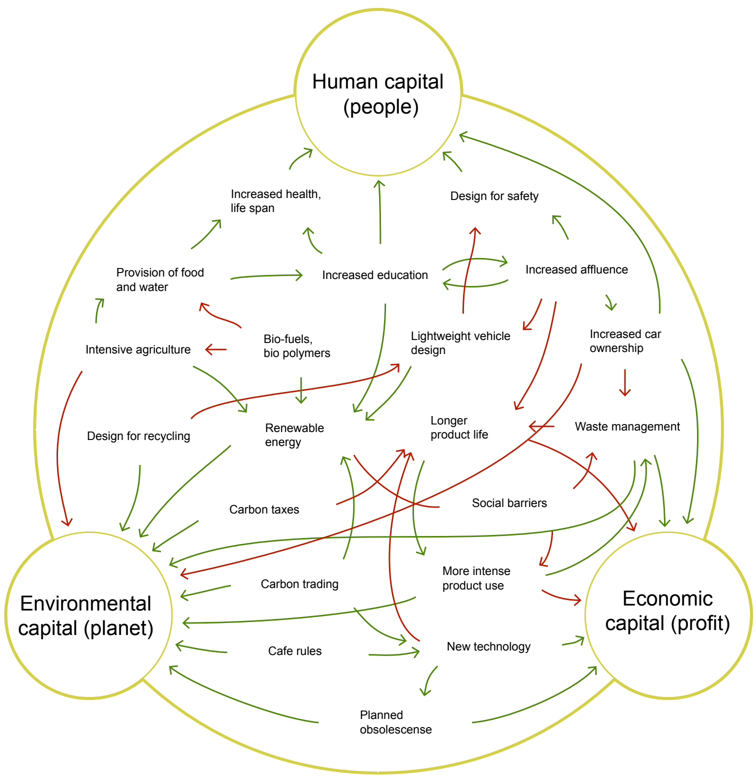


Figure 25. Examples of interactions and conflicts in sustainable development (Ashby and Johnson 2014: 161).

between sustainability initiatives and how they may affect each other. Mulder et al. calls these 'articulations of sustainable development' and describes them as all the topics that relate to sustainable development which are (often) conflicting (Mulder et al., 2011). Articulations compete in the choices you have to make, and they conflict, as they are interconnected.. Therefore the challenge is to ensure strings of articulations that create better overall conditions. To illustrate the interactions and connections between articulations, Ashby and Johnson use a diagrammatic network of sustainability articulations inherent in social, environmental and economic sustainability. An example of a network from Ashby and Johnson (2014: 161) is shown in figure 25. Here, for example, it is illustrated, how intensive agriculture is negative for environmental capital (it goes against nature), but positive for provision of food and water (it provides more food) as well as renewable energy (the crops are used for bio-fuels); and how longer product life is positive for more intensive product use (this again is positive for environmental capital), but negative for economic capital (longer lasting products means smaller demand).

Perspective 5: Culture and experience

The fifth and last perspective, 'culture and experiences', puts emphasis on experience as a means to create value with initiatives that strengthen the consumer-product relationship or that prolongs the lifetime with having multiple consumers (Börjesson, 2008; Chapman, 2009; Tseng and Ho, 2012). Thereby it shares multiple characteristics with the 'services and use' perspective and the 'strategies' perspective. The aforementioned services, MinBilDinBil, Jepti and DinnerSurfer are examples of services that enhance the experience and use of a product. The perspective also include cultural interventions such as flea markets and swap parties and the immense amount of online platforms for sharing and exchanging goods on for example Facebook.

A solution that can be related to the 'experience'', but also 'processes', 'products' and 'services' is provided by the Danish start-up company Organic Basics that offer a subscription service on boxer shorts for men in organic cotton ("Organic Basics," 2015). Besides using manufacturing processes that are (considered) good for the environment and with a service that automatically provide you new boxers, the company put high emphasis on the costumer experience through social media. Here they for example share pictures of visits to the farm in Turkey where their cotton is grown, of their Friday morning breakfasts and of photo shoots with friends and family wearing boxers ("Organic Basics - Instagram," 2015).

Organic Basics is an appropriate example of experiential approaches to sustainable design that is promoted through social media and online platforms. These allow customers to increasingly take part of the realization of products through crowd funding platforms such as Kickstarter ("Kickstarter," 2015) and Indiegogo ("Indiegogo," 2015) or prepaid product systems that allow companies such as Fairphone ("Fairphone," 2015) to ensure funding for new products before production is initiated. Fairphone can also be used as an example of a company that wants to create an inclusive environment centered on the products to create stronger bonds between the user and the product. In the Fairphone community this includes blog posts from product developers and travel reports from mining visits, a forum and support system where users can get immediate help and open source files for 3D-printing phone cases among other things.

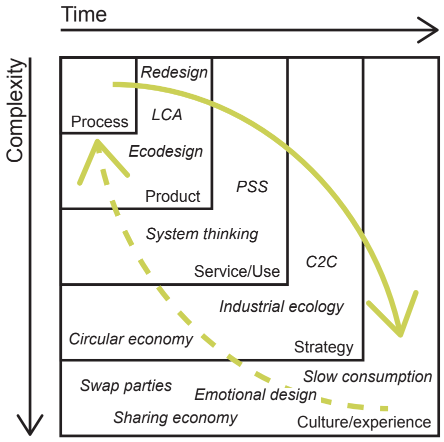


Figure 26. The hierarchical perspectives model including concepts from sustainable design.

Across perspectives

The five perspectives have introduced different approaches to sustainable design with focus on materials ranging from predominantly quantitative and singular aspects in the 'processes' perspective to qualitative and interacting networks of aspects in the 'culture and experience' perspective. The model has been made to provide an overview of aspects. In figure 26 a selection of sustainable design concepts has been added to the model. So far little attention has been put on concepts and products that overlap; however these are also occurring.

Biomimicry is the imitation of nature's systems and models and can in sustainable design relate to all five perspectives in the model. In 'processes' it can relate to technologies such as optical colors known from beetles (Lenau and Barfoed, 2008) and butterflies (Chua, 2010), hydrodynamic surfaces from shark skin (Oeffner and Lauder, 2012) or super hydrophobic surfaces from lotus flowers (Latthe et al., 2014; Nosonovsky and Bhushan, 2012), in 'products' it can relate to shapes such as topologically optimized constructions of canopies and opening-mechanisms that react to sunlight, and in 'strategies' the essence of circular economy is based on nature's own systems and its ways of maintaining them.

Figure 27. Dress of Morphotex textile by Australian designer Donna Sgro (Chua, 2010).

What is sustainable design in the thesis?

As it has been stressed in the previous sections, sustainability has become one of the key issues on the political agenda for the future and as designers take part in constructing the future, it is vital that they are able to navigate the complex networks of articulations that promote sustainable development. It is no longer believed that it is enough to reduce our impact – it is necessary to improve practices and to change people's understanding of what sustainability is and can do. Accordingly designers are responsible for not deceiving consumers with insufficient sustainability labeling and marking products as fully sustainable, even when they are not.

The interpretation of sustainable design in this thesis is that it can be all of the above as well as many other aspects. However an important premise is that no inherently sustainable materials exist. The sustainability impact of specific materials has to be considered for any application and practice of use as the interaction between multiple sustainability articulations. Furthermore it has to be considered from multiple perspectives and principles such as from the 'hierarchical perspectives'-model and the 'six principles of sustainable design' that was proposed by McLennan (2004).

In the materials teaching at Design School Kolding students are continually asked three questions. They have been framed with basis on the works of Papanek (1971), Thorpe (2007) and Manzini (2009, 2006) among many others and are:

- *"What is the need?"*
- *"If there is a need, how can it best be satisfied?"*
- *"If this requires a new product, how can it best lower its sustainable impact?"*

The questions can eliminate many new products and increase the probability of introducing products on the market that are efficiently used. As paradoxical as it is, in product design, a discipline that builds its foundation on 'making products', no product will always be the best solution for lowering the environmental impact.

It is however also important to acknowledge that emphasis on sustainable design has influenced the material landscape and has boosted interest in emerging materials. Consequently many emerging materials and technologies have been developed to address sustainability issues and thereby the introduction of many emerging materials can be regarded as a sustainability articulation in itself.

Material value parameters in design practice

The fifth perspective, 'culture and experience' in figure 22 introduces the concept of 'experience', which does not fit well into any of the three pillars in the Triple

Bottom Line. Consequently, Fleming and Sherman have proposed a Quadruple Bottom Line that incorporates the extra 'experience' pillar (Fleming, 2014). The approach has not been integrated in the materials teaching the project builds on as it was discovered too late in the process. Consequently it is not part of the empirical analysis, but will return in the discussion as a frame to reflect retrospectively on the use of sustainability aspects in the courses.

The approach that was predominantly applied in the project is based on domain theory. The domain theory (figure 14) was used to elaborate on the role of quality, with strings to experiential and sustainability aspects, in the material practice. Sustainability was not a part of the original domain theory and the following will therefore elaborate on, how experiential, technical and sustainability aspects can cohere and work together. According to the domain theory model, a technical and a human system and the active environment provide inputs to the process in the transformation domain as it was described in the Theory of Technical Systems (the triangle in the upper part of the model in figure 15). These three components could be called physical, experiential and sustainable aspects.

The triangle can be used to provide a perspective that jointly considers physical, experiential and sustainable attributes (P-E-S triangle). The triangle integrates the physical versus experiential range of material attributes that was previously discussed (p. 60ff) as well as it connects sustainability aspects to physical and experiential material attributes. The sustainability-physical scale corresponds to environmentally oriented material aspects with focus on the first, second and third perspective in the hierarchical model, whereas the sustainability-experiential scale corresponds to human and social aspects of sustainability in design with emphasis on the fourth and fifth perspective in the hierarchical model. Hence the triad consists of three scales: a physical/experiential, an experiential/sustainability and a sustainable/physical scale. The triad, as shown in figure 28 recognizes that even though sustainable impacts are important in product design, there are also some materials and product requirements that are without direct sustainable concerns. Hence the triad can be used to indicate the emphasis a design concept has on physical, experiential and sustainability aspects. Here technical product design will be oriented towards the physical attributes corner, emotional product design will be positioned towards the experiential attributes corner. Consequently environmental design will be placed on the physical/sustainable scale and sustainable emotional design will be placed on the experiential/sustainable scale as it is shown in figure 29.

Material value parameters in design practice and for sustainable design in particular are more than this simplistic triad. Nevertheless the triad has been made

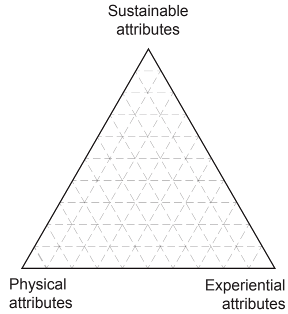


Figure 28. Scales triad with physical, experiential and sustainability attributes incorporated.

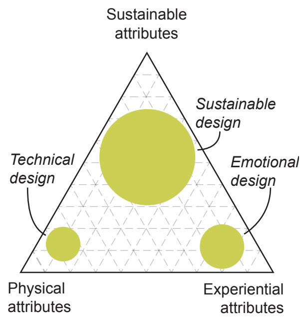


Figure 29. Scales triad with examples of technical design, emotional design.

as a first step to establish a frame to navigate for actors such as students that are challenged with the potentials and boundaries of sustainable thinking for the first or second time.

CHAPTER SUMMARY

This introductory chapter on material perspectives has served to establish the basis for understanding materials that will be applied throughout the dissertation. In the chapter it was argued that materials as non-human and designers/design students as human actors are part of actor networks. The actor networks mediate and inscribe meanings and create power relations and stability.

The chapter has further introduced material value parameters based on domain theory with emphasis on physical, experiential and sustainable material attributes. Material values acknowledge that different perspectives are necessary to understand the holistic use of materials, but also that some perspectives are more important in some designs than in others. In the present design practice sustainability is an important parameter and aspect of this has been discussed.

Summary

- Materials consist of both a physical and a social dimension. The physical material dimension considers performance based on the material's physical composition, while the social material dimension considers performance based on the material's societal role.
- Materials are hybrids, with material meanings inscribed by numerous human and non-human actors such as manufactures, suppliers, designers, consumers, processing equipment and competing materials.
- Material values should be considered with respect to physical, experiential and sustainable material attributes.
- Physical attributes are rooted in the composition of the material and experiential attributes relate to the meanings and emotions users give materials.
- Sustainability considerations in product design can relate to environmental, economic and social aspects as well as increasingly experiential aspects. The understanding of sustainable design in the thesis embraces all of the above.

5. LEARNING AND MATERIALS

The next chapter explores education and learning as theoretical concepts and discusses the role of didactic approaches in different learning environments. The argument serves to establish a foundation to look specifically at teaching of materials in design education.

Learning approaches and didactics have been essential in this project especially for two reasons. The first reason is that learning approaches are strongly attached to epistemological and ontological traditions and therefore learning and didactics have been a way to illustrate how and why artistic design courses differ from both natural sciences and engineering and humanities and social sciences courses. The second reason is that because the empirical data have been based on exercises and observations in materials courses, it was essential to understand the role of learning environments in order to improve the materials teaching curriculum.

WHAT IS LEARNING?

Learning (as a gerund) can be defined as "the activity of obtaining knowledge" ("Cambridge - Learning," 2014) or "the acquisition of knowledge or skills through study, experience or being taught" ("Oxford - Learning," 2014). The two definitions from the Cambridge Dictionary and the Oxford Dictionary respectively relate learning to processes where stimuli and unprocessed input are developed, transformed, linked and related to previously acquired knowledge. However, because learning can approached from different disciplines it is not always adequate to stick to a narrow definition of the term.

Several different taxonomies and structures can be used to dissect learning approaches. The two structures introduced here take different points of departure. Illeris recognizes that learning is a holistic human process, but differentiates between cognitive, emotional and social processes (Illeris, 2004). In parallel Beck et al. introduce three learning models based on the relation between the learner ['den lærende'] and 'what is learned' ['det som læres'] (Beck et al., 2014). It can be added here that the learner can be regarded as 'internal', while what is learned will occur as 'external'. The two structures are intertwined and originate in similar epistemological discussions and are therefore used interchangeably.

Three overall learning approaches are provided in the following. The introduction leads to an elaboration of the definition of learning and how it has been approached in this project.

Reactive, active and interactive learning

Beck et al. base their learning model on a 'reactive learning scheme', an 'active learning scheme' and an 'interactive learning scheme' (Ibid). The learning schemes provide an overall understanding of learning traditions that go beyond common taxonomies and relations to classic and modern worldviews and learning theories and can be demonstrated in specific theories and learning approaches. The three schemes are illustrated using a learning arrow that shows the 'cause-effect' relation between the learner and what is learned. A cause-effect relation clarifies the cause (the 'active' actor) and the effect (the 'passive actor) in a relation. In figure 30, the three learning schemes are illustrated focusing on the relation between 'the learner' and 'the learned' with arrows that point from the cause to the effect.

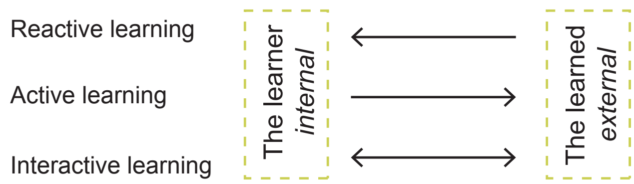


Figure 30. The relation between the learner and the learned for respectively reactive, active and interactive learning (with inspiration from Beck et. al. 2014).

Reactive learning

In a reactive learning scheme, learning is the result of external influences that change the behavior and mindset of the learner. In figure 30 this is illustrated by an arrow from the external influences to the learner. In reactive learning, learning originates from something external that dictates the information and characteristics of the learner's learning experience. The learner is perceived as an object that can be manipulated through external influences to preprogrammed knowledge (Ibid: 18). It means that learning according to a reactive learning scheme is not controlled by the learner as a human being, but by external mechanisms. The reactive learning scheme is demonstrated in behaviorist learning theories that origin in naturalist, rationalist, positivist, objectivist and determinist world-views (see for example Qvortrup, 2014). Behaviorism is closely related to natural scientific approaches to possessing and acquiring knowledge and as an educational learning approach it has traditionally and especially recently been linked to natural scientific and engineering educational institutions.

Active learning

An active learning scheme starts with the belief that every human being is unique, with their own distinctive learning possibilities embedded in their identity (Beck et al., 2014). Learning is regarded as the person's free and independent actualization of human potential with an active (conscious and reflective) internal relation, where people, initiated by their own resources, will and freedom, explore their own potential (Ibid.). This corresponds to an arrow pointing from the learner to what is learned in figure 30. With origin in humanities, in active learning, it is stressed that the learner's surroundings are regarded as learning resources and as the medium for the learning processes (Ibid.).

Interactive learning

In the interactive learning scheme a 'trans human' learning understanding is applied. Trans human means that learning takes point of departure in the human, but at the same time it tries to expand the limits of what is human (Ibid.). As active learning is a response to reactive learning, interactive learning is a further response to active learning based on the argument that the measures for human development and learning are too stiff and restrictive. It is not determined what the individual can and should learn, and a person's potential develops in the interaction with a changeable and dynamic world (Ibid.). Consequently interactive learning develops the idea of constructing the reality by realizing potentials through modes of expression, technological development and interactions with the surroundings. In figure 30 it means that interactive learning occurs between humans and their surroundings and hence with arrowheads that both point towards 'the learner' and 'what is learned'. The interactive learning scheme corresponds to social constructions and a reality in constant change influenced by networks of actors as it was introduced in Chapter 4.

Even though the active and the interactive learning schemes are different, they still touch upon the same philosophical paradigms and complement each other. Here the active learning scheme can help us to understand, how we as human beings work with ourselves to develop abilities, while the interactive learning can help us to understand, how we experience and approach things we did not knew was possible. The scheme can further help us to unravel, how we as human beings develop already embedded potentials in unfamiliar situations. In this thesis, the discussion will not apply a strict differentiation between the two schemes, but rather acknowledge that different learning approaches are acquired for what could be called embedded practices (for active learning) and explorative practices (for interactive learning).The keyword to the understand both active and interactive learning is therefore 'practices', being how humans approach and acquire knowledge when interacting with other human beings. Learning as a social practice is introduced later in the thesis, first the three dimensions of learning processes as proposed by Illeris are discussed (Illeris, 2006, 2004).

Cognitive, emotional and social learning processes

Knud Illeris has an educational perspective to learning and has worked with adult education both in academia and practice-oriented professions. Illeris states that learning can be many different things, but he also suggests an overall definition being that "learning fundamentally is conceived of as an integrated process consisting of two connected part processes which mutually influence each other. Firstly, the interaction process between the learner and his or her environment - an interaction which may take place by direct contact or be indirectly brought about through various media and secondly, the internal psychological acquisitional and elaborative process which leads to a learning result" (Illeris 2002: 16). Based on this Illeris define three dimensions that each and together can be used to study and analyze learning. The first considers learning as a 'cognitive process', influenced by the traditional learning psychology and behaviorist learning with Piaget (assimilation and accommodation) (e.g. 1964, 1950) and Vygotsky (e.g. 1926) as important influencing theorists. The second considers learning as a 'psychodynamic process' that involves psychic energy communicated through emotions, attitudes and motivations that can both mobilize and be an influence in the learning process. The psychodynamic process originates in the psychoanalytical understanding and tradition originally developed by Sigmund Freud (1856-1939) Finally, the third considers learning as a 'social and societal process' that includes learning as the direct or indirect social, interhuman and interactive space in which learning happens and the society that influences the characteristics of the interactive process and the degree of involvement of actors.

Characteristics of learning artistic design courses were briefly introduced in Chapter 2 and will be further introduced. For now it is stated that design courses are predominantly rooted in learning based on emotional and social influences. However in recent years, design courses have developed and progressed both in terms of the curriculum that embraces an increased amount of different design aspects and in the foundation the curriculum has been built on.

Bloom's taxonomy of learning

In the 1950s a group of educational psychologists around Benjamin Bloom developed a classification system for three learning domains referring to 'cognition' (also called knowing/head), 'affection' (also called feeling/heart) and 'psychomotion' (doing/hands) (Bloom et al., 1956; Krathwohl et al., 1965) (the domains are similar to Illeris' processes described above).

The system first described the cognitive learning domain based on a taxonomy of learning, now known as Bloom's taxonomy of learning, but never finished describing it. Since the 1950s other taxonomies have been proposed (for example Anderson 1983; Ausubel, 1968; Gagné, 1985; Merrill, 1983), but Bloom's taxonomy has remained the dominant way to structure learning and is used in educational institutions, including Design School Kolding, to clarify learning goals and objectives in the curriculum.

The three domains each consists of hierarchical ordered steps ranging from lower to higher-level processes. For the cognitive domain the steps are (1) 'knowledge', (2) 'comprehension', (3) 'application', (4) 'analysis', (5) 'synthesis' and (6) 'evaluation' (Bloom et al., 1956)* and for the affective domain the steps are (1) 'receiving', (2) 'responding', (3) 'valuing', (4) 'organizing' and (5) 'characterizing' (Krathwohl et al., 1965).

* The steps were later revised to (1) 'remember', (2) 'understand', (3) 'apply', (4) 'analyze', (5) 'evaluate' and (6) 'create' (Anderson et al., 2000; Krathwohl, 2002).

With widespread applications this taxonomy has proved successful in creating a common language for communicating learning goals and establishing a congruence of educational objectives, activities and assessments (Krathwohl, 2002: 212). However while it is intuitively structured, it also appears simplistic and restrictive and very much in line with the behaviorist learning tradition it was developed from. That said, the taxonomy has still inspired the tools and methods, which are introduced, discussed and developed in the following chapters, focusing primarily on the cognitive domain.

While Bloom's taxonomy offers a structure to assess learning (primarily in education), different aspects of learning influence the scope of this project. Learning entails processes that for the human being happen internally (such as in cognitive processes) and that occur externally in interaction with other human beings and the surroundings (as part of a social practice). To understand how students learn about materials, two learning approaches have been applied in the project, being 'learning as a social practice' (or social learning) and 'learning about materials as a sense making and sense giving mechanism'.

LEARNING AS A SOCIAL PRACTICE

This section explores learning as a social practice with special emphasis on learning materials. The introduction touched upon tension in materials teaching, a traditionally behaviorist and natural scientific and engineering-oriented topic in an artistic design school that is rooted in a practice-based and highly constructivist tradition. It creates an ontological tension and battle between definite, analytical and objective versus relative, reflective and subjective knowledge creation. In the studies it was also observed that students expect materials teaching to follow a pattern similar to or inspired by its natural scientific tradition, which clashes with the normal educational practice in an artistic design school.

Situated action, a concept introduced by Lucy Suchman describes how every action depends on physical and social circumstances meaning that action is dependent of the situation (Suchman, 2006, 1987). In situated learning, the learning experience and outcome of the learning experience are thus dependent on the physical and social conditions and frames in which the learning is conducted. Plans include principles, rules and procedures that are projective or retrospective accounts of action that serve to formalize and set some guidelines for action and processes (Suchman, 2006). Put in other words, in learning this means that instructors base their learning approach on previous experiences in, how students act and the knowledge they obtain. If the approach does not succeed in obtaining the anticipated knowledge, the learning approach can be adjusted. However, according to situated actions, it is still not possible to predict, how students will react to these adjustments. Thereby learning should not focus on transmitting already fixed plans, but to develop skills to construct and reconstruct plans with respect to demands and opportunities in different situations (Duffy and Jonassen, 1991).

Situated action is a holistic framework and therefore lacks detailing and standpoints on some aspects. Wenger and Lave have considered situatedness (meaning how things are situated) as part of the learning process based on practice-oriented disciplines where acquisition of knowledge is part of social processes; accordingly, Wenger and Lave have called this situated learning (Lave and Wenger, 2003, 1991). With situated learning Wenger and Lave wanted to break with traditional learning theories building on behaviorism and cognition (Beck et al., 2014: 371) and with theories that consider learning as independent of theoretical practice (Lave and Wenger, 2003: 107). Consequently, situated learning as a theory builds on a few concepts that can be interpreted in various ways. Two central concepts that will be explored in the thesis are 'communities of practice' (CoPs) and 'legitimate peripheral participation'.

Communities of practice

After working with situated learning, Wenger introduced the concept of communities of practice [praksisfællesskaber] to highlight the role of the collective in learning processes (Wenger, 2000, 1998). In communities of practice, members are bound together by their collectively developed understanding of their community, built through mutual engagement and sharing a repertoire of communal resources (Wenger, 2000: 227). Our experiences of who we are as individuals and social human beings are shaped by our 'engagement' in communities of practice where a joint 'imagination' of the society is created through 'alignment'. In that sense communities of practice has much in common with the notions of black-boxes and punctualized actors known from actor network theory (such as Callon, 1991; Callon and Law, 1982; Latour, 1999).

The concept of communities of practice is relevant in the project, as it acknowledges that students are individuals, who learn different things inspired by the environment of learning. It means that interaction between students and their learning environment influence the learning process and its outcome. In this project several relevant practices can be mentioned, especially learning practice, materials practice and design practice. For these practices the community influences how each is developed. Wenger emphasize on the role of identity in learning and argues that "learning is not just an accumulation of skills and information but a generation process to become a specific human being" (Wenger, 1998). Thus learning can be regarded as individual and social as well as contextual and time-related. Communities offer a social frame that allows or offers pathways [deltagelsesbaner] that shape the identities of the participants.

Legitimate peripheral participation

The second concept, legitimate peripheral participation [legitim perifer deltagelse] (Lave and Wenger, 2003, 1991) relates to individuals with different levels of experience within communities of practice. It further considers, how newly arrived actors can become part of a practice community and participate fully in its sociocultural practices. Changing positions, perspectives and roles are parts of the learning process and form the identity that shapes the membership of a practice community.

Design practice can be used as a case of a strong and tradition-bound professional practice for discussing legitimate peripheral participation. In such participation, the apprentice-master relationship is of vital importance. The artistic design practice is rooted in hands-on craftsmanship where apprentice-master relationships of learning have been common. The apprentice observed the work of his/her master and imitated it based in his/her interpretation and reflection of the master's practice.

In the book 'The Craftsman' by American sociologist Richard Sennett wrote about the roles of traditional and modern craftsmanship in society (Sennett, 2008). He states that "craftsmanship is founded on developing skills through an extensive amount of time spend practicing. (...) As skills develop, the technique ceases to be a mechanical activity and people can feel fully and think deeply about what they are doing, once they do it well" (Ibid.: 20). This touches upon characteristics of craftsmanship as part of design practice and of other practice-based disciplines in general. A characteristic is that the process of doing, being the essence of craftsmanship, is not formalized, meaning that in craft disciplines the process of doing is not always conscious and thus not articulated. However, as artistic design has developed, different demands arise that stress the necessity for designers to reflect on processes and argue for choices.

LEARNING MATERIALS IN DESIGN EDUCATION

Based on observations from the School of Industrial Design at Politecnico de Mi-

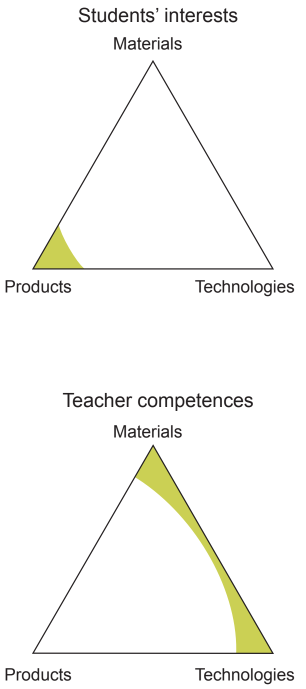


Figure 31. Competences and interests of freshmen versus initial competences of teachers of material classes (de Nardo & Levi, 2014: 320)

lano, De Nardo and Levi have highlighted differences in interest and competences between students and teachers in materials teaching (De Nardo and Levi, 2014). In the study these differences are illustrated using the triangular relationship between products, materials and technologies, as used in the Material Explorer tool (Van Bezooyen, 2002) (see figure 31). The study presents that design students' skills and interests, especially in the beginning of their studies, are predominantly focused on the product, while teachers in materials often have a technical background and therefore their competences are based on materials and technologies (De Nardo and Levi, 2014: 320). The gap in interest and competences makes it difficult to conduct an integrative materials approach in design projects.

From my own experiences with teaching materials I can endorse the findings of this study fully. I still remember my astonishment and fascination in the first materials courses I took part in. What I imagined and wanted the students to learn and what they found relevant were two different things and this imbalance interested me. Thus the study by de Nardo and Levi points towards an essential challenge being how we (as educators, design institutions and preferably also students) can make the gap between educators' and students' expectations smaller and increasingly combine interests and competences in products, materials and technologies from the beginning?

In many technically oriented design courses, introductory and natural science-oriented aspects of materials are taught in decontextualized and multidisciplinary courses and thus without special emphasis on materials for design and how materials can be applied. It risks discouraging students, who are mostly interested in applied materials. It is however difficult to describe why some materials are conductive and why materials can have different colors, and many other material phenomena based on physical material behavior, if students are not familiar with molecular structures and what for example tensile strength, thermoplasticity and chemical properties are and entail.

Prior to one of the fashion and textiles courses I taught in I thought about course structures to allow time to introduce a substantial amount of theoretical background and to give the student space to work with materials on their own. The course had been conducted earlier and therefore I had some experience to base my reflections and concerns on. The theoretical lectures introducing textile materials seemed overwhelming for the students and as a lecturer it was difficult to maintain the students' interest. One of the aims of the course has been to establish a basic understanding of physical material properties based on textiles, but because of the limited time, it was difficult to cover everything and still provide enough practical examples. In a dialogue with one of my supervisors, Torben Lenau, we talked about how broad and how deep the theoretical input should be. Was it better to use time to introduce all important textile fibers? or was it better just to introduce one or two materials and provide a structure and method for students to investigate other materials afterwards?

To elaborate on these questions, I will return to Bloom's taxonomy of learning (pp. 83-84). In the revised version an additional knowledge dimension was introduced that identifies different kinds of knowledge acquisition. The knowledge dimension includes four categories being 'factual', 'procedural', 'conceptual' and 'meta-cognitive' knowledge generation (Anderson et al., 2000). For a description of the categories see the box below.

Knowledge dimensions

Factual knowledge relates to terminology and specific details and elements, such as isolated bits of information and knowledge about specific details.

Conceptual knowledge relates to systems of information, classifications and categories, principles and generalizations and theories, models and structures.

Procedural knowledge relates to subject-specific skills and algorithms, subject specific techniques and methods and knowledge about when to use methods and procedures.

Meta-cognitive knowledge relates to strategic knowledge, knowledge about cognitive tasks, knowledge about thinking processes and self-knowledge.

(Anderson et al., 2000)

The traditional approach to teaching materials (also in design education) is to acquire factual and to some degree conceptual knowledge. However it is here claimed that in order to provide a better basis for students to learn about materials (both in the materials courses and in their future materials and design practice) knowledge generation should increasingly include procedural and meta-cognitive approaches. One of the main obligations as a lecturer is that you give as much as you can. Experience shows that students tend to return to the materials they have been introduced to as part of lectures rather than through own explorations.

In the materials courses that take part of this project, students have been asked questions that could elicit some of the puzzlements that constantly have arisen in this project. From dialogues and group discussions it can be extracted that students rarely seem to remember specific technical material properties, but they store materials mentally based on specific functions and applications that have caught their attention. These aspects often concern sustainability aspects and functional properties that are related to a ‘wow’-effect.

It will never be possible to cover all materials and aspects and it is therefore better to prepare students to explore and investigate materials providing tools and methods that allow procedural and meta-cognitive knowledge to grow. Therefore the following will elaborate on shifting knowledge generation towards the procedural and meta-cognitive dimensions. The first argue for the necessity of recognizing meta-cognition with emphasis on reflection both on material attributes and on the material practice and sense making and sociomateriality. The second argue for the importance of methods and structures in the materials practices. According to Anderson et al., methods and structures should be categorized as conceptual knowledge (Andersen et al, 2000). However, in the use of methods and structures, it is also stressed that methods should be used with care and be constantly reflected upon.

Materials in a reflective practice

Design practice is often referred to as a reflective practice (for example Hansen 2014). Reflection occurs in the translation of meanings to materializations of design intents in products. Products are made of materials and thus, materials are important components in design as a reflective practice.

In the establishment and development of a material practice in the design education, two particular kinds of reflection appear: ‘meaning reflection’, being how students reflect on the meanings they embed in materials, and how they choose to materialize them and ‘methodological reflection’ corresponding to how students reflect on the process of working with and selecting materials. A very simplistic way to unravel these two dimensions of reflection could be to explore reflection from respectively design engineering that puts much emphasis on structure and methods and artistic design that traditionally has worked with emotional design. However it is not that simple and the conception of reflection is deeply rooted and embedded in design as a practice and ‘methodological’ and ‘meaning’ reflections are strongly intertwined.

When reflection as part of design practice is discussed three scholars are usually highlighted. These are John Dewey, who introduced the concept of ‘learning by doing’ in the 1930s (Dewey, 1938), Polanyi, discussing the role of ‘tacit knowledge’ in the 1960s (Polanyi, 1966) and finally Schön with his work on the ‘reflective practitioner’ (Schön, 1987, 1983). The three concepts will be the points of departure for understanding reflection in the material practice that also include, why the concepts are insufficient in some aspects and why reflecting on materials may call for additional concepts to describe such reflection.

Learning, knowledge and reflection

In Dewey's understanding of learning, experience is central. Humans learn while doing and this has set the basis for experience pedagogics [erfaringspædagogik] (Berdin, 2007; Illeris, 1999). In Dewey's most known book, 'Experience and Education' from 1938, he analyzed traditional (such as behaviorist) and progressive (such as constructivist) courses and proposed a Theory of Experience that argued that educational experience involves continuity and interaction between the learner and what is learned (Dewey, 1938: 10). This corresponds to interactive learning as used by Beck et al. (2014), where the experience is expressed through the coordination between stimulus and response. In an earlier work, 'Democracy and Education', Dewey described experience as a twofold affair, involving trying (active) and undergoing (passive) and argued that to 'learn from experience' is to make a backward and forward connection between what we do to things and what we enjoy or suffer from things in consequence (Dewey, 1916). Under such conditions, doing becomes 'trying'; an experiment with the world to find out what it is like and the undergoing process becomes instruction-discovery by learning about things (Ibid.: 140). 'Undergoing' used by Dewey is similar to reflection but the nature of the reflection is not further elaborated. Nevertheless as learning is based on experience and experience is developed through reflecting on (consciously or unconsciously) stimuli from activities, learning is based on practice – for example by doing something. The title of the thesis 'Learning trough Materials' has been inspired by Dewey's term 'learning by doing' as it wants to stress that learning about materials should be obtained in the interaction between students and materials and individual and collective meaning creation in the process.

The failing in Dewey's works, however, is the lack of detail on how students reflect and what comes out of it. Individual reflection as a meaning creation process is an essential component of the design process, but it can be challenging to articulate the meanings, as they are still 'tacit'.

Tacit knowledge was first described by Michael Polanyi, a natural scientist and philosopher (Polanyi, 1966, 1958; Polanyi and Prosch, 1977). In his book, 'The Tacit Dimension' tacit knowledge was described as the kind of knowledge we have, but which we are not able to describe and communicate. It was divided into 'phenomenological', 'instrumental/functional', 'semantic' and 'ontological' aspects of knowledge (Polanyi, 1966). Phenomenological aspects refer to knowledge based on subjective experiences (meanings and values), instrumental aspects refer to knowledge of using an instrument (actions in a practice); semantic aspects refer to knowledge of spoken languages (intents and meanings expressed in speech and words) and finally, ontological aspects refer to knowledge of being, (intelligibility and comprehension of being) (Mullins, 2006). The last aspect embraces and deduces the three first aspects of tacit knowledge (Prosch, 1986). In design practice, tacit knowledge is commonly referred to and primarily considers the phenomenological and functional aspects of tacit knowledge (for example Brix, 2008; Rust, 2004; von Krogh et al., 2000). Nevertheless being aware of the language you use and how it develops are just as essential parts of considering materials in current design practice.

This project explores how students can train their abilities to articulate knowledge in the boundary between tacit and comprehensive knowledge and to reflect on why they have values they have and why they do as they do. There are things that are intrinsically embedded in individual people and impossible to describe to others. However, referring to articulating materials, it is necessary to have acquired knowledge of the different ways to approach materials and to have a language to articulate them, before it is possible to explore and evaluate materials based on them. Materials are physical objects and many materials are intuitively embedded in our previous use and understanding of what they can do. Interacting with materials generates a mental library of sensorial, associative and emotional references, but unless they are trained or have special interests, few people stop and reflect on how they experience materials; they just do!

Furthermore, if people do not have a vocabulary to describe materials performance, materials observations remain personal and enclosed. Most people are able to distinguish between different material surfaces by touching and feeling them with a finger, but it requires a materials-oriented vocabulary to be able to communicate how the materials are distinguished in terms of for example friction, thermal conductivity, elasticity etc. When designers work with materials, they transfer meanings into the materials they select or develop for products based on intentions and expected use. Hence it is vital that designers are trained in reflecting and articulating, why materials have been chosen or developed as they have to be able to communicate this to users, producers and other stakeholders such as collaborative companies.

In design research as well as in many other practice-oriented research communities, the American architect Donald Schön has become one of the favored references when discussing reflection (Schön, 1987, 1983). In this book ‘The Reflective Practitioner’, he writes that designers are “thinking what they are doing and, in the process, evolving their way of doing it” (Schön, 1983). This means that the actions designers do in their practice are developed while doing it, cf. Polanyi’s instrumental or functional tacit knowledge dimension. The action is influenced by reflections on and thus experiences from previous actions, not necessarily articulated and described, but through subjective and tacit senses (Ibid.). To describe characteristics of reflection-in-action Schön has introduced four constants that, combined, show how different professions have different reflection-in-action schemes. The four constants are (Ibid: 270):

- The media, languages that practitioners use to describe reality and conduct experiments, being the vocabulary, tools and methods and other means used to communicate material choices.
- The appreciative systems they bring to problem setting, to evaluation on inquiry and to reflective conversation, being the value system and individual mindset of the designer (cf. introduction to value systems, mindsets and appreciative systems in the previous chapter).
- The overarching theories by which they make sense of phenomena, being the ontological and epistemological tradition in which the designer has been trained and practices.
- The role frameworks within which they set their tasks and through which they bound their institutional settings, being the ways designers are expected to act in the environment they are practicing in.

In different ways, this dissertation considers Schön's four constants with inspiration in a broad range of disciplines. Schön is often referred to when discussing reflection-in-action as an approach to understand and describe, how practitioners work with informal and tacit processes. In material practice, or at least establishing the material practice as part of design education, formalizing tools and methods are important means. In the next chapter, the increasing complexity in the material landscape makes it relevant and necessary to use more formalized and restrictive methods to explore and evaluate methods. I will claim that reflecting on how to use methods and tools is a different kind of reflection from the one used in the practice-based processes Schön builds his studies on. Traditionally reflection of methods and methodological approaches comes from a different approach to that taken in the design discipline. This incomplete understanding of reflection is debated in the discussion based on design students using methods for the first time.

Making and giving sense to materials

In the previous section the role of reflection in the material practice was discussed. However it partly missed a discussion on, how the reflection is appropriated and transferred. It was touched upon with Bloom's taxonomy, but it did not further elaborate on, how cognitive meaning creation can be transferred into physical appearance, such as how students transfer the meaning they create in materials and products. This translation of meaning is here operationalized through the concepts of 'sense making' and 'sense giving'. These are discussed in the context of materials use in the product design practice.

Sense making in design practice

In design practice sense making can be defined as "a motivated, continuous effort to understand connections (among people, places and events) in order to anticipate their trajectories and act effectively" (Klein et al., 2006) pointing towards the idea that sense making is "a constant process of acquisition, reflection and action" (Kolko, 2010). Additionally Dervin has stated that we make sense of complicated ideas by doing them rather than studying them abstractly (Dervin, 2003), which corresponds to Dewey's understanding of learning (Dewey, 1938).

Kolko has worked with sense making in design practice and writes that "embracing of subjective interpretation as a fundamental aspect to both internal, reflective sense making as well as external, collaborative sense making are the same qualities that describe 'design synthesis' " and that "design synthesis is an abductive sense making process of manipulating, organizing, pruning and filtering data in an effort to product information and knowledge" (Kolko, 2010a). Abductive synthesis here corresponds to a logic that combines inductive and deductive thinking that "allows for the creation of new knowledge and insight" (Kolko, 2010b).

Sense making in organizational theories

Sense making has previously been much discussed in organizational theories with basis in sociomateriality studies to understand how groups of people make sense as described by for example Leonardi (2013), Orlikowski (2007) and Orlikowski and Scott (2008). Sense making has here been described as the "meaning construction and reconstruction for the parties involved (…) as they attempt to develop a meaningful framework for understanding" (Gioia and Chittipeddi, 1991: 442) and as "the experience of being thrown into an ongoing unknowable, unpredictable streaming of experience in search of answers to the question what's the story?" (Weick et al., 2005: 410). Sensegiving has here been less discussed it seems, but has been described as "the process of attempting to influence the sense making and making construction of others toward a preferred redefinition (…)" (Gioia and Chittipeddi, 1991: 442).

These two very similar and yet slightly different approaches to sense making and sense giving are both at stake in materials teaching. The internal process of making sense (i.e. the design practice approach) corresponds to the individual students' meaning creation, while the external process of making sense (i.e. the organizational theory approach) corresponds to the individual students' meaning creation process as part of a larger group in a learning environment with students with other values and appreciations.

Sense making and product experience

The foregoing approaches to sense making link to other theories used to understand the experience of artifacts such as product semantics and product semiotics (Krippendorf, 2006), Vihma, 2013, 1995). Based on product experience, Krippendorf differentiates between three qualities or stages of experience, being 'recognition', 'exploration' and 'reliance' (Krippendorff, 2006), and states that human interfaces with technology are always one of these (Krippendorff and Butter, 2008).

Recognition means to identify something as previously known, and refers to categorizing "artifacts according to what they could afford us to do or prevent us from experiencing" (Ibid.: 360) and thus relates an action with previous related actions.

Exploration "describes the stage in which we search for ways to handle an artifact" (Ibid.: 361) and thus relates to the expectations created through a sequence of interactions that lead to required results.

Reliance is "the stage in which we have mastered the interface with an artifact and proceed naturally, seamlessly and flawlessly" (Ibid.: 361) and thus relates to the stage, where human beings have become familiar with the object and the interaction between them. Krippendorf's approach builds on the psychologist James J. Gibson's Theory on Affordances (Gibson, 1986) and corresponds to Donald Norman's use of affordance in interaction design to describe "the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used" (Norman, 2013: 8).

Based on design semiotics, Vihma differentiates between the syntax (technology), material (physical) and pragmatics (use-relation) of artifacts through representations, contents and interpretations (Vihma, 2013: 199). Building on three reference relations, an 'iconic', an 'indexical' and a 'symbolic' relation, she elaborates on the interaction between the individual cognition and social mediation of values as a learning process, and states that "even solid static material objects can seem to move forward (…) and acquire characteristics which are not related to their actual practical function, but ascribe expressive and representational attributes to them" (Ibid.: 203).

The foregoing approaches to product experience and semiotics have been used as a reference for the theoretical framework in the thesis, but they will not be further explicitly referred to. The predominant part of the theories used in the project can be more broadly applied and are positioned in the boundary between design research and other research traditions. This was a deliberate choice in order to allow theories from multiple research areas to merge and to apply notions and terminologies found also outside the design community.

Sense making and material meaning creation

Based on the above descriptions, 'sense making' and 'sense giving' can be interpreted as somehow similar concepts as Akrich's 'descriptions' and 'prescriptions', which were introduced in Chapter 4. 'Sense making' and 'descriptions' deal with meanings and associations created and embedded in both designers and users while 'sense giving' and 'prescriptions' deal with the designer's intentional transfer of meanings and associations through materials and products. This thesis subscribes to the above definitions.

In whatever we do, we embed meanings and values through intentions in our actions and the things we make and the input/output relation exists for many practices. When you cook, your interpretation of combinations of ingredients is intended to create sensations for diners and when you compose music, your preferences of the use and combinations of instruments are intended to provide listeners with particular emotions. The design practice and the part practice that considers materials such as materials selection and material development is no exception. In the expansion of understanding design students' material practice, sense making and sense giving are therefore two vital aspects.

In material meaning creation in design education sense making is the inward and tacit meaning creation process, where the student experiences a material and starts to embed meaning in it, giving the material an identity and sense giving is the outward and translative process, where the student embodies meaning into a material (or by using a specific material in a product) through the material's composition and appearance. The ability to reflect on and articulate meaning can both facilitate the process for the student and make the process more accessible for others.

Fachin has looked at how materials and meanings are dynamically connected with focus on professional identity creation of entrepreneurial designers in sustainable fashion using sense making and sense giving (Fachin, 2013). He perceives the relation between sense making and sense giving as a reversible process that translates professional identities of designers into material creations and from material creations to professional identities through discursive and material resources. The model shown in figure 32 has been further developed from a model proposed by Fachin.

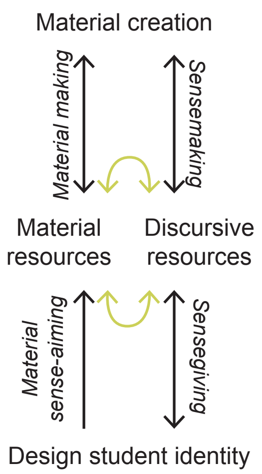


Figure 32. The reversible process of translating meanings from the design student to the physical materials (after Fachin, 2013).

In the model Fachin operates with two supplementary notions, being 'material making' and 'material-sense-aiming'. Material sense-aiming relates to the meanings the designer wants users to be attracted to, while material making is the understanding of how the discovery and use of different materials and techniques lead to a creation (Ibid.: 362). This can also be called the 'materialization of a design intent'. Fachin differentiates between a practice-oriented (and tacit) process of making the material (material sense-aiming and material making) and a discursive process of articulating and embedding meaning into the material (or product) (sense making and sense giving).

The meaning and role of 'identity' for the design professionals that Fachin has studied and the design students in this project are slightly different. Through experience design professionals establish a professional identity, while design students are still developing their professional identity as part of their education. Here they need to acquire design skills and develop an individual design identity, as well as understand and be able to apply themselves in in a professional setting (Leerberg et al., 2010: 309). Consequently it is essential for establishing modes for creating material meanings to combine practical and discursive resources and make them intrinsically intertwined. Therefore in the model in figure 32, practical (material) and verbal (discursive) resources are linked through an iterative process.

Sense making and sense giving are commonly discussed in studies that involve organizational structures with many actors that require a stronger need for open communication being different than the learning environment that is studied in this project. Nevertheless, as general social activities to create a common ground for the actors involved, such as design students, future collaborators, consumers and producers among others and as identity-generating means in materials teaching considering sense making and sense giving opens up an interesting argument, that it is necessary to provide a continuous duality of focus in the curriculum, by asking:

> *'How do design students create their own professional identity?'* and
>
> *'How do you ensure that students (remember to) integrate their professional identity in their work?'.*

Thus, an aspect of materials in design education is the translation of meanings from designers (students) to materials and products and conversely to train students in this translation by different means. In Chapter 7, an overview of courses in the fashion and textiles curriculum has been provided (see figure 50). This overview has served to demonstrate that initiatives introduced in the materials courses do not stand alone and other courses train students in translating meanings and associations to design concepts. In the present curriculum for instance, this accounts for a folklore project on second semester, where students interpret cultural and historic attires and translate them into new garments based on materials and techniques and a trend and collection course, where students interpret present and previous trends to create collections.

Unraveling associative textile meanings

The following provides an example of an exercise in materials teaching that serves to make students reflect on meanings and associations and to translate them into physical material samples. It is based on the paper: 'How associative material characteristics create textile reflection' (Hasling and Bang, 2015) [P4]. The paper corresponds both to the relation between experiential and physical material attributes using sensual attributes as the entry gate between two worlds (as a boundary object) and to the understanding of sense making and sense giving processes that were just discussed. Although the majority of the empirical studies are found in Part III, I have included this exercise here to exemplify the role of meaning creation and translating in the material practice.

The exercise explored how interpretations of associative meanings translate into physical textile samples, evaluated by means of similarities and differences. The exercise was conducted during seven days in the Materials Introduction course at Design School Kolding for first year fashion and textile students in the spring 2014. Translations of associative meanings are fundamental parts of the fashion and textile design discipline and therefore the procedural components of the exercise were considered familiar to the students.

Each student was given the assignment to interpret five key phrases from a poem into five different textiles or textile compositions, embracing the atmosphere of the key phrases based on their subjective associations. The five key phrases were distributed randomly to the students from a selection of eleven key phrases from the book 'Det værste og det bedste' [The Worst and the Best] of the Danish poet, Søren Ulrik Thomsen (2008). The key phrases, translated into English, were 'drizzle', 'peeled elder', 'the molten mattress', 'freshly baked rye bread', 'crystals', 'Suzi Quatro is playing at a harbor festival', 'run-over hedgehog', 'high-ceilinged teahouse in Budapest', 'the diary is full of appointments', 'Gothersgade's (a street in Copenhagen) dirty traffic' and 'cobbles'. Written in Copenhagen, some of the key phrases have clear contextual and cultural associations, while others are more abstract.

From the assignment, 40 material samples from 8 students were collected. Some key phrases had been interpreted through six textile samples, while some only linked to a single sample. In the further analysis only key phrases with three or more textiles have been included. These were ‘Suzi Quatro is playing at a harbour festival’, ‘freshly baked rye bread’, ‘the molten mattress and peeled elder’ (three samples), ‘high-ceilinged teahouse in Budapest’ and ‘the diary is full of appointments’ (four samples) and ‘drizzle’ (six samples). Some students had accompanied their samples with keywords that served to describe underlying associations to facilitate the translation process from associations to sensorial qualities and further to the textiles and techniques applied.

The evaluation of the textile samples stressed sensorial qualities such as color and tactility as well as technical means and raw materials used to obtain the sensorial experiences. From the presentations it was possible to get an idea of the level of verbal reflection in the assignment. Observations and results have been condensed to general tendencies that will be presented. First two examples of the translation of associative meanings to physical materials follow.

Example 1: Drizzle

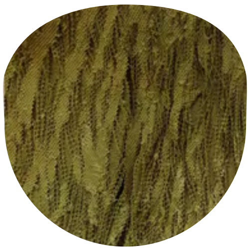
The key phrase ‘drizzle’ was translated into six textile samples that are shown in figure 33. One student (lower right sample) used the keywords ‘gap’, ‘fall’, ‘airiness’, ‘light’, ‘irritating’, ‘unpleasant’, ‘sneezing’ to illustrate her interpretation of the key phrase and as inspiration for her translation process. The keywords have been clustered in three categories that relate to lightness, movement and negative implications of drizzle. In general the color use is light and pale and in the samples

Two samples: One sample is a woollen woven textile that has been coated with felting-reserve and then felted, while the other sample is a plain polyester weave that has small heat-treated dots imitating raindrops.

Different kinds of light textiles have been dyed with dark dyes exploring fineness and detailing of the dyes used.

Two cotton and one silk woven fabrics have been burned out creating transparency and motion. All textiles are undyed and demonstrate lightness.

Three layers of different semi-transparent fabrics have been used as a composite. The layers of textiles create spatiality.



Dark tulle fabric has been shredded in vertical strings to imitate rain.

Woven fabric has been shredded vertically in a bow.

Figure 33. Six textile samples that materialize the key phrase ‘drizzle’.

that work with color differences, the contrast is small. The materials used for the samples have low densities and are transparent or semi-transparent. The materials' visual appearances are alike, but the raw materials and techniques are all different.

Example 2: Run-over hedgehog

The key-phrase 'run-over hedgehog' was translated into three textile samples that are shown in figure 34. In the mid and right hand samples shreds or spikes of brown synthetic leather fabric have been used in combination with twisted or crocheted red textile strips that create longer tongues. The shreds and spikes imitate hedgehog quills and the red tongues imitate blood and intestines. In the material sample to the left, only bright colors have been used, which makes the sample appear 'pure'. The sample contains three different raw materials with different materiality and expression. The student who made the sample, described the choice and composition of materials as "fur illustrating the internal and vulnerable part of the animal, the lines as the internal and life-essential part of the animal, while the band symbolized both the boundary between the external and internal as well as road on which the hedgehog was run over. (…) Being run-over, the animal's external parts had become visible".

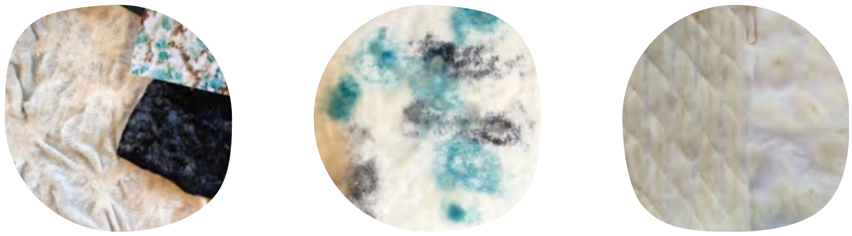
Figure 34. Three textile samples that materialize the key phrase 'run-over hedgehog'.

Overall tendencies

The two examples served to illustrate some of the multifarious translations of the keywords. From the examples, similarities and differences have been identified. Next, additional characteristics of the remaining three phrases will be shortly introduced. It will stress the use of sensorial attributes linking associations to physical objects. The samples are shown in figure 35.

Visual attributes appear strong in the samples. The color palettes used in the samples are in many cases similar and you do not doubt which one of the key phrases the samples originate from. Students have put emphasis on tactile attributes and explored, how different materials and techniques enhance the tactility of the samples. Molten mattresses are hairy, new-baked rye breads are bubbly and airy, while the samples on Suzi Quatro (…) combine many different materials. The tactility has nevertheless been obtained through different means.

Molten mattress



Newly baked rye-bread

Suzy Quatro plays at a harbor festival

Figure 35. Examples of textile samples that materialze the three key phrases 'molten mattress' (top), 'newly baked rye'bread' (middle) and 'Suzy Quatro plays at a harbor festival' (bottom).

For all the key phrases the translation has been achieved with comparatively simple raw materials and techniques and associations have stressed small details. It is however apparent that the level of abstraction of translations is different and partly depends on the level of contextual and cultural familiarity of the keywords.

Similar assignments have been given to the student in the course in previous years, but it was the first time the textile samples were systematically photographed afterwards, which made it possible to analyze. Unfortunately the setup of the exercise did not allow students to take part of the analysis and discussion after the assignment had finished. The assignment worked with the individual student's ability to translate associative meaning to physical materials and the ability to reflect could have been further enhanced, if the students had discussed each other's work in group sessions. The considerable large differences in, how students have translated the same key phrases show that their associations vary or their translation processes are subjective. Being asked why? and how? this could have strengthened students' ability to reflect on their processes and argue for their choices. This will be further discussed in Part III and in the discussion in Part IV.

Sense making and giving in a learning environment

Sense making and sense giving are essential components of the design profession, as it enables designers to transfer intentional meanings into or with a material. Sense making and sense giving occur among all individuals that interact with other individuals, but for designers it is part of the disciplinary fundament and something that is developed and facilitated in the design education.

The introduction to sense making and sense giving beginning at p. 94 in the thesis is here supplemented with seven properties that form the basis for sense making proposed by Weick (2005). These are 1) social, and 2) grounded identity construction, 3) ongoing and 4) retrospective, 5) enactment and 6) focused on extracted cues and 7) driven by plausibility rather than accuracy (Eneberg, 2012).

Weick talks about sense making in organizations, but here 'organizations' are considered as similar to 'communities of practice'. Individuals create identities in the interaction with other individuals, where a common language is established and where social interaction creates inter-subjective agreements in the group (Ibid.: 55). Value systems are cognitive structures open to change through the questions the individual poses and as a result of the actions involved (Döös, 2007: 146). Consequently in sense making different value systems merge in the interaction between tacit and explicit meanings.

In the design practice, the designer translates explicit knowledge in dialogue with an object such as a material, a technique or a product and therefore the practical works of the design discipline are essential. When design students make mood boards or material samples they train their ability to translate material meanings or value systems to visual articulations that can be interpreted by other individuals. As sense making can be regarded as retrospective, it is based on the memory of what has previously been experienced that bring along emotions and associations. In design education students learn to translate meanings and make sense in all components of their work from sketches and mockups to finished products, although this is often done tacitly in a social manner.

Therefore even though it may seem simple, the exercise to unravel associative textile meanings serves as an important tool in the sense making process. As part of the process, students had to relate to the key aspects and try to extract sensorial characteristics and techniques that could be used to promote the sense of the key aspect. The exercise was individual, but students were allowed to discuss with and inspire each other as part of the process, which created a continuous interaction between tacit and explicit knowledge and individual and social knowledge creation. As a design student the role of materials as part of the creation of a professional identity is relevant for the future practice and various design disciplines have different emphasis on materials. As a result it is beneficial to have students with different experience of using materials to collaborate, as it will permit students with similar value systems but with different practical experience to interact and progress simultaneously.

Methods use in material education

In the introduction design was described as a human activity that translates present needs to future solutions (Simon, 1996) and earlier in the chapter emphasis was put on the interaction between reflections on meanings and methods.

Methods can be regarded as intuitive or formal structures, embedded as mental constructs or as recognized systems to obtain a goal and are widely used in design practice (profession, education and research) (for example Andreasen, 2011; Cross, 2006; Daalhuizen, 2014; Dorst, 2008) to explore scenarios and users and to structure different kinds of decision-making processes. Daalhuizen has written that "methods are means to help designers achieve desired change as efficiently and effectively as possible" (Daalhuizen, 2014: 4). While reflection in design practice is rooted in artistic design tradition methods used in design practice originate in the engineering stream of design that has focused more on the systematic nature of methods (Jensen and Andreasen, 2010) rather than the methods' situated nature (Daalhuizen, 2014).

Based on the above short introduction the role and importance of methods in material education can be summarized to the following statements:

- Methods can help students to formalize material exploration processes.
- Methods can help students to build up mental constructs to establish personal material taxonomies (facilitate reflection).
- Methods have to be appropriated and customizable in order for students to use them properly.

The project has been established on a method (or more correctly, combinations of research methods), but the methods and tools discussed in the following are primary methods used for learning. A tool is defined in the Oxford Dictionary as "a device or implement, especially one held in the hand, used to carry out a particular function" ("Tool," 2014) and a method is "a particular procedure for accomplishing or approaching something, especially a systematic or established one" ("Method," 2014). Based on these definitions, tools are here understood as specific processes and methods as the overall frames, structures and interactions that define tools. Hence the term "methods" also covers the intangible space of design practice that seeks to structure the processes and cognitive development between the uses of tools. Even though there is a difference between tools and methods, in literature the distinction is not as clear-cut and a continuum between tools and methods will be used in the thesis.

Daalhuizen describes a method as a set of instructions that should be systematically followed to reach certain results (Daalhuizen, 2014: 8). Methods are important and essential parts of the design curriculum and considerable amounts of educational literature works with the use of methods. Examples of these are the 'Delft Design Guide' (van Boeijen et al., 2013), Design School Kolding's own 'Method Cards' (Friis and Gelting, 2011), IDEO's 'Methods Cards' (IDEO Method Cards, 2002) the toolbox '75 Tools for Creative Thinking' (Rubino et al., 2012), '101 Design Methods: a structured approach for driving innovation in your organization' (Kumar, 2013), 'Design Methods 1: 200 ways to apply design thinking' (Curedale, 2012) and the classic 'Product Design: Fundamentals and Methods' (Roozenburg and Eekels, 1995) among many others. Methods literature often put methods in categories based on the purpose of the methods. The Delft Design Guide applies the categories: 'discover', 'define', 'develop', 'evaluate & decide' and 'articulate & simulate' (van Boeijen et al., 2013) and the DSKD Method Cards use the categories 'collaborate', 'collect', 'comprehend', 'conceptualize' and 'create' (Friis and Gelting, 2011).

Methods can facilitate, and are intrinsic parts of, decision-making (I hope I do not have to argue this point!). However in the design course on where students have limited experience with using methods, the risk is that methods are used without reflecting on what they are good for and how they can be inadequate. To understand how design students approach methods, it is necessary to look at who uses the methods and in which context (meaning how methods are situated and how designers and the environment in which the method is used interact). Methods are especially helpful in uncertain situations, where they can guide the designer in how to progress (Daalhuizen, 2014). Uncertainty is strongly related to experience, and therefore students with a lower level of experience, experience a higher degree of uncertainty. In general identification and selection of appropriate actions are based on prior experience of a similar situation (…) and if not similar situations can be identified then related situations and contexts are stimulated (Badke-Schaub et al., 2011: 186). Daalhuizen adds that for experienced designers, behavior is largely driven by intuitions and methods play a role when intuition fails to provide an answer (Daalhuizen, 2014). In his PhD dissertation 'Methods Use in Design', Daalhuizen developed a situated design methodology that aimed to 'support method makers with understanding when they might be used and to develop them in such as way that they are better suited for a designer's adaption and use in those non-routine situations' (Daalhuizen, 2014: 65). In his work on uncertain situations he predominantly focuses on experienced design professionals, who have different needs from those of design students. From my experience with introducing tools and methods, especially the materials selection matrix in the second year Materials and Sustainability course, the impact of students being familiar with methods use and being able to reflect on what the method does and how it can be used is significant. Even though students find methods challenging, they are vital means to communicate and make intuitive and tacit decisions more transparent.

SUSTAINABILITY IN DESIGN EDUCATION

The incorporation of sustainable development into design education is evident when reviewing the curriculum of various design courses, nationally as well as internationally. The emphasis on sustainable thinking in design education corresponds to similar trends in design practice, where sustainability aspects are increasingly gaining focus as a result of the general higher demand for sustainable considerations in society. Conversely, as a discipline that contributes to framing the future, design practice is also responsible for setting a standard and providing solutions that make it easier for consumers to act responsible with respect to sustainability issues.

The learning environment and course structure in artistic design schools are both beneficial and challenging for incorporating sustainable design in the curriculum. The following section is dedicated to discussing these benefits and challenges to establish the premises for creating a curriculum that provides students with a profound and meaningful understanding of sustainable development as a philosophy and sustainable design as an approach.

Divided focus in design schools

In Chapter 1, an overview of Danish courses with a design profile was sketched. Here the profiles were divided between ‘Arts and Craft’, ‘Engineering and Technology’ and ‘Business and Industry’ (figure 6 on p. 18). In his book ‘Design Education for a Sustainable Future’, Fleming points at diverse focuses of courses within design education as a challenge for integral sustainable thinking in design education (Fleming, 2013: 27). He argues that splitting the design discipline since the industrial revolution into a rational and objective profession that supports basic human functions (needs-driven) and an emotional, aesthetic and subjective profession (wants-driven) has created a false division. This can be demonstrated by engineering and artistic design education respectively. The division causes design students to be educated based on different ontological foundations, both with respect to the content of the course and the learning methods. It creates students with rather homogeneous mindsets and narrow and specified disciplines that are dependent on adjacent disciplines.

Acknowledge existing competences

In a society that emphasizes rational systems, non-rational values have difficult premises. As it was discussed in the section of sustainable design, the result is that approaches to measure and deal with sustainability issues have long been based on rational and quantitative assessments such as life cycle analyses and measurable environmental impacts, but that 'soft values' and 'qualitative experiences' increasingly become ways to approach sustainable development.

When sustainability was first introduced in the curriculum at Design School Kolding, it was based on materials and with primary focus on environmental aspects. The materials aspect is still the first encounter students have with sustainability in a course that is presented in Chapter 7. The result of introducing sustainability accompanied by a specific topic such as materials and how raw materials and production impact on the environment risk affecting, how students will remain to approach sustainability. In order to establish a holistic understanding of sustainable development as a philosophy much effort has to be put afterwards to altering students' practice.

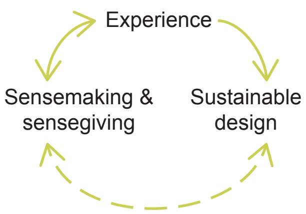


Figure 36. The connection between sustainable design and sense making and sensegiving mechanisms.

It is a paradox that essential aspects of sustainable design, especially those corresponding to the 'strategies' and 'culture and experience' perspectives in the hierarchical perspectives model (see figure 22 on p. 72) are already deeply embedded in design practice, but that design practice and education have still to recognize and exploit it fully. The notion of 'affective sustainability' as used by Börjesson builds on timelessness through 'time', 'tradition', 'aesthetics' and 'perception' (Börjesson, 2008). She argues that product attachment is a precondition for the sustainability of products, which highlights the designers' ability to create strong user-product bonds (Ibid.: 153). Based on Desmet and Hekkert (2007), Börjesson deduces that affection and experience can be used interchangeably, which connects sustainability and experience. This is further stressed by Krippendorff, who argues that needs and desires are partly related to material and function, but reach mostly beyond the physicality of an object (Krippendorff, 2006). Previously in the chapter a relation between sense making and experience was established stating that sense making is the process in which experience is condensed. The two reactions are not necessarily fully reversible (sustainable design does not automatically entail experience), but overall they connect sense making and sustainable design as notions that affect each other.

The above relationship describes the connection between design practice and sustainable design in the ways design practice understands and appreciates the world. Design practice can also be connected to sustainable design through its investigative approaches such as user-centered and participatory design that designs 'with' users instead of 'for' users to achieve large-scale changes (Chick and

Micklethwaite, 2011) and through formalizing strategies and processes based on design thinking (McKay, 2011; Verhulst and Boks, 2012). This means that design practice and sustainable development can be linked through the design object such as with sense making and meaning creation, investigative approaches that include a wider group of relevant stakeholders and in the procedural framing that provide strategies to work with sustainability.

The relevance of these competences is for example demonstrated in the publication 'UNESCO and Sustainable Development' that among some of the challenges in sustainable education identifies to "ensure quality education by adapting it to different cultural contexts and needs", to "emphasize sharing of knowledge, skills and values" and to "ensure participation of populations and community decision-making" (UNESCO, 2005: 13).

Additionally the inclusive, dynamic and low-hierarchical structured learning environment in artistic design schools (at least the ones in Denmark) can support sustainable thinking. Fleming identifies inclusion and cooperation as two core concepts of integral design (Fleming, 2013: 6) and states that studio teaching, as appearing in most design schools is excellent environments for integrating sustainability. Similarly it is argued in an editorial for the Journal of Sustainability Education that educational environments that put emphasis on engagement and experiential learning and that address "the physical, mental, emotional and spiritual components of our roles in the world and in the human society" are the essence of the optimal learning environment for sustainability education (Medrick, 2013). These characteristics all very well described the learning environment in artistic design education at for example Design School Kolding.

Even though students are trained in becoming designers, they also learn to collaborate with other disciplines with other mindsets and feedback from fellow students, plenary discussion, collaborations with companies and exhibiting projects are part of the education. In contrast to the majority of higher education programs in Denmark, the design schools have the advantage of being small institutions that allow curricula in continual flux, meaning that the schools can adjust more easily to societal trends and incorporate new initiatives.

Adjusting the content and form of the curriculum

It is impossible to fit everything into the curriculum and most organizers of educational programs experience the frustration of having to make compromises. This for example means that economics usually gets little emphasis in the design education (Fleming, 2013: 72). The challenge can therefore be to shape a curriculum that provides knowledge and insights into fundamental aspects of the design discipline such as materials, aesthetics, ergonomics and methods and that also succeeds in preparing students to combine and apply the competences in a holistic framework such as sustainable design.

In artistic product design that puts emphasis on materiality and craftsmanship, materials are an inherent means to realize prototypes and it is obvious to consider materials, and how materials choices can benefit sustainable design. However it is essential to acknowledge that sustainable design is so much more.

Due to the above circumstances, design schools (and the design discipline) can and should benefit from increasingly acknowledge the competences and learning styles that are the essence of the design practice to further strengthen sustainable design as a holistic approach rather than as point-based initiatives with less impact.

CHAPTER SUMMARY

This chapter has approached learning and materials from different perspectives. Learning has primarily been presented as a social practice, where learners in interaction with the learned get experiences that translate into knowledge. In the social practice learning further occurs when students start to make sense of things through reflection and structure in constant iterations.

Learning is here linked to sustainability approaches in design education. It is here argued that the practice-based and experientially oriented learning environment can function as a promoter for working with materials in sustainable design.

Summary

_ Learning is regarded as a social process that builds on the interaction with external stimuli by reflecting on experience and creating knowledge that cognitively develops in six steps being: remembering, understanding, applying, analyzing, evaluating and creating. The steps are often used to structure curricular progress.

_ In practice-oriented disciplines such as design, learning through master-apprentice relationships has been common. In social learning theory apprentices are peripheral participants in a community of practice.

_ Material learning occurs when students reflect on experiences with materials and explore how materials can express intended meanings and emotions through iterative sense making mechanisms that shift between internal and external modes.

6. MATERIAL COMMUNICATION AND METHODS

The amount of materials grows day by day. The increasing availability and decreasing transparency of materials make it difficult for designers to find the right materials. Consequently new ways of communication and materials selection approaches are developed. The use of the Internet and databases with flexible search functions increase accessibility to existing materials, but probably also makes them more confusing, as the massive amount of materials can seem overwhelming. It is therefore worth questioning whether intangible material information from books and Internet databases provides enough material information to grasp technical as well as experiential material aspects or whether it necessary to have access to physical materials in order to understand fully the potentials of a material? This has further lead me to question how material information should be framed to encourage designers to apply materials.

This chapter considers how access to materials is provided through a selection of analogue and digital media and introduces different methods to explore and select materials for specific design intents. The material communication section of specifically looks at material media such as literature, blogs, libraries and collections, databases and exhibitions and the methods section primarily focuses on methods used in materials education of which some emphasize on sustainability.

MATERIAL COMMUNICATION

First I would like to highlight three particular books that stand out to me when it comes to making materials easier to grasp, access and use. In different ways the books succeed in telling the story of materials.

Mark Miodownik's 'Stuff Matters - The Strange Stories of the Marvelous Materials that Shape Our Man-made World' (Miodownik, 2014) communicates materials based on personal relationships with materials and the interaction between the social and physical material worlds. Based in the Institute of Making, University College London, Miodownik succeeds on making materials interesting for lay people through encounters of materials and technologies told in narratives. His broadcast series 'Materials: How they work' ['Materialernes Hemmeligheder'] from BBC2 is also highly recommendable (Miodownik, 2012).

Ashby and Johnson's book 'Materials and Design: The Art and Science of Material Selection in Product Design' has become a classic for designers working with materials (Ashby and Johnson 2014 [1984]). It challenges the traditional natural scientific understanding of learning about materials and has made materials science more comprehensible for students and professionals without specialist knowledge of or interest in technical terms. The book is supported by further publications in

‘Materials: Engineering, Science. Processing and Design’ (Ashby et al., 2007), ‘Materials Selection in Mechanical Design’ (Ashby, 2007) and ‘Materials and the environment: eco-informed material choice’ (Ashby, 2009).

Pedgley, Rognoli and Karana’s anthology ‘Materials Experience: Fundamentals of Materials in Design’ stresses materials for design as an interdisciplinary field, which should focus more on experience acquired with the materials used (Karana et al., 2014). Researchers from the materials/design/education communities have contributed to this book, which addresses students and educators in materials for design disciplines in topics such as aesthetics, sustainability, material functionalities and teaching approaches among others.

Literature - books, blogs and webpages

The majority of books concerned with materials in design describe concrete materials by means of basic information and potential applications. The books are typically divided into topics that cover material families and/or specific material functions.

Each year a couple of relevant books are published that include new emerging materials and materials in alternative applications. Examples of these books are Brownell’s ‘Transmaterial(s) 1-3’, which predominantly introduce new materials without a specific application (Brownell, 2010, 2008, 2005), the ‘Material World’ book series from Frame and Birkhäuser (Blokland, 2005; Ternaux, 2009; van Onna, 2003), Kula’s ‘Materiology’ (Kula, 2008), Howes and Laughlin’s ‘Material Matters’ (Howes and Laughlin, 2012) and Dent and Sherr’s ‘Material Innovation’ (Dent and Sherr, 2014). Design-oriented literature stressing specific materials includes for example Lefteri’s materials for inspirational design series on glass, ceramics, plastics metals and wood (Lefteri, 2006a, 2006b, 2004, 2003a, 2003b, 2002, 2001). This links to his book on manufacturing techniques (Lefteri, 2012) and his recent book ‘Materials for Design’ (Lefteri, 2014). Within textiles, there is for example Clarke and O’Mahony’s ‘Techno Textiles’ (Clarke and O’Mahony, 2008, 1998), O’Mahony’s ‘Advanced Textiles for Health and Wellbeing’ (O’Mahony, 2011) and Quinn’s ‘Textile Futures’ (Quinn, 2010). A comprehensive overview of relevant literature for materials in design can be found in Appendix [A1].

Many the books include the same materials, but communicate them in different ways. It is however evident that the majority of the materials and technologies that are included in the books are emerging materials with some kind of special function or feature. The books describe potential materials of the future, but with little interest in the materials they may or may not remove from the market. The same tendency can be observed in blogs. ‘The Transmaterial Blog’, from the same editors as 'Transmaterial(s) 1-3', includes the same kinds of materials, but with a deeper level of detail and information than in the books ("Transmaterial blog," 2014). New material entries can be included more frequently on a blog than in books, because of the dynamics of blogs compared to printed books. The 'Hello Materials'-blog was launched as part of the 'Hello Materials'-exhibition at Danish Design Center (now Design Society) ("Hello Materials blog," 2012). The blog intended to provide a blog space for people involved with materials to share knowledge on emerging materials and material methodologies.

Furthermore and in addition to the material-specific media, the Internet is overflowing with materials applied in products. Online magazines and blogs such as 'Design-Milk' (2014), 'Designboom' (2014) and 'Dezeen' (2014) introduce emerging and often applied materials and technologies for design and architecture.

Material collections and databases

The increasing number of materials available has made the use of materials collections, libraries and databases relevant. Formal physical material libraries have emerged within the last two decades to provide a space for designers and architects (Berggren, 2006) to acquire sensorial and tangible experience with new and old materials in a structured manner. Materials collections (as in (formal) collections of materials) are not new concepts, but the higher degree of flexible indexing possible with the use of digital databases and the Internet have boosted the level of complexity and amount of accessible material information.

Materials in physical collections and libraries consist typically of material samples with an information sheet providing useful information such as material family, manufacturer, properties and application. Digital databases are usually based on a physical materials library, where users can explore materials using their senses. However, there is a geographical restriction on the accessibility of physical material libraries and therefore digital databases have become increasingly popular.

Company-driven materials collections are usually developed from material samples from collaborating suppliers either because the material has been used in a product or because the material could potentially be used in a product. The materials collections are often not systematized or indexed and are merely there to facilitate employees. However there is a tendency for companies to formalize their materials collections and make them partly publically accessible. An example is the Danish Architecture firm 3XN's material database ("3XN Material database," 2012). They have indexed, collected and developed materials in an Internet-based, open source database that is linked to an in-house physical materials collection accessible in the 3XN office. 3XN is known to put a high emphasis on material

Figure 37. Materials from the material collection at The Royal Danish Academy of Fine Arts, School of Design.

Figure 38. Examples of material samples from Made Of.. (left) and a exhibition space with emphasis on wood from Centrum Hout, an organization that strenghtens sustainable design and construction in wood (right) (from the introduction movie: The Making Of).

Figure 39. Selection of exhibited materials and products
Collection at the Swedish School of Textiles.

Figure 40. The material collection at Copenhagen School of Design & Technology in collaboration with MaterialConnexion (left), wood section in the material box (right).

development, especially focusing on technology and sustainability and therefore collaborate with and maintain a large network of material suppliers.

Commercially driven material libraries are libraries that address companies within design and architecture and provide access to a broad range of materials. The libraries are often combinations of one or several physical libraries linked to a subscription-based digital database. Examples of commercially-driven material libraries and databases are MaterialConnexion that have subsidiaries in New York, Milan, Tokyo and Bangkok among others ("MaterialConnexion" 2012) and Materia that used to have a physical library in Amsterdam, but know primarily runs a free-access material database and participate in material fairs ("Materia," 2014). Other material libraries with subscriptions are for example Matrec (2014), Materio (2012) and Innovathèque (2012).

Material libraries developed and maintained in educational institutions (some in design) serve to make materials accessible to students. Educational materials collections can have many different forms, depending on traditional financial support, motivation and integration in the institution. In the following, four examples of formats for educational material libraries are provided. The descriptions are based on visits to the collections and discussions with people responsible for and development of the respective collections. Pictures from the four material libraries can be found in figure 37-40.

The materials collection at The Danish Royal College of Arts – School of Design consists of materials collected the last forty years and includes both conventional and emerging materials (see figure 37). The materials are not digitally indexed (yet) and the collection is only accessible in specific opening hours, where a responsible for the collection is present. The collection is supplemented by physical materials from Futation ("Futation" 2014) and with digital access to the MaterialConnexion database. The collection primarily contains product design oriented materials, but is set to merge with the collection from the School of Architecture that primarily contains materials for architecture.

The material library at Faculty of Industrial Design Engineering at Delft University of Technology serves to "inspire and inform our students, staff and visitors and to establish a link between the (future) creative industry and the material (and manufacturing) industry" ("Made of.. Material Library," 2012) (see figure 38). The library consists of a 'classics' section exhibiting 200 commonly used materials, a section with 200 'novel in design'-materials with a potential to be used in product design, an exhibition space where material suppliers can exhibit material and product samples and a student platform where students can exhibit projects with use and development of specific materials. The materials in the 'classics' and 'novel in design' sections are described with pictograms and bars indicating 'recyclability', 'compostability', 'embodied energy' and 'security of source'. The materials library is placed in an open space atrium, where students pass by on a daily basis when going to and fro lecture rooms, workshops and the canteen.

The Textile Material Library (Textila Materialbiblioteket) at the Swedish School of Textiles (Textilhögskolan) is a collection of (in 2012, 215) conventional and emerging textile and non-textile materials, products and prototypes from commercial suppliers and the Smart Textiles research department in the institution (see figure 39). The library serves to make textile materials accessible for the institution's students, researchers and companies in the surrounding textile industry (Valtersson 2012). Each material or product has a label with a description of the material. The company or person that has developed or supplied the material has been responsible for the description. In the library, materials are physically divided into sections that include materials developed in institution materials from commercial suppliers, fundamental materials, special-function materials, recently added materials as well as object or prototypes with specific materials incorporated. The library is placed in a central place in the institution where students, employers and commercial users can access when the collection is open.

The materials library at Copenhagen School of Design and Technology (KEA) can be called a hybrid library (see figure 40). It includes a collection of 1500 materials from MaterialConnexion situated in an enclosed space, as part of the open space library at the campus. It holds boxes of materials, providing examples from raw material sources to final products. The materials collection is linked to MatrialConnexion's online database and the materials exhibition in the boxes has been developed at KEA, focusing on materials that students in the institution work with.

In table 3, an overview of the four educational materials collection concepts is provided. The four educational materials collections have different formats and premises and they serve to illustrate the broadness of educational materials collections found. Another interesting materials collection is Elisava's, a design school in Barcelona, collaboration with Barcelona-based MaterFad, a material consultancy and holder of the Materío materials collection ("Elisava," 2015, "MaterFad," 2015). This review of small materials collections will be helpful in Part III, in discussing how materials collections can become more intrinsic parts of students' material practice. For this purpose I have benchmarked the four above-described educational materials collections using the requirements 'facility or students to borrow materials', 'commercial interest', 'available digital database', 'student integration' and '(physical) open-access'. I have used these requirements, as I find them especially important in the considerations of materials collections in design institutions. I will return to my arguments for choosing these requirements and what the benchmarked meant for determining the setup for collections provided at Design School Kolding in Part II.

Table 3. Benchmarking of four design institutions based on the requirements 'students can borrow materials', 'commercial interest', 'digital database', 'student integration' and 'open access (physical) area'.

	DKDS	DUT-IDE	THS	KEA
Borrow materials	●		●	
Commercial interest		[●]	●	●
Digital database			●	●
Student integration	●	●	●	
Open access	[●]	●		

DKDS - The Royal Danish Academy of Fine Arts, School of Design
DUT-IDE - Delft University of Technology, Faculty of Industrial Design Engineering
THS - The Swedish School of Textiles / Textilhögskolan
KEA - Copenhagen School of Design & Technology

Literature and libraries with emphasis on sustainability

Sustainability plays an essential role in both physical and interactive media. In the development and commercialization of emerging materials, sustainability is vital, as it acts as a driver and incentive for the materials to be used. It is seldom appropriate to discuss sustainability solely based on materials used, nevertheless materials have a considerate impact. McDonough and Braungart's Cradle-to-Cradle (2002) and The Upcycle (2013) are usually used as reference books when discussing overall methods and paradigms to understand and approach materials and sustainability. Other books such as 'Sustainable Materials – with both eyes open' (Allwood and Cullen, 2011) and 'Sustainable Materials, Processes and Manufacturing Techniques' (Thompson, 2013) provide information and methods on specific materials and techniques in the search for sustainable use of materials. In fashion and textiles, Fletcher's 'Sustainable Fashion & Textiles' (2008), Fletcher & Grose's 'Fashion and Sustainability – Design for Change' (2012) and Fletcher and Tham's 'Routledge handbook of sustainability and fashion' (2015) provide approaches to materials specifically within fashion and textiles.

In addition many of the above-mentioned books and blogs stress sustainability in different ways. In Materials for Design (Lefteri, 2014), sustainability issues have been addressed as one of six key aspects that include additionally: 'typical application', 'production', 'cost', 'key features' and 'sources'. In Material Innovation: Product Design (Dent and Sherr, 2014) two chapters are assigned to 'grown materials' and 'recycled materials'. In Materials Experience (Karana et al., 2014) one out of four sections focuses on sustainability aspects such as materials and social sustainability (Chapter 7), waste as a resource (Chapter 9), prolonging product use based on materials' aging (Chapter 10 and 11) and materials with multiple purposes (Chapter 13). The materials collections MaterialConnexion (2012), Rematerialise (2014) and Matrec (2014) specifically focus on sustainable materials aspects, while other collections have incorporated sustainability aspects in more general materials descriptions.

A list of material information and attributes provided from material libraries can be found in Appendix [A2]. The list contains a bit more than 100 different material aspects identified from 11 different sources. The overview aims to illustrate the diversity (or lack or diversity) of material information accessible in the materials collections. It is further made as a guideline to know, which materials collections that are relevant if you have specific material requirements and as inspiration.

MATERIAL EXPLORATION AND SELECTION METHODS

With increasing numbers of materials available, new methods and tools are being developed to explore and select from among them. The material collections introduced in the previous section can facilitate the exploration of materials, but they do not provide a structured means to select materials. Some of the digital databases provide rather effective details within search criteria, but browsing around in materials is still restricted by the algorithms the search functions are based on.

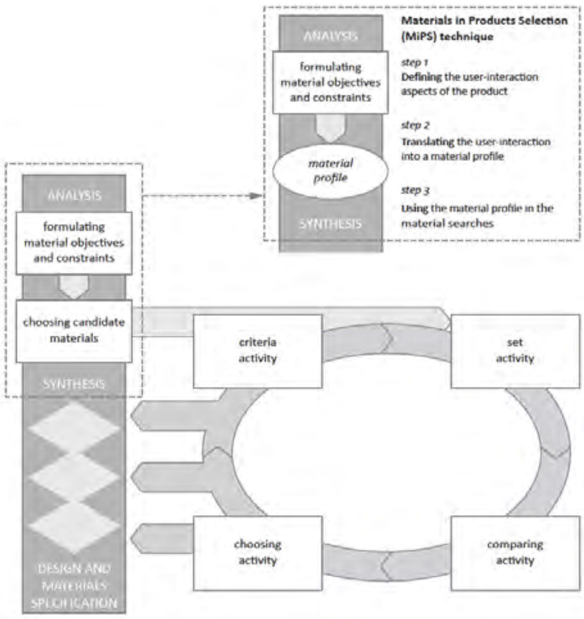
In the following section, an introduction to tools and methods to explore and select material is provided. The tools and methods focus on educational purposes. The introduction distinguishes between meaning creation tools that serve to create material meanings rather than select materials and material selection tools that provide structures to compare and select specific materials. The latter are primarily found as digital tools.

Material meaning creation tools

In this section material meaning techniques, models and tools are presented. They have been used as inspiration for the tools and methods I have worked with in the project and I will refer to these several times in the dissertation. In the short introduction here, I will not go into detail with specific aspects of the techniques, models and tools, but will leave these for when they are relevant. The four techniques, models and tools are presented based on the PhD dissertations that document the projects they were developed in. Even though all have been further developed, I regard their PhD dissertations as state of the art within the field of materials for design research.

In 'Selecting Materials in Product Design'', Ilse van Kesteren developed a tech-

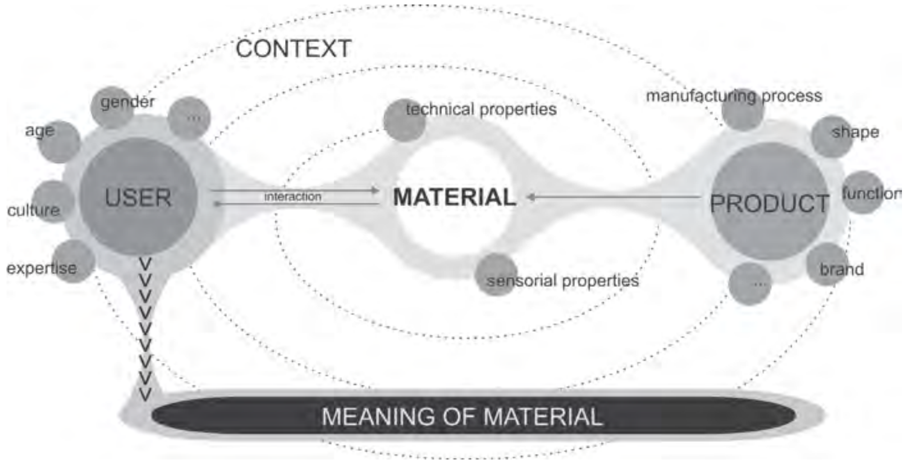
Figure 41. Schematic overview of the Materials in Products Selection technique emphasizing the analysis phase in product development (van Kesteren, 2008: 106)



nique called the Materials in Products Selection technique (MiPS) (van Kesteren, 2008) focusing on analysis, synthesis and design and material specifications (see figure 34). As part of the technique, she proposed to use three tools: a questions tool, a picture tool and a sample tool use to define needs phase in collaboration with clients to enable communicating and discussing their visions with a design.

In ‘Meanings of Materials’, Elvin Karana proposed a ‘Meanings of Materials’ model that embraces the multifarious natures of materials used in product design (Karana, 2009). The model emphasizes attributes embedded in the material itself such as technical and sensorial properties, attributes as results of the product the material has been used in such as manufacturing processes, shape and function and the user experience defined by for example expertise, culture, age and gender among other things. In figure 35, the model is illustrated, showing the interaction between material and user and the influence on product in the appreciation of a material.

Figure 42. Meanings of Materials model as proposed by Karana in her PhD project (Karana 2009: 76).



The above technique and model develop holistic frameworks to understand different dimensions of materials using different means to extract knowledge on materials, products and users, rooting in Desmet's work on emotional design (Desmet, 2008, 2003). Desmet and his colleagues at Delft University of Technology use Design for Emotions in the education to deepen students knowledge of how product design elicits emotions and of the relationship between human emotions and happiness, which is associated with creating awareness on the value systems in product design.

The two have inspired the holistic materials teaching methodology that is one of the core contributions of the dissertation and have been used to explore the dimensions of material aspects and to inspire a structure that evenly considers physical, experiential and sustainability in materials exploration and selection.

The next two examples present materials exploration approaches with based on subjective beliefs and personal constructs. The approaches have been used as inspiration for more specific explorations of material meanings in the Comparative Material Scale.

In the PhD 'The Expressive-Sensorial Characterization of Materials for Design', Valentina Rognoli developed a Expressive-Sensorial atlas to explore sensorial material characteristics and to investigate their correlation with corresponding physical material properties using four parameters being 'texture', 'touch', 'brilliancy' and 'transparency' (Rognoli, 2004). The Expressive Sensorial scale is further described on p. 151. In figure 43, examples of the parameter 'touch' are shown as well as a sensorial scale with light/weighty materials.

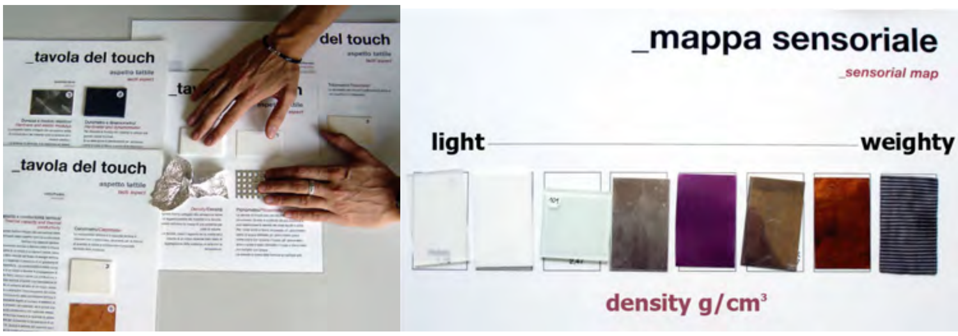


Figure 43. Sensorial scale based on eight material samples compared according to a light/heavy (Rognoli, 2010: 291).

In the PhD 'Emotional Value of Applied Textiles - Dialogue-oriented and participatory approaches to textile design', Anne Louise Bang developed a participatory material exploration tool using a Repertory Grid technique focusing on emotional values embedded in textiles (Bang, 2010). The Repertory Grid is further described on p. 167. In figure 44 the essential steps of the grid are included.

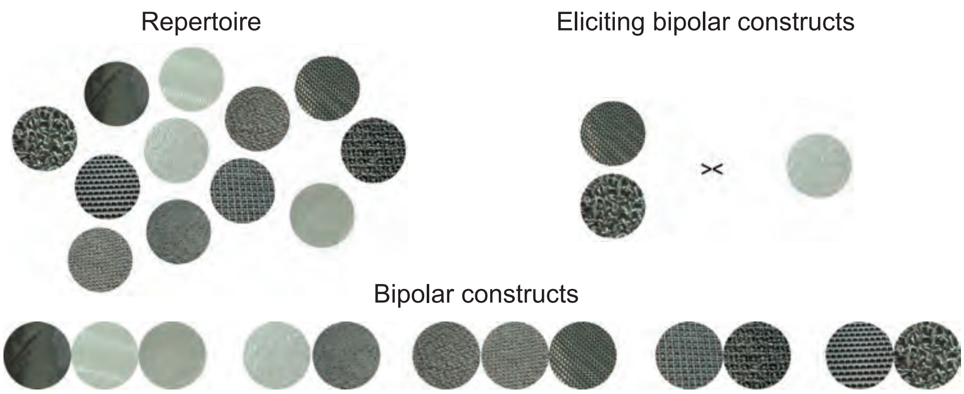


Figure 44. Applying the Repertory Grid technique in Bang's work with emotional values of textiles (Bang, 2010: 138-139).

Material selection tools

The Cambridge Engineering Selector (CES EduPack) is a design-led procedural collection of material exploration and selection tools developed by Granta for design engineering (Ashby and Cebon, 2007; Granta, 2014). The tools focus on translating material requirements, screening materials based on constraints, ranking using objectives and seeking documentation before making a final material choice (Ashby and Cebon, 2007). The CES system provides multifarious kinds of material information based on numeric data, texts, figures and images. It is possible to compare numeric data of technical properties based on figures as shown in figure 45. The figure explores materials based on their relation between electrical resistivity (how electrically conducting a material is per length unit) and thermal conductivity (how conductivity changes with temperature).

The CES EduPack primarily considers mechanical and manufacturing aspects of materials, but has progressed and now includes environmental and sustainability aspects (for example with an Eco Audit tool) (Ashby et al., 2012) and discusses experience of materials using measures to explore sensorial attributes.

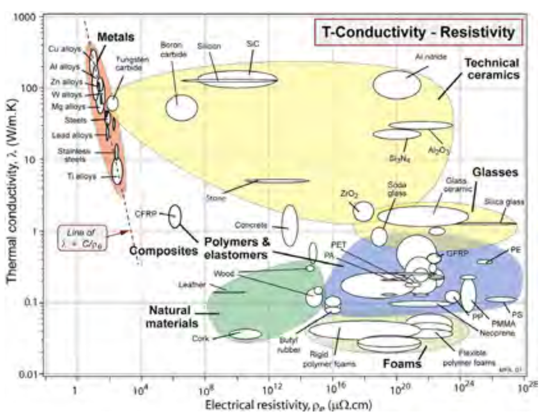


Figure 45. Chart that illustrates the relation between electrical resistivity and thermal conductivity for common materials and material families from CES EduPack (Ashby and Cebon, 2007).

Material evaluation tools emphasizing sustainability

Along with the stronger emphasis on sustainability, the number of material evaluation tools is continually increasing. The following presents a selection of tools that emphasize sustainability. All the tools are based on life cycle assessments (LCAs) that compare environmental effects in the development, production use and disposal of products and services (reference) by quantification of input and output effects. LCAs are described in the two standards: ISO 14040:2006, which includes the principles and overall framework (ISO, 2010a) and 14044:2006, including the assessment as a procedure with requirements and guidelines (ISO, 2010b). LCAs were developed to focus on environmental impacts, but increasingly also consider social and economic effect in the life cycle (UNEP, 2009).

The Ecodesign web is a tool to compare two or more materials, products or services (Andresen, 2010; Van Boeijen, 2013). In a circular web, eight parameters are evenly distributed. From each parameter a linear scale from the center to the periphery, typically a 5- to 7-point scale, is found. Each repertoire is individually assessed according to the eight parameters using the defined grading scale. The area of the web created from peripheral points corresponding to the grades of each parameter can be used to compare the repertoires. Thereby the Eco design-web offers a graphic way to assess sustainability aspects. Figure 46 shows an Eco design-web used to assess materials for a sustainable raincoat. The eco-web has been used as inspiration for the material selection methodology proposed in Chapter 10.

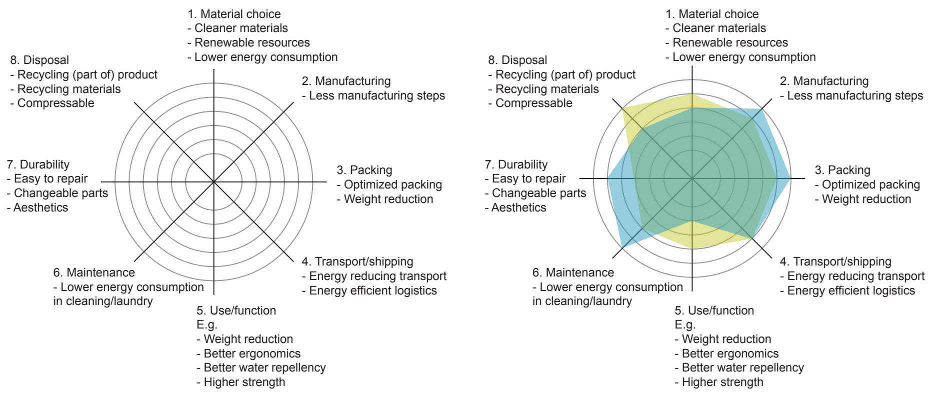


Figure 46. Left: an Ecodesign web using the parameters: material choice, manufacturing, packing, transport/shipping, use/function, maintenance, durability and disposal. Right: used Ecodesign web comparing a PVC and a PLA raincoat (Andresen, 2010: 63).

The Made-By environmental benchmark for compares textile fibers based on life cycle analyses (MADE-BY, 2013a). Also benchmarks for social standards and wet-processing have been developed (MADE-BY, 2013b). The analyses are used to create material 'ScoreCards' that companies collaborating with the Made-By organization can use to assess materials. Made By has made a simple version of their benchmark where conventional and 'environmental-friendly' fibers are categorized in five classes ranging from A (best) to E (worst) and class for unclassified fibers and has been obtained by means of 'emission of green house gases' (20%), 'human toxicity' (20%), 'eco-toxicity' (20%), 'energy input' (13.33%), 'water input' (13.33%) and 'land use' (13.33%) (MADE-BY, 2013a: 4) (see table 4).

Table 4. The environmental benchmark for fibres made by Made-By (source: www.made-by.org)

MADE-BY ENVIRONMENTAL BENCHMARK FOR FIBRES www.made-by.org

CLASS A	CLASS B	CLASS C	CLASS D	CLASS E	UNCLASSIFIED
Mechanically Recycled Nylon	Chemically Recycled Nylon	Conventional Flax (Linen)	Modal® (Lenzing Viscose Product)	Bamboo Viscose	Acetate
Mechanically Recycled Polyester	Chemically Recycled Polyester	Conventional Hemp	Poly-acrylic	Conventional Cotton	Alpaca Wool
Organic Flax (Linen)	CRAILAR® Flax	PLA	Virgin Polyester	Cuprammonium Rayon	Cashmere Wool
Organic Hemp	In Conversion Cotton	Ramie		Generic Viscose	Leather
Recycled Cotton	Monocel® (Bamboo Lyocell Product)			Rayon	Mohair Wool
Recycled Wool	Organic Cotton			Spandex (Elastane)	Natural Bamboo
	TENCEL® (Lenzing Lyocell Product)			Virgin Nylon	Organic Wool
				Wool	Silk

More Sustainable → Less Sustainable

The ‘Hanger model’ is a physical tool developed to explore and discuss impacts of products by the Laboratory for Sustainability at Design School Kolding. Based on the life cycle (categorized as ‘development’, ‘production’, ‘distribution’, ‘use’, ‘end of use’ and ’recycling’) and with inspiration from the sustainability aspects highlighted in the books ‘Sustainable Fashion & Textiles - Design Journeys’ (Fletcher, 2008) and ‘Fashion and Sustainability - Design for Change’ (Fletcher and Groose 2012), the tool presents 52 different means to affect the sustainability impact of a product represented by individual hangers. I will return to the Hanger model, when different ways to approach sustainability in teaching are presented in Part III. In figure 47, the ‘Hanger model’ is introduced in a meeting on sustainability at Design School Kolding.

Last the Higg Index and the Material Sustainability Index (MSI) are presented. The Material Sustainability Index is a cradle-to-gate index originally developed by Nike to facilitate in-house product developers in obtaining more sustainable goals (Nike Inc., 2012). In 2012, it was adapted by the Sustainable Apparel Coalition (SAC) and incorporated into the Higg Index. SAC is a coalition of world leading companies within development, production and management from the apparel and footwear industry including Nike, Patagonia, Burberry, Levi’s, H&M, JC Penney, Target and many others (SAC, 2015a). The Higg Index is a to be ho-

Figure 47. The Hanger model is demonstrated in a meeting at Design School Kolding (spring 2013).

listic sustainability measurement tool consisting of the three modules: ‘Facility’, ‘Brand’ and ‘Product’ (MSI is part of the ‘product’ module). In addition to the Material Sustainability Index, the Higg Index is further based on Eco Index, Global Social Compliance Program (GSCP) Reference Tools, and Social/Labor Best Practice Tools (“Higg Index,” 2014).

Previously the Higg Index was based on a collection of spreadsheets that companies could fill in information. In the recent version SAC has introduced the beta version of the Rapid Design Module (RDM), an online-based interactive tool, where users can fill in information on materials use, manufacturing, packaging, product use and end of use of garments in development (SAC, 2015b). Based on the information the tool calculates a material impact score on a 0-100 grading scale (the higher the score, the lower impact the garment has). Each section has different weighting being materials: 30%, manufacturing: 25%, packaging: 10%, product use: 20% and end of use: 15% (Ibid.).

In figure 48, an example of a very simple of use of the RDM tool is shown based on a shirt. The shirt consists of 100g knitted cotton (50% is recycled and 50% is organic) and 10 g 100% recycled polyester fabric (detail). The garment has not been finished and has been packed and labeled using a barcode tag only. The impact from maintenance and care is medium and the garment has come with low impact care label instructions and materials can be identified and separated after use. In total this gives the score 54.

Transparent information processing

The review presents, how exploring and selecting materials have become more complex. There are many methods and tools to guide users in this. However the risk is, as it is with all methods and tools, that they are used uncritically and without reflecting on the process and the outcome. Digital tools have the advantages that they can store large quantities of information, they can provide calculations based on complex algorithms, and they can link information to visually appealing graphics, which can be easier to comprehend and access. However digital tools are seldom transparent and it can be difficult to understand, how materials are evaluated, if you do not use a substantial time in looking into the architecture of the database. For students, material exploration and selection tools and methods can facilitate the development of the material practice. However being relatively inexperienced in materials perspectives as well as methods use, attention has to be put on how tools and methods are used.

The Danish lecturer in fashion textiles and sustainability, Birgit Bonefeld has investigated and discussed and criticized the use of sustainable selection tools in the

Figure 48. Screen shot of the Rapid Design Module, where a T-shirt is assessed.

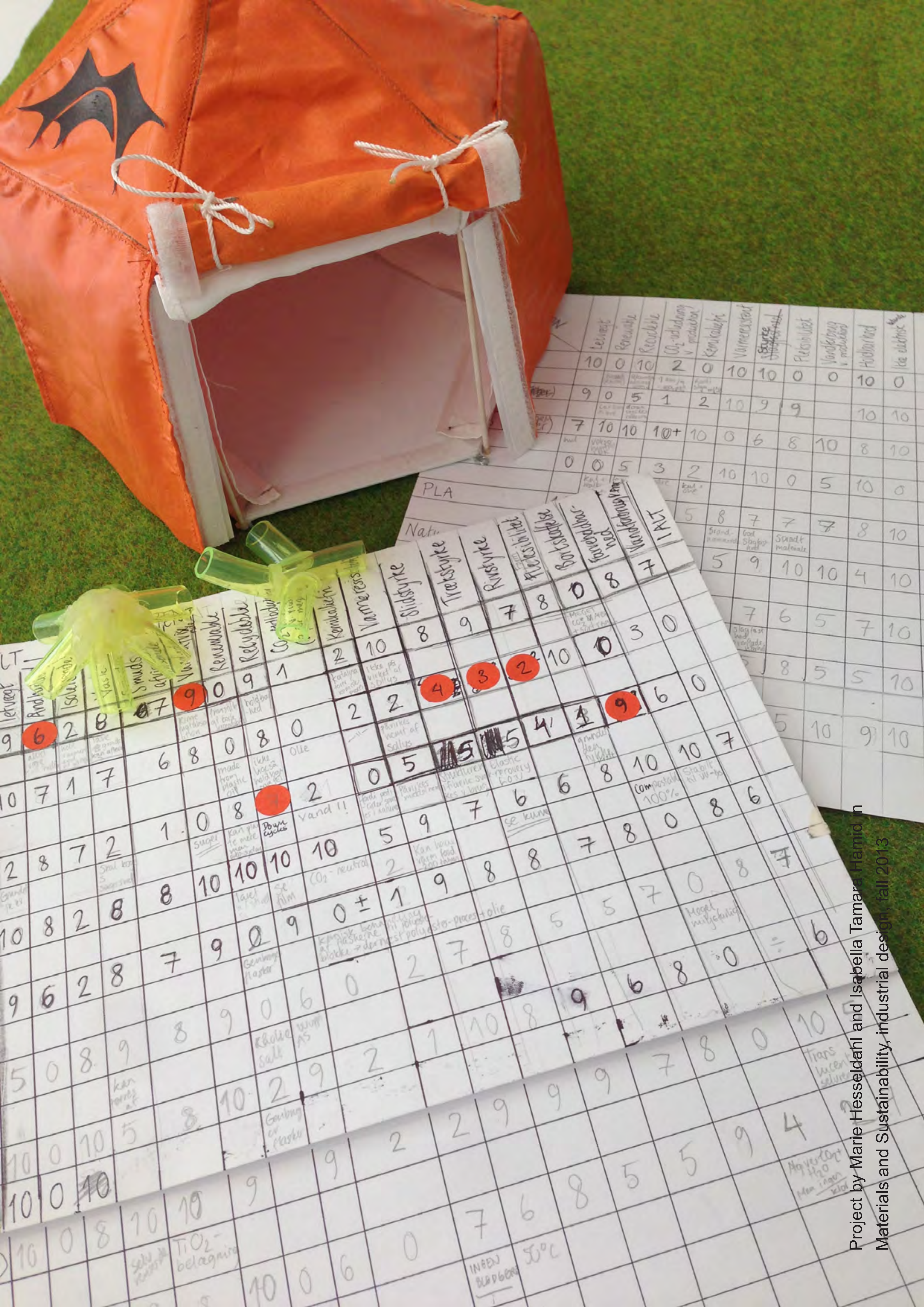
materials teaching using hemp as a case). Presently hemp fiber is appraised for its sustainable benefits such as versatility and durability and as a potential alternative to cotton (for example Fletcher, 2010, 2008). In the MSI, hemp obtains a score of 22.5 that compared to conventionally grown cotton has 43% better chemistry, uses 7% less water, but requires 343% more energy and generates 16% more waste ("Material Sustainability Index - Materials," 2014). The hemp benchmarked in the MSI is conventionally grown and is by some means better than conventional cotton. The Made-By environmental fiber benchmark includes conventional hemp (Class C) and organic hemp (Class A) (see table 4). Therefore Birgit Bonefeld suggests that sustainable selection tools should be used with care and as inspiration rather than uncritically determining the material choice. It is necessary to understand the data basis the benchmark is based on and know that the amount and detailing of data for especially non-conventional fibers vary (personal conversations in spring 2015).

CHAPTER SUMMARY

This chapter has emphasized on approaches to explore and consider materials in product development. The first part of the chapter introduced a selection of literature and collections providing information on materials. The introduction focused on materials for design useful in design education. The second part of the chapter presented a selection of materials exploration evaluation and selection tools and methods emphasizing experiential and technical aspects of materials. The majority of the tools and methods that put emphasis on sustainability use the product life cycle as an overall frame for assessment.

Summary

- Materials for design literature primarily focus on newly developed materials and stress properties, functions and potential applications.
- Material collections and libraries apply different ways to index materials. From ten sources about one hundred different material aspects have been identified.
- Material selection tools and methods based on sustainability issues are continuously developed. Most tools are based on a life cycle assessment approach. All methods and tools should be used with care and it is vital to remain critical and reflect on, how materials are selected.



Project by Marie Hesseldahl and Isabella Tamara Hamid in Materials and Sustainability, industrial design, fall 2013

PART III_ MATERIAL EXPLORATION METHODS IN PRACTICE

Contents_

7. MATERIALS TEACHING - PAST, PRESENT AND FUTURE

This chapter provides an overview of past and present learning experiences based on materials teaching at Design School Kolding. The retrospective view and further analysis serves to establish a basis for more structured empirical studies in the next two chapters. The overview is framed on the educational tool called the materials selection matrix that has been part of, is still and will remain part of the materials teaching at Design School Kolding.

The first part of the chapter introduces the learning environment looking at previous and present materials courses and how students have used the materials selection matrix in the past. The second part introduces preliminary findings from using the matrix and the matrix as a structural decision-making tool influenced by established tools developed for design engineering. The chapter also discusses how the materials selection matrix can support student's material practice in a changing learning environment and design practice. The third part explores existing knowledge of materials, asking 'what do students know?', 'how do students articulate?' and 'what do students want to learn?'. This is based on a pop quiz and interviews with eight students.

THE TRADITION OF MATERIALS AND SUSTAINABILITY COURSES

Materials courses have been part of the curriculum at Design School Kolding from its establishment in the 1960's. For many years, materials for fashion and textile students were taught by the Danish Technological Institute in courses emphasizing measurable properties and materials testing and introducing the most common textile fibers. Materials were taught in a joint course with coloring techniques, but in the mid-1990s the course was transformed to consider increasingly the contextual aspects of materials with more emphasis on experiential and functional attributes. Typically students had lectures on technical aspects before noon and practical assignments and exercises in the afternoon (conversation with Joy Boutrup). In the course, each student was asked to bring two textiles (s)he was fond of and describe why based on emotional and associative aspects. The textiles were also drawn and analyzed by means of composition and construction to make students aware of the links between physical and experimental material aspects.

The Materials and Sustainability course was first established in the early 1990s at School of Design at The Royal Danish Academy of Fine Arts by Vibeke Riisberg and Joy Boutrup. In the beginning it was a challenge to obtain information and materials for the courses, but the documentation that was generated each year functioned as a knowledge bank for the following years' students (conversations with Joy Boutrup and Annette Andresen). Design School Kolding has taught sustainability-related courses for textiles design since the mid-1990s, but only in 2001 were fashion students also included on the course. The course was developed and taught by the textile engineer, Joy Boutrup. It was based on technical approaches to materials and sustainability that have figured strongly throughout the years Joy Boutrup was part of the permanent staff at Design School Kolding and has provided continuous technical expertise and support to students and in maintaining the school's practical workshops.

The materials selection matrix has been part of the textiles course from the outset and was developed to emphasize the textile life cycle and assessments of textile techniques. The form of the materials and sustainability course has varied in length, theme, participating disciplines and teachers and therefore the content of the course and the premises for using the matrix have changed. In Appendix [A3] a schematic overview of the development of the Materials and Sustainability course is provided for the years 2003 to 2015, shown in characteristics of students, themes and groups of teachers. The overview also shows that the industrial design course took part of a common course or had an individual course in materials and sustainability from 2010 to 2013. In the present curriculum for industrial design, sustainability is integrated into other courses.

The role of sustainability in the materials courses at Design School Kolding was documented 2010 in the publication 'Sustainability in the design process. Method and materials in teaching fashion and textiles' (Andresen, 2010). It states that the sustainability course puts emphasis on the consequences on the material choices made in product development and product and functionality requirements (Andresen, 2010: 12). In the publication Joy Boutrup says that what we do [in the teaching] is to approach materials [in theory and practice] and present the kinds of knowledge we want students to master ["(…) det vi gør i undervisningen er at have en materialetilgang og sætte den viden, vi kommer til at beherske, ind på formel, som ganske langsomt skulle komme til at sidde på rygraden"] (Andresen, 2010: 36).

While the Materials and Sustainability course has predominantly emphasized functional aspects of sustainability, other courses in the curriculum have put emphasis on the relation between user experience and sustainability. From 2009 to 2011 students had the 3-week course 'E-circle: 100% polyester' building on Cradle-to-Cradle principles using Teijin's ECO CIRCLE concept of recycled polyester ("Eco Circle," 2015) as a case. 'Local Wisdom' was a 3-week course conducted in 2012 and 2013. The course was part of a larger fashion research project initiated by Dr. Kate Fletcher from London College of Fashion ("Local Wisdom," 2015) with focus on the 'craft of use' and how values and meanings of fashion items are created through associations and emotions. Recently the course 'Design for Change' has been introduced as a 9 week-long course in the fall 2014 that puts emphasis on traditional textiles and techniques and present and future fashion distribution systems ("Course description - Design for Change," 2014).

Empirical learning environment

The primary empirical studies have been conducted in two materials courses in Design School Kolding. The courses, conducted in the first and second year respectively of the bachelor's program, are mandatory for students from fashion textiles and industrial design. The courses are intended to establish a foundation for understanding and working with materials. The curriculum has changed slightly during the project making it difficult to provide unambiguous descriptions of the courses. The course descriptions have been written in past sense, as the course in the spring 2015 had a different format.

Materials Introduction

Lasting four weeks students have been introduced to fundamentals of materials including material science. In the recent years more emphasis has been put on subjective material aspects. In the first week, all students (fashion textiles and industrial design) have had lectures on plastics, textiles and been presented to emerging materials. In the next three weeks, the course has been split up. The fashion and textiles material course has been framed as a textile design project, where students, supported by lectures in textile science topics, textile analyses and requirement analyses, have been given the assignment to create a textile collection exploring materials and techniques introduced in the course. The parallel industrial design materials course has been framed as a redesign assignment with materials issues covered in short lectures and exercises and by industry visits. In both courses, students have been encouraged to start collecting and indexing materials in personal collections.

Materials and Sustainability

The second materials course focused on materials-related functionality and sustainability issues in three-week group projects. In the course, students have used sustainability issues to develop on a design concept. The concepts have been developed through moodboards and mindmaps, user scenarios, sketches and drawings, and practical material explorations among others. In Appendix [A5] examples of presentations from projects from the fall 2012 are provided.

The first Materials and Sustainability course included in the project was held as a joint course for fashion textiles and industrial design students in the fall 2012. The following years, the course was split up into respectively fashion and textiles design and industrial design. In the fashion and textiles course, students have been supported by additional textiles science lectures focusing on conventional materials as well as emerging and 'sustainable' materials as well as exercises that encouraged reflection on their understanding of sustainability. In the industrial design course, students have been supported by examples of products that emphasize sustainability, by relevant guest lecturers and former student that have shared their experiences and with exercises to reflect on and discuss sustainability aspects. In both courses, materials selection has been based on the materials selection matrix.

Both the Materials Introduction and the Materials and Sustainability course stress a strong coherence between theory and practice and encourage students to explore and test materials in practice during the course. Table 5 provides an overview of the content of inputs in the two courses.

Table 5. Overview of the course content in the materials courses.

	Fashion and textiles design	Industrial design
Materials Introduction	*Assignment: Textile collection*	*Assignment: Analysis and redesign*
	Plastics (both)	
	Innovative materials (both)	
	Vegetable fibers	Plastics+
	Animal fibers	Engineering drawing
	Textile analysis	Industrial visits (~8)
	Industrial visits (~3)	Material descriptions
	Material collection (both)	
Materials & Sustainability	*Assignment: Sustainable design* (both)	
	Synthetic & regenerated fibers	
	'Sustainable' materials	'Sustainable' materials
	Functional materials	Functional materials
	Material selection approaches	Material selection approaches
	Material collection (both)	

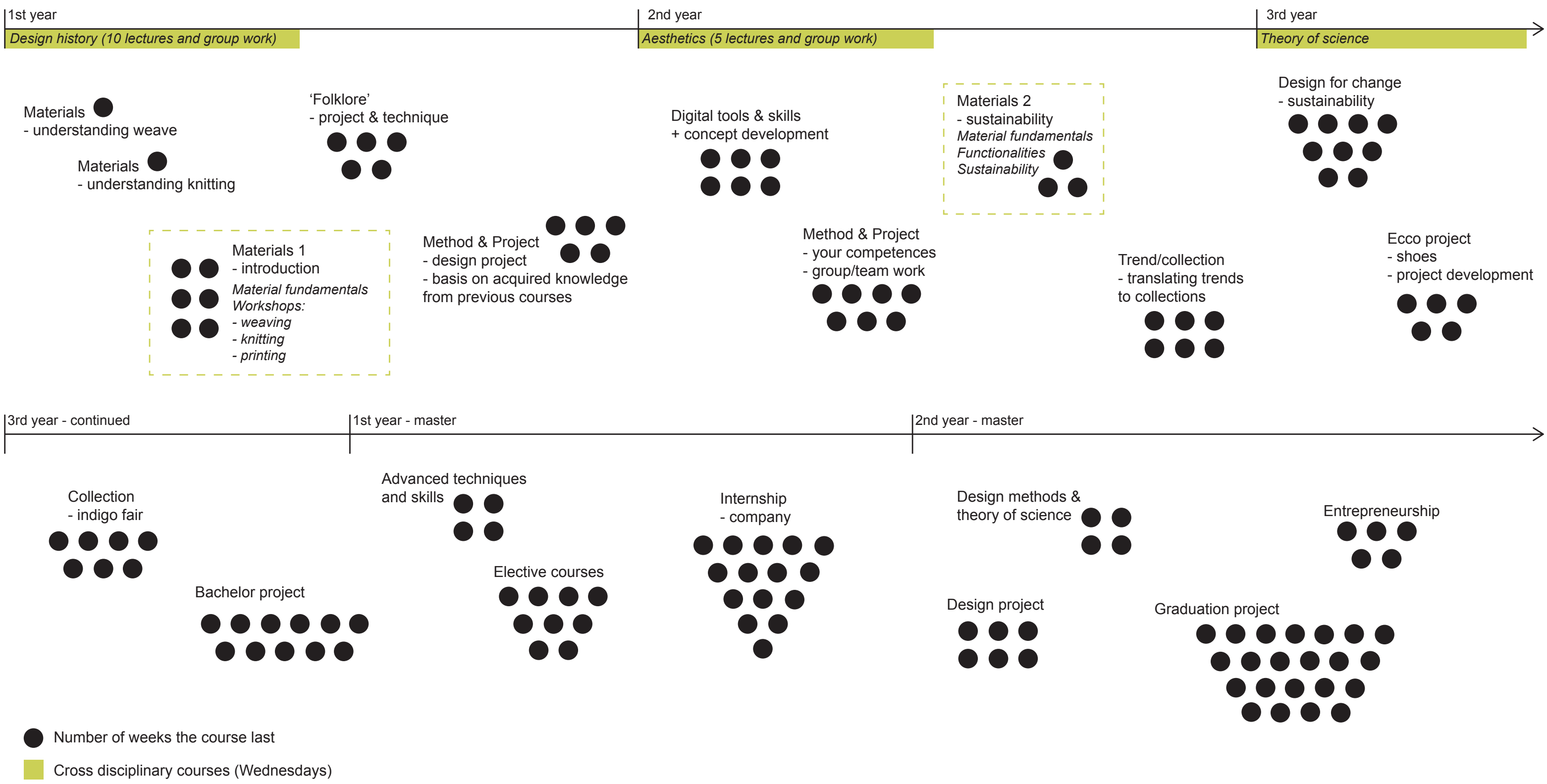
Material courses combined

The project is based on three years of materials courses. The first two Materials Introduction courses were conducted in the second semester and the sustainability course was conducted in the third semester, which created a strong link between them being conducted only half a year apart. It was possible to provide a contiguous structure, desirable for especially more technically oriented materials science lectures. This continuity also facilitated the development of more intuitive and reflective materials articulations, because students remembered things from the Materials and Introduction course, when they had the Materials and Sustainability course half a year later.

It is also important to note that the two materials courses do not stand alone. Both before and after, students have courses in practical uses of materials, for example in the school's practice-based workshops and in methods use. Students are expected to use the knowledge they acquire in the materials courses in following projects. Hence the order of the courses provided is just as essential as the content of each course.

An overview of the knowledge generation in the curriculum, a mapping of the textile design program at Design School Kolding is shown in figure 49. It corresponds to the curriculum as of the fall semester 2014 (DSKD - timetable) and therefore not to the curriculum when the empirical studies were made. The duration of each course has been indicated in weeks (dots) and the two materials courses are marked with a green box. In first, second and third year, students have cross-disciplinary courses in design history, aesthetics and theory of science that are indicated as green bars.

Figure 49. Course mapping of the curriculum for the textile design education at Design School Kolding (valid from fall 2014).



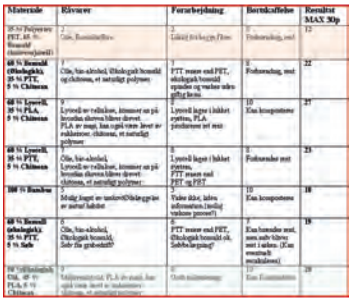
The materials selection matrix used in the past

In the mid-1990's Joy Boutrup introduced the materials selection matrix in the Materials and Sustainability course as way to overview and assess materials. The matrix was inspired by a benchmark of cotton and polyester published in a paper in the Society of Dyers and Colourists (conversation with Joy Boutrup). She considered the matrix as an appropriate way to keep track of and structure information of the fibers and it has been used to benchmark materials for functional and sustainable purposes in the materials courses since. The materials selection matrix was found interesting as a means to become better in reflecting on material requirements and exploring potential materials.

To demonstrate the use of the matrix, a selection of matrices from student projects made from 2007 to 2009 is provided in figure 50-55. The courses had more or less the same content, duration and students. Nevertheless, at the end of the chapter, I shall return to some differences in the premises for conducting the course. More information of the matrices is provided in the figure texts.

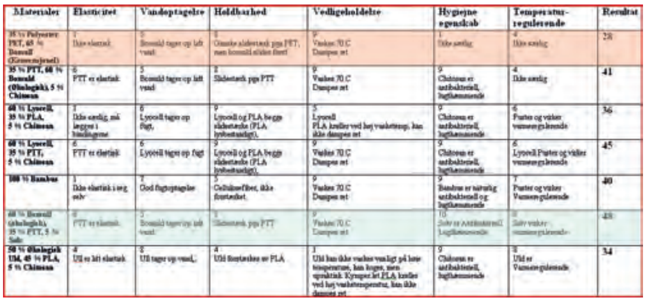
Figure 50 shows two material selection matrices from a group in the course in 2007 used for nurses' coats in hospitals. The two matrices combine emphasis on the life cycle and functionality. Each material has been assessed with a grade and key aspect according to its individual advantages and disadvantages relevant to the life cycle phases and functional properties. Figure 51 shows four material selection matrices from a group in the course in 2007 used for nurses' coats in hospitals. Two matrices assess antiseptic treatments based on grades (top matrix) and descriptions (bottom matrix), one matrix assesses four textile techniques based on production and maintenance aspects and one matrix assess fibers based on functional requirements predominantly using 'smiley'-assessments. Figure 52 is from a project on developing a sustainable (waterproof) poncho from the course in 2008. The selection is obtained through a list of (dogmatic) requirements and a matrix focusing on functionality requirements assessed with a 0-5 numerical scale. Figure 53 shows the material selection approach from the course in 2008 used to assess materials for a sustainable furniture piece. The assessment has been conducted using a matrix that emphasizes on production and disposal requirements and one that emphasizes on functional requirements. The matrices are supported by a consumer test of the stuffing material. Figure 54 shows an evaluation approach from course in 2009 where the Eco-design web has been used to assess materials for a UNICEF drinking bottle. Figure 55 shows a materials selection matrix from the course in 2009 used to assess materials for a solution to prevent children being transmitted with HIV from their mothers.

In general the material selection matrices show great detail and seem well thought



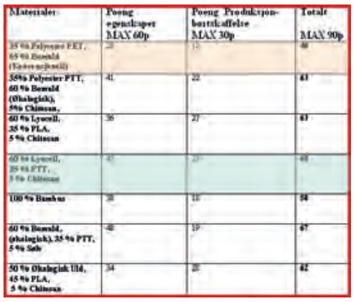
Lifecycle

+



Functionality

=



Combined assessment

Figure 50. Two matrices used for material selection for nurses' coats in hospitals in a materials course in 2007 - the course focused on materials, functionality and sustainability. The two matrices combined emphasize raw materials, processing and disposal (Life cycle) and elasticity, water absorption, durability, maintenance, hygienic properties and temperature regulating (Functionality) In the matrices each material has been assessed with a grade and key aspect according to its individual advantages and disadvantages relevant to the life cycle phases and functional properties.

	BORTSKAFFELSE	PRIS	RÅMATERIALE	VEDLIGEHOLDELSE	HYGIEJNE
TITANDIOXID	2	1	2	1	2
SØLVBELÆGNING	2	3	1	3	3
CHITOSAN	3	2	4	4	4
CYCLODEXTRIN	4	4	3	2	1

	BORTSKAFFELSE	PRIS	RÅMATERIALE	VEDLIGEHOLDELSE	HYGIEJNE	SLITAGE	ANVENDELSE
TITANDIOXID	Titan er et metal, og kan ikke bortskaffes. Vil ligge tilbage i aske/jord.	I nanoteknologisk sammenhæng er titandioxid forholdsvis dyrt.	TiO2- titanium i forbindelse med luft. I madvarer: E-171.	Behøver UV-lys for at nedbryde organiske stoffer. Almindelig vask.	Ved belysning aktiveres radikaler som nedbryder bakterier.	Belægning på fibren har en god slidstyrke. Overfladebehandling mindre holdbar.	Tandpasta, hvid maling, belægning på bygninger, stivelse i madvarer
SØLVBELÆGNING	Sølv er et metal og kan ikke bortskaffes. Vil ligge tilbage i aske/jord.	Sølvbelægning er en gammel teknologi, derfor billig, dog er sølv et dyrt materiale.	Sølv er grundstoffet AG. E-174	Almindelig vask.	Har en naturlig anti-bakterial virkning. Er rensende og nedsætter fugtproblemer.	Har en god holdbarhed. Belægning på fibren er bedst.	Bruges til smykker, fyldninger hos tandlægen, ved anti-statisk brug, varmeledere etc...
CHITOSAN	Chitosan kan komposteres, men forbrænding er mere realistisk, dog udvikles kvælstof.	Er stadig under udvikling, så derfor varierer prisen, dog ikke billig.	Biprodukt af skaldyr. Cellematerialet kitin udvindes	Almindelig vask	Anti-bakterial. Forbedring af immun-system i ren form. Sårhelende. Luftfugt-absorb.	Belægningen er holdbar og hårdfør.	slankeprodukter, plantegødning.
CYCLODEXTRIN	Cyclodextrin kan både komposteres og forbrændes.	Cyclodextrin er et rimeligt billigt produkt.	Biprodukt af stivelse og glycogen.	Skal vaskes for at virke optimalt. Almindelig vask.	Indkapsler lugtstoffer, ikke antiseptisk skal vaskes for at fjerne urenheder.	Lang holdbarhed.	cholesterol-fri produkter. Papirprodukter.

Antiseptic treatment

+

	BRODERI	VÆV	STRIK	INDFARVNINGS-TRYK
ENERGI		10-30 mj/kg	5-20 mj/kg	[illegible] mere dyrere end væv med farve
PRIS			billigere end væv	flere farver øger pris
ARBEJDSPROCES		begrænset farvevalg	Nemt farveskift	ubegrænsede farver
VEDLIGEHOLDELSE				
HOLDBARHED	samme som væv	høj farveægthed og slidstyrke	samme som væv	risiko for udflydning af farver
MILJØVENLIGHED		?	?	?

Textile constructions

+

	PET	PTT	PLA	BOMULD
VARMEISOLATION	☹ ☹	☹ ☹		☹
FUGT/VAND-ABSORBERENDE	0,2-0,4	0,2-0,4	0,4-0,6	7,5
KRØLLE-FRIT	☺	☺		☹
SMUDSAFVISENDE	☹	☹		☹
VASKENEMHED	0	0		☹
ANTI-STATISK	☹	☹	0	0
VEJRFORHOLD	☺	☺		0
RESISTENT OVERFOR MIKROORGANISMER	☺ ☺	☺ ☺		☹
BLØDHED	☹	☺ ☺		
TRÆKSTYRKE	2,4-7,0	7	2,0-6,0	4
LUGTFRI	☹ ☹		☺	☺ ☺

Fiber properties

Figure 51. Four matrices used for material selection for nurses' coats in hospitals in a materials course in 2007 - the course focused on materials, functionality and sustainability. Two matrices assess antiseptic treatments based on disposal, price, raw materials, maintenance, hygiene, wear and use based on grades (top matrix) and descriptions (bottom matrix). One matrix evaluates four textile techniques (embroidery, weave, knitting and dyeing/printing) based on energy consumption, price, working process, maintenance, durability and environmental friendliness using both values and descriptions. The last matrix explore fiber properties of four fibers (PET, PTT, PLA and cotton) basing the assessment on the fiber properties: water/moisture absorption, crease tendency, dirt repellency, washing ease, anti static properties, weather conditions, anti-microorganims, softness, tensile strength and odor free. The matrix has predominantly been graded based on happy and sad smileys.

- **billig produktion!**
- **lokal produktion!**
- **100 % vandtæt!**
- **komposterbart!**
- **høj brudstyrke!**
- **stor fleksibilitet!**

Material requirements

+

	BRUD-STYRKE	VAND-TÆTHED	VAND-DAMP-TÆTHED	FLEKSI-BILITET	LYD	BORT-SKAFFELSE	PRIS
PVC	4	5	0	1	4	Afbrænd-ing GIFTIG!	5
PLA 20/40 Mikrometer	3	5	0	4/3	2/3	Komposter-bart	4
TYVEK (PE)	5	5	5	2	5	Afbrænd-ing. CO2 neutral	1
PLA OLIE-BASERET	3	5	0	4	1	Komposter-bart	3

Material analysis

Figure 52. A material selection approach from a materials course in 2008 for materials for a sustainable (waterproof) poncho. The group first list ssix (dogmatic) requirements for the material (inexpensive production, local production, 100% waterproof, compostable, high tensile strength and high flexibility and second assesses four materials (PVC, PLA, Tyvek and oilbased PLA) using predominantly numerical grading (0-5).

Fremstilling - Bortskaffelse

Materiale	Energi forbrug v fremstilling	Vandforbrug	Pesticideforbrug	Klorblandinger	Efterbehandling (Formaldehyd)	Energi v forbrænding	Udslip v forbrænding
Uld	God	Middel	Dårlig	Dårlig	———	God	Dårlig CO2 N
Polyester PET	Dårlig	———	———	———	———	God	God CO2 H2O
Bomuld	Middel	Dårlig	Dårlig	Dårlig	Dårlig	Middel	God CO2 H2O
Viscose	Dårlig	———	———	Dårlig	Middel	Middel	God CO2 H2O

Production and disposal

\+

Materiale egenskaber

Materiale	Slidstyrke	Tilsmudsning	Vedligeholdelse	Mørning	Fugtighedsoptagelse	Komfort
Uld	Dårlig	God	Middel	Dårlig	God	Middel
Polyester PET	God	Middel	God	God	Dårlig	Middel
Bomuld	Middel	Dårlig	Dårlig	Middel	Middel	Middel
Viscose	Dårlig	Middel	Dårlig	Middel	Dårlig	Middel

Material properties

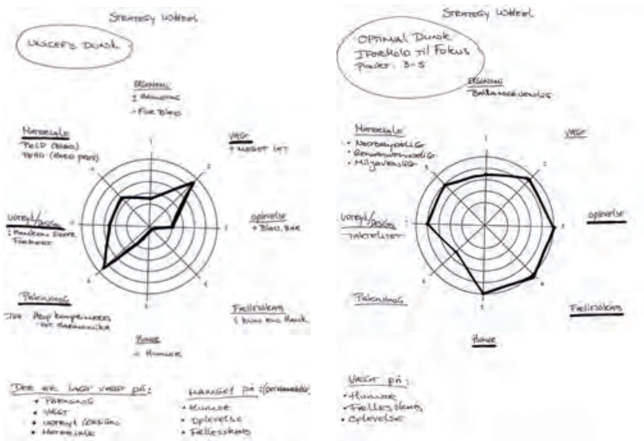
\+

Forbrugertest af fyld-materiale
1-5 point (5 = bedst)

Materiale	1 pers	2 pers	3 pers	4 pers	5 pers	6 pers	7 pers	8 pers	9 pers	10 pers	Bedst i test
Hirse	3	5	4	2	4	5	5	2	5	5	Nr. 2 40 / 50 point
Grød Ris	1	3	3	1	3	3	1	4	2	2	Nr. 4 23/ 50 point
Boghvede Kerner	2	2	2	4	3	2	4	5	3	3	Nr. 3 30 / 50 point
Krøyer Kugler	4	1	1	3	1	1	2	1	1	1	Nr. 5 16 / 50 point
Mini Krøyer Kugler	5	4	5	5	5	4	3	3	4	4	Nr. 1 42 / 50 point

Consumer test - stuffing material

Figure 53. Three material selection matrices from the materials, functions and sustainability in 2008. The matrices have been used to assess materials for a sustainable furniture. The matrices to the left and in the middle assess four materials being wool, polyesyer, cotton and rayon and use the grading scale bad, medium and good. The matrix to the left considers processing and disposal based on the energy consumption in production, water consumption, pesticide consumption, chlorine containing substances, finishing (formaldehyde), energy generation when incinerated and emissions when incinerated. The matrix in the middle considers material properties including abrasion resistance, dirt repellency, maintenance, roting, moisture absorption and comfort. In the matrix to the right, ten consumers have assessed possible filling materials using a 1-5 assessments scale.



Ecodesign web

Figure 54. Material assessment based on the eco-web used in the materials, functionality and sustainability course in 2009. In the project students proposed an alternative product to a Unicef drinking bottle. In the eco-web product and material aspects relating to ergonomics, weight, experience, community, humor, packing, expression/design and material have been used.

Name :	*Polypropylen* PP	*Polyhydroxy-buturat-valeriat* PHBV
Produktino :	Cheap 1	Little more expensive 2
Sustainability :	Recycable 2	Compostable 1
Type plastik :	Thermoplastic 2	Bioplastic 1
Lifetime :	Long 1	Long 1
Charakter :	-flexible -strong -hard -light -becomes "dry" plastic when it gets cold 1	-hard -strong -"dry" plastic 2
Hygienic :	1	1
Weight :	0,9 g 1	Ca. 1,0g -2,0 g 2
Result :	**9**	**10**

Material matrix

Figure 55. Material assessment matrix made in the materials, functions and sustainability course in 2009. In the project, students worked on a solution to prevent children to be transmitted with HIV from their mothers. In the matrix two materials (PP and PHBV) are assessed according to product info, sustainability, plastic type, lifetime, characteristics, hygiene and weight.

out, customized for the specific application and using different means to evaluate the materials. It is evident that the matrices primarily focus on functional and technical material aspects. That said, according to Joy Boutrup, concerns about experiential characteristics have been part of the course throughout. Sensory perceptions, emotions and associations have been explored using mindmaps, moodboards and in practice-oriented exercises. Students have been encouraged to integrate experiential attributes in the matrices, but have usually failed to do so, or done have done only to a very limited extent.

GETTING TO KNOW THE MATERIALS SELECTION MATRIX

The first experience I had with materials teaching was in the Materials Introduction course in the spring 2012, where I observed the final presentations for the fashion and textiles students. The second contact was in the Materials and Sustainability course in the fall 2012, where I coordinated the course and took part in lecturing and supervising students as part of a team of five lecturers with different specialisms.

When observing the final presentations in the Materials Introduction course, I had recently initiated the PhD project. I was still trying to understand the learning environment and how the materials courses were taught, so the first experiences primarily provided me with preliminary insights that could function as the basis for my future investigations. Attending the courses also served to meet the students, who have been such essential components of this project.

The Materials and Sustainability course in the fall 2012 was both overwhelming and interesting: overwhelming to teach for the first time and to supervise students and interesting to experience how information should (and should not) be communicated, and what students found easy and difficult. The materials selection matrix was already an integral part of the course, but it caught my attention. Maybe this was because of its applied structure and because it was evident that students found it challenging to work with and understand.

The first studies on the matrix focused on the information that could be extracted from it. Therefore the first investigations are based on my immediate experiences and observations from the first course in the fall 2012. Thereafter attention on the structure and the process the matrix constructs was given. The first investigations are included in the following section while the structure and components are discussed in the section that comes next.

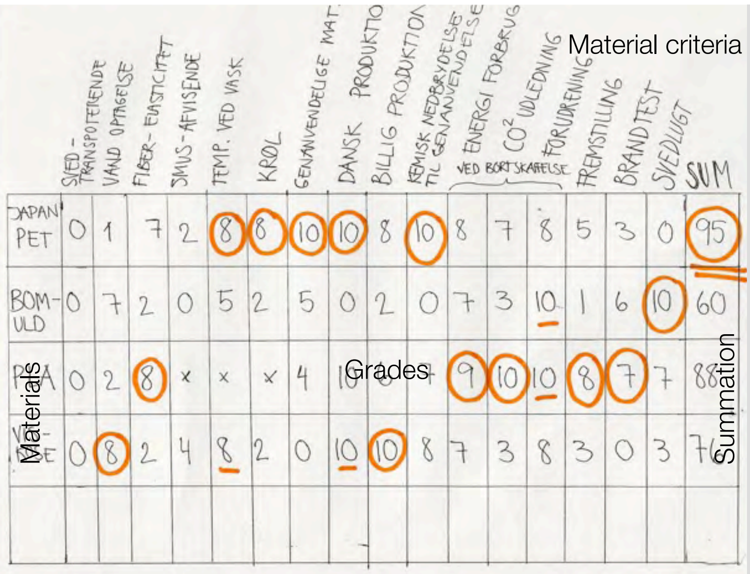
Initial empirical findings from the matrix

The following study is based on the paper: ‘Articulating Material Criteria’ (Hasling,

2013) [P1]. The paper was written just a of couple months after the first encounter with the materials selection matrix, but it provided some valuable insights that afterwards took long time to grasp and fully understand.

In the course, the materials selection matrix was used to help groups of students to select materials for applications in design projects. A more comprehensive introduction of the matrix follows, but basically the matrix assesses materials based on identified material requirements relevant for a design intent. After the course, the matrices were collected and this first study investigated the requirements that had been identified and how they had been articulated. This served to understand how the matrix facilitates students' ability to identify essential material requirements, not only improving the quality of products, but also expanding the knowledge of materials and their potentials among students.

Figure 56. Examples of four material selection matrices from the Materials & Sustainability course at Design School Kolding, fall 2012. The matrices serve to illustrate the diversity of matrices and are not further described here.



Betegnelser		Fremstilling		Egenskaber					
Materiale	Fork.	Råvarer	Energi	Vægtfylde (g/cm³)	Pris	Smeltepunkt	Isoleringsevne	Holdbarhed	Vedligeholdelse
High-density Polyethylene	HDPE	Petroleum	9	8 0,93 - 0,97 g/cm³	5	7	6	7	6
Polypropylene	**PP**	**Petroleum**	**8**	**9** **0,855 – 0,946 g/cm³**	**7**	**9**	**5**	**8**	**6**
Polyphenyl Sulfone	PPSU	Petroleum	2	6 1,29 g/cm³	2	1	-	8	8
Acrylonitrile Butadiene Styrene	ABS	Petroleum	5	7 1,05 – 1,10 g/cm³	4	3	2	7	5

Betegnelser		Egenskaber				Bortskaffelse			Resultat
Materiale	Fork.	Mulighed for Injection Moulding	Indfarvningsevne	Smudsafvisning	Lugt-/smagspåvirkning	Genbrug	Bionedbrydelighed	Forbrænding	Samlet sum
High-density Polyethylene	HDPE	10	9	6	4	10	0	1	88
Polypropylene	**PP**	**10**	**9**	**9**	**10**	**10**	**0**	**1**	**101**
Polyphenyl Sulfone	PPSU	3	2	4	10	0	2	0	48
Acrylonitrile Butadiene Styrene	ABS	10	8	8	7	10	3	8	87

Fyld	Fleksibilitet	Blødhed	Bortskaffelse	Egen vægt	Produktions Energi	Pris	Point
Latex Hevea Brasiliensis	9	9	8	7	5	1	39
Tempur (Polyurethan)	1	8	0	10 (85-110 kg/m3)	1	1	21
Krøyer (polystyren plast EPS)	8	2	9	10	8	10	47

Overflade	Vedligeholdels	fleksibilitet	Blødhed	Pris	Bortskaffelse	Friktion	Produktions energi	Vand smuds afvisende	holdbarhed	Point
Velour bomuld stræk.	1	7	8	7	7	7	1	2	6	46
Polyester	7	9	8	8	10	0	8	9	9	68
Natur Gummi	7	9	9	1	8	10	5	9	6	64
lycra	8	10	3	6	1	0	1	8	3	40
Flock (nylon)	6	5	8	7	1	10	8	6	7	58

	Uldfilt	Presset bambus (strandwoven bamboo)	PET	PLA (polymælkesyrer)	PMMA polymethylmethakrylat (plexiglas/akrylglas)
Lyddæmpende	10	2	2	2	2
Transparens	0	0	10	10	10
Lasercut venligt	10	2	10	10	10
Blødhed	10	2	0	0	0
Letvægt	8	7	5 1,37g/cm^3	6 1,25g/cm^3	7 1,19g/cm^3
Flexibilitet	8	0	0	0	0
Smudsafvisning	9	10	10	10	10
Aftøring med klud	5	10	10	10	10
Husstøvmider	0	10	10	10	10
Brand	8 Flammehæm-mende. brænder ikke, men forkuller ved 120 grader celsius.	0 Brænder.	6 Atmosfærisk luft indeholder ca. 21% ilt, Pet skal bruge 23% ilt før det brænder. Dvs. Ilden slukkes når flammen slukkes. Ved brænd og ophedning udskilles følgende: Vand,carbondioxid, kuldioxid, carbonmonooxid, kulilte, acetaldehyde CH3-CHO, formaldehyd HCHO, acrolein, eddikesyre CH3-COOH, myresyre HCOOH.	7 Lav brandbarhed.	2 Brænder ved 17% ilt. Dvs. Selvom flammen slukkes brænder materialet videre. Ved brand og ophedning udskilles følgende: Vand, carbondioxid, kuldioxid, carbonmonooxid, kulilte, formaldehyd HCHO, methylmethakrylat.
I alt	68	43	63	65	61

Requirements from matrices from six groups were extracted. In figure 56, four of the matrices considered have been included. The matrices serve to illustrate the diversity of matrices developed in the course. The specific content of, and approaches applied in, the four matrices will not be further elaborated on here.

The matrices showed that many students found it difficult to identify requirements and to compare materials based on the requirements. Some found it difficult to reflect on material demands of their design concepts, while some found it difficult to find potential useful materials. Both challenges seemed to be caused by lack of familiarity with the technical material vocabulary, limiting their ability to understand, discuss and apply properties from materials literature. The materials requirements identified were both experiential and physical (cf. the section on material values in materials for design from p. 61). During the course a considerable amount of time was spent on discussing qualitative requirements and how intended aspects could be 'normalized', translated or reinterpreted into comparable requirements. The intention was to give students something to work from, but also to take them a step further and encourage them to discuss, what material attributes are, and why they had chosen the ones they had.

From the six groups 75 requirements were mapped in accordance to a three-phase product life cycle (production, use and disposal). The mapping is illustrated in fig-

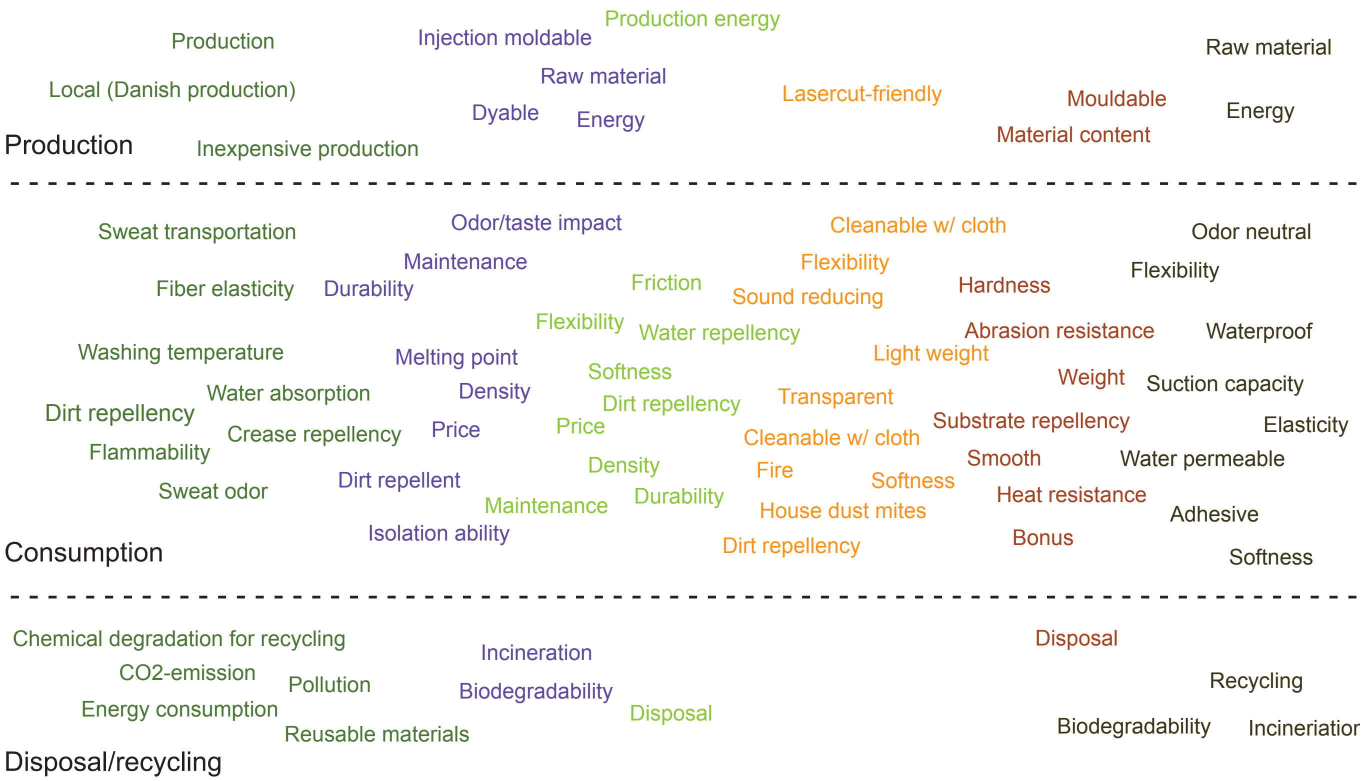


Figure 57. Structuring of material criteria for six groups in the course structured by three main phases in a product life cycle. Each color indicates a criterion identified by individual project groups and the horizontal line indicates the differentiation of material criteria in the production, consumption and disposal/recycling respectively.

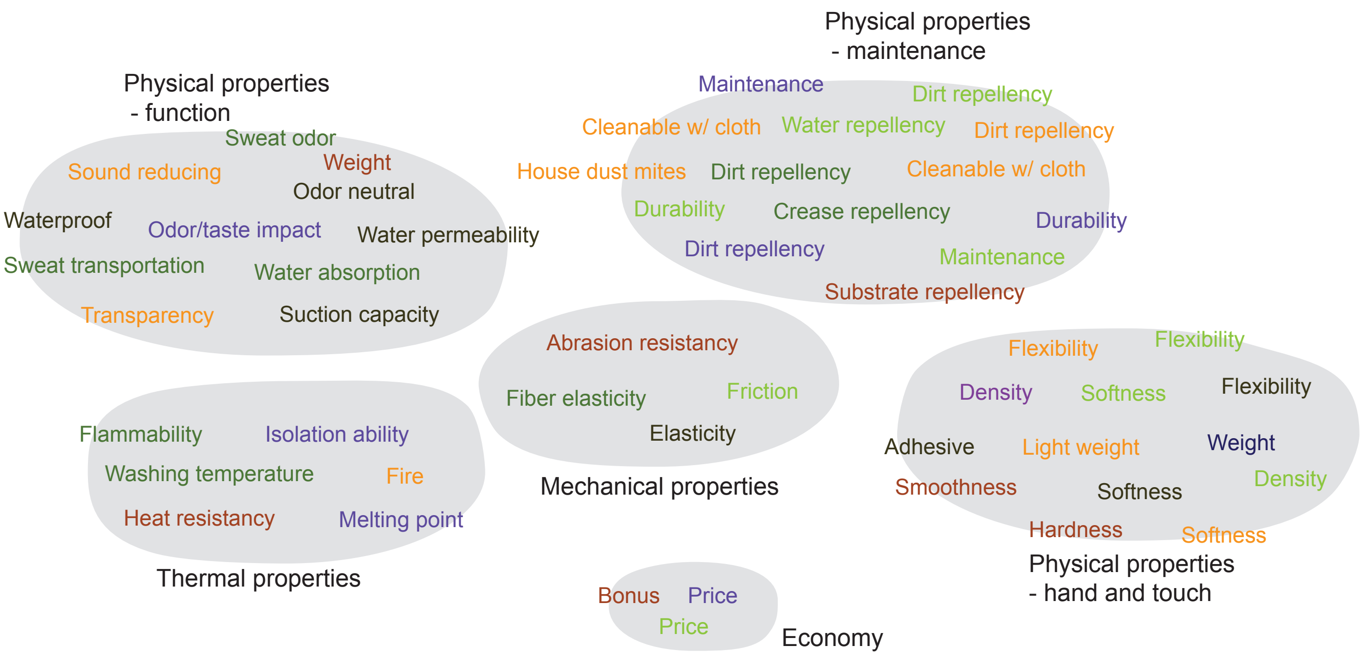


Figure 58. Clustering material criteria identified as being in the consumption phase in categories of properties for six groups in the course. The colours indicate the different groups and as a result some criteria might occur more than one time.

ure 57. Here each color corresponds to requirements from different projects. From the mapping, it was evident that even though students were asked to consider the entire material life cycle, requirements corresponding to the use and consumption phase accounted for two thirds of the requirements. This indicated that these attributes are more tangible and easier for students to relate to.

The use and consumption attributes that correlate to functional and experiential aspects of materials were further studied using a cluster diagram approach. Here larger groups of requirements with shared kinds of attributes were identified. The clusters are shown in figure 58 and the color codes are similar to the ones used in figure 57. The colors have helped to display the uneven distribution of requirements in the clusters.

The majority of the requirements related to ‘physical attributes’, but also ‘mechanical’ and ‘thermal properties’ were represented. The physical attributes could be further divided into the clusters: ‘function’ that included absorption and transportation of media such as water, air and light; ‘maintenance’ that related to use of material in terms of repellence and cleaning, and ‘hand and touch’ that contained properties related to direct use and the senses. The data were collected and analyzed before the differentiation between technical and experiential attributes was recognized and the clusters do not necessarily correspond directly to these. However, the original clusters have intentionally been kept to emphasize the understanding and interpretation in that phase of the project.

Different aspects can cause the distribution of requirements. One aspect is that projects had different objectives and therefore different kinds of requirements were relevant. This has previously been touched upon in Chapter 4 when the P-E-S triangle was introduced (see p. 79). Another aspect is that the students defining the requirements had different knowledge, experience and values, which have affected the requirements they have identified. Therefore cluster diagrams can help illuminate, if some categories of requirements need be further elaborated in order to perform valid material assessments. They can further contribute to the identification of 'tacit' or 'unknown' requirements, being requirements students do not know exist or do not have the vocabulary to communicate. With reference to Bloom's taxonomy of learning and especially its four knowledge dimensions (see p. 84ff), the clusters transform factual knowledge into conceptual knowledge, using graphic representations of categories of requirements, based on primarily functional aspects linking to the context.

Structure and components of the materials selection matrix

After the first study emphasis was put upon the structure and mindset of the materials selection matrix. It resembles established multi-criteria decision-making models used in design engineering such as Quality Function Deployment with its 'House of Quality' (Bouchereau and Rowlands, 1999; Hauser and Clausing, 1988; Revelle et al., 1998), Harris profiles (Harris, 1961; van Boeijen et al., 2013) and Pugh (Selection) Matrices (Pugh, 1987, 1981). The three models have been used as inspiration for further developments of the materials selection matrix, but individual models will not be described in detail; these will be referred to in the references above. The description here highlights a few pros and cons that were relevant for the further development of the materials selection matrix.

In table 6, an overview of the three methods is provided including selected pros and cons for each. Whereas the House of Quality provides a structure to compare

Table 6. Overview of advantages and disadvantages with the three methods.

	House of Quality	Harris Profile	Pugh Matrix
+	Compare candidates based on requirements Consider a broad range of influencing factors	Intuition-driven evaluation Visual representation of scores Simple to use	Structure comparison of candidates Relatively simple to apply
-	High complexity High time consumption	Low reliability Difficult to compare materials	Numeral scores are challenging to apply

choices based on the product's requirements and considers a broad range of influencing factors, it is very complex, time consuming and requires experience. The Harris Profile is based on an intuition-driven evaluation that both represents evaluations visually and is easy to use, but its reliability is relatively low. Finally the Pugh Matrix offers a structured and relatively simple approach using weighted criteria and numerical scores.

KNOWLEDGE, ARTICULATION AND EXPECTATIONS

The following section investigates, 'what students know about materials', 'how they articulate materials' and 'what expectations they have of materials teaching'. The investigations are based on studies that have been conducted during the project and have therefore not functioned as the starting point, but to provide support and additional knowledge.

What do students know?

The first enquiry into what students know has been expanded, using data from a quiz conducted in an annual materials introduction course in the School of Design at The Royal Danish Academy of Fine Arts. In the Introduction it was written that Design School Kolding and School of Design are rooted in the same arts and crafts tradition. Therefore a study based on students from School of Design should also be representative for students from Design School Kolding. To further elaborate on the study, the questions: *"To what extent are students able to recognize materials?"* and *"What is the distribution of the level of mental recognition?"* are added.

The quiz was conducted in a weeklong generic introductory materials course covering how we define and describe materials, materials properties, sustainability and materials and how materials information can be acquired. The participating students were first year students from industrial, interior, furniture, textiles, ceramics, visual communication and clothing design. The quiz was repeated in two consecutive years with thirteen students participating each year (fall 2013 and fall 2014). Even though the sample of the study does not necessarily represent design students in general, the quiz was thought as a good way to extract information that could give some indications of the current situation.

The quiz consisted of fifty unidentified materials that students had to identify and the data from the completed forms were analyzed after the course. Specific insights into the knowledge of materials in general and specific material groups were of interest.

The fifty materials ranged from basic and conventional materials such as cotton wood, brass, copper, oak and teak to (comparatively) newly developed materials

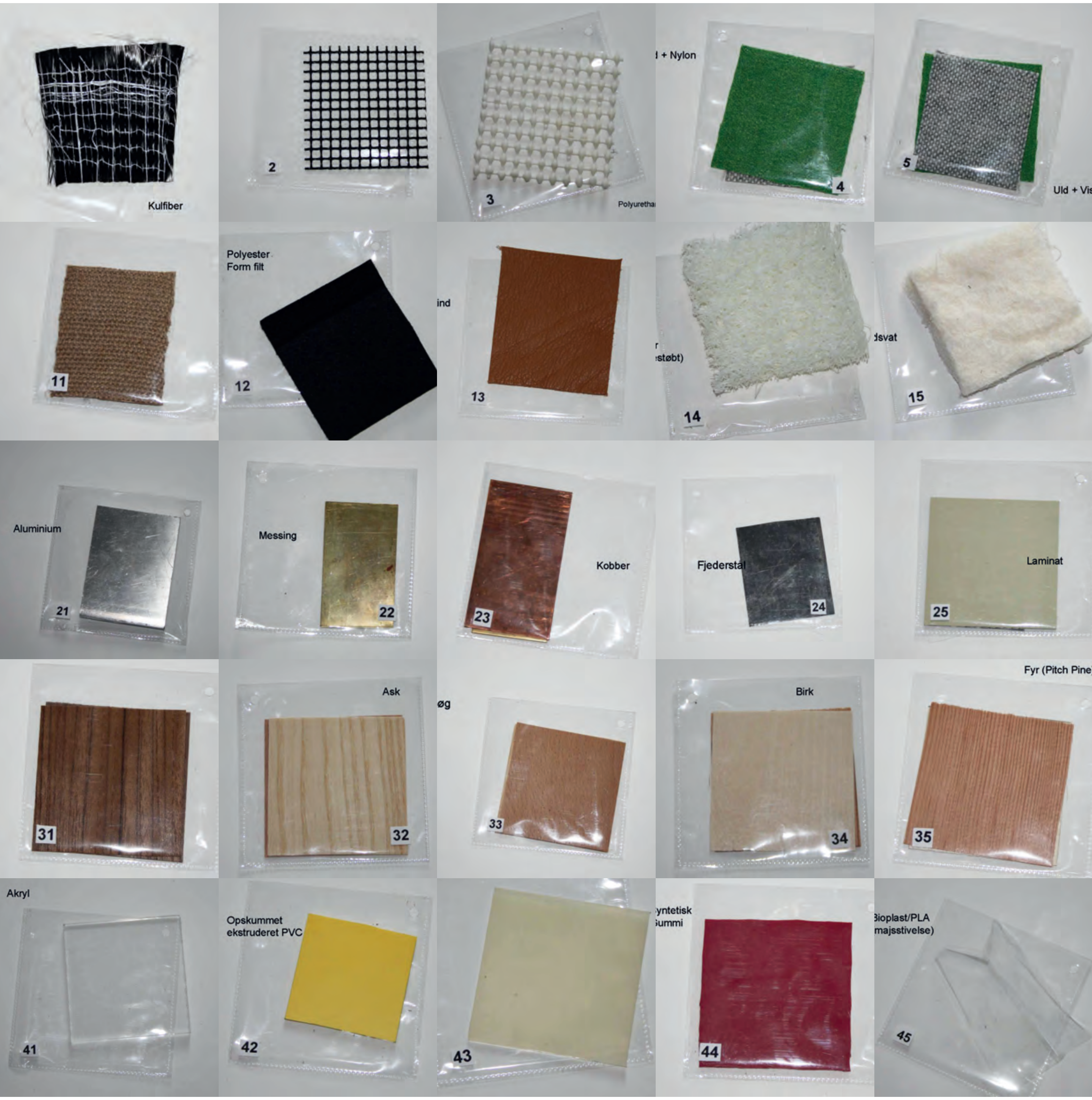
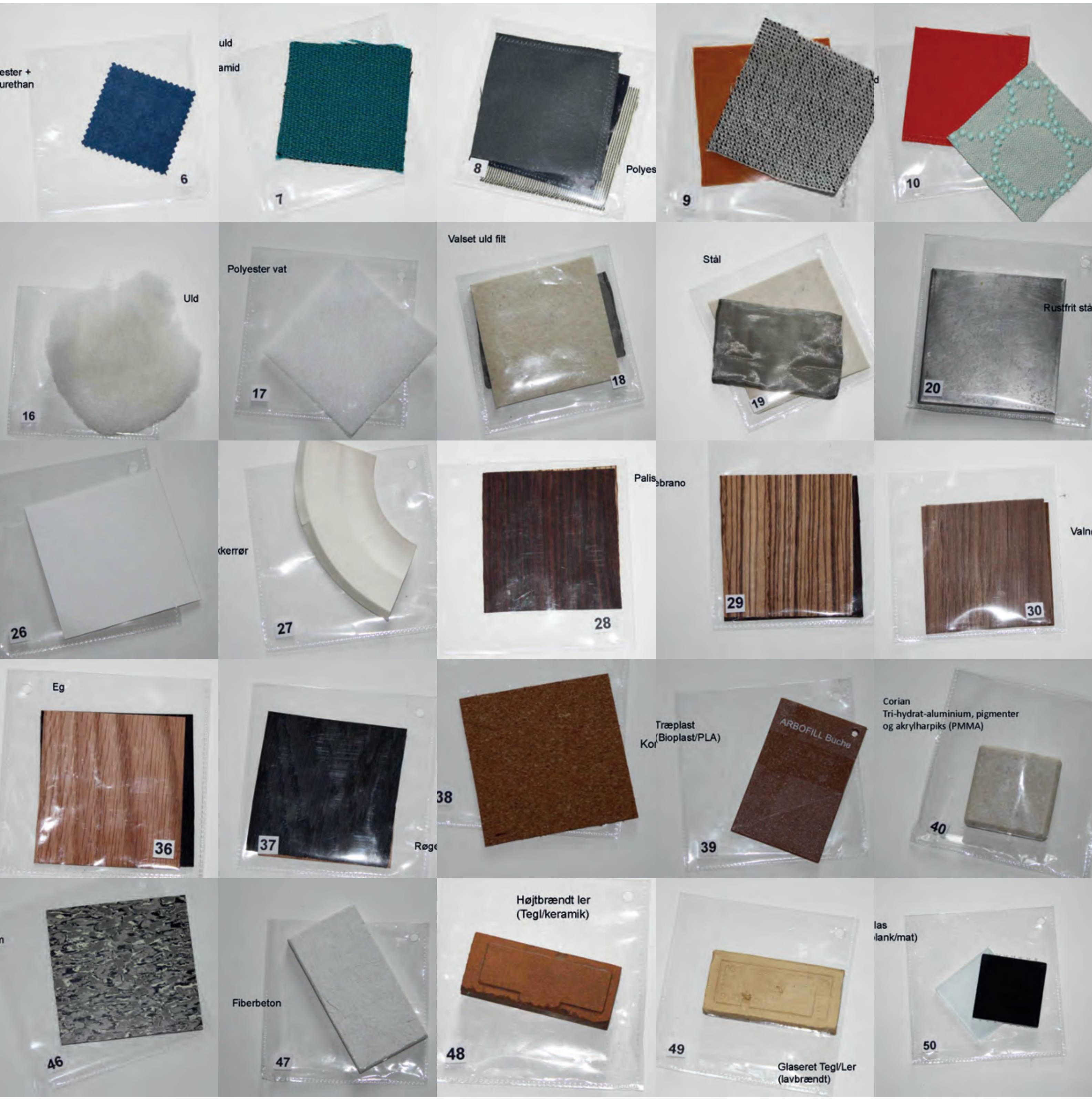


Figure 59. Material samples from the material characterization exercise conducted at KADK in the fall 2014. From top left to bottom right : 1. Carbon fiber, 2. teflon, 3. polyurethane, 4. wool/polyamid blend, 5. wool/rayon blend, 6. polyester/polyurethane, 7. wool/cotton/blend, 8. polyester, 9. wool, 10. cotton, 11. linen, 12. form felt - polyester, 13. leather, 14. extruded polyester foam (Zenxit), 15. cotton wool, 16. poor wool, 17. polyester wool, 18. flattened woolen felt, 19. steel (fabric), 20. stainless steel, 21. aluminium, 22. brass, 23. copper, 24. laminate (paper/melamine),



25. springsteel, 26. paper, 27. sugarcane, 28. zebrano, 29. palisander, 30. walnut, 31. teak, 32. ash, 33. beech, 34. birch, 35. pine, 36. oak, 37. smoked oak, 38. cork, 39. woodplast (Arboform), 40. Corian, 41. PMMA (DK: akryl), 42. foamed PVC, 43. silicon, 44. synthetic rubber, 45. PLA, 46. linolium 47. fiber concrete, 48. ceramics (brick)/highburned, 49. ceramics (brick)/lowburned, 50. glass.

Category 1: 0-20% (0-5 correct)	Category 2: 21-40% (6-10 correct)	Category 3: 41-60% (11 to 15 correct)	Category 4: 61-80% (16-20 correct)	Category 5: 81-100% (21-26 correct)
Carbon fiber (1)	Wool (9)	Cotton padding (15)	Leather (13)	Cork (38)
Teflon (2)	Linen (11)	Woolen felt (18)	Aluminum (21)	
Polyurethane/foam (3)	Shapeable PET felt (12)	PMMA (41)	Brass (22)	
Wool/PA blend (4)	Pure wool (16)	Rubber (synthetic) (44)	Copper (23)	
Wool/rayon blend (5)	Polyester padding (17)	Glass (50)	Linoleum (46)	
Polyester+PUR (6)	Steel (stainless) (20)		Brick – glazed (49)	
Wool/cotton/PA (7)	Paper (26)			
Polyester (8)	Beech (33)			
Cotton (10)	Pine (35)			
Polyester foam (14)	Oak (35)			
Steel textile (19)	Smoked oak (36)			
Laminate (24)	Silicone (43)			
Spring steel (25)	Brick (48)			
Sugarcane (27)				
Zebrano (28)				
Palisander (29)				
Walnut (30)				
Teak (31)				
Ash (32)				
Maple (34)				
Woodplast (39)				
Corian (40)				
Foamed PVC (42)				
PLA (45)				
Fiber concrete (47)				

Table 7. Overview of correct answers in the pop quiz. In the overview, five categories have been used to group answers.

such as Zenxit polyester foam ("Zenxit," 2014), Arboform woodplastic ("Arboform," 2014) and PLA sheets ("NatureWorks - PLA," 2015) among others. They included materials from a broad range of categories including textiles, metals, plastics and wood. They were provided as approximately 6x6 cm size samples with a maximum thickness of ~10 mm. The fifty materials used in the quiz are shown in figure 59 (pp. 142-143).

In the analysis, correct answers for each of the material samples for each year were counted. The trends of the two years corresponded and were therefore merged into one final result. As the exactness of the answers varied, some answers had to be assessed individually. For instance for material #12, students were credited with a correct answer if they had answered 'felt' even though the full answer was shapeable (or thermoplastic) felt and for material #44, students got a correct answer if they had answered 'rubber' even though the correct answer was synthetic rubber. Overall 29% of the materials were assessed correctly. The result should however be taken with a pinch of salt, as many students did not specify the species of wood samples and the fiber composition of the textiles samples.

The number of correct answers for each material is summarized in table 7. This shows which materials are widely recognized and which materials few students can identify. The level of recognition has been divided into five categories. Cork is the only material in category 5, which comprises materials with 81%-100%

correct answers. Category 4, comprising materials with 61-80% correct answers, includes leather, aluminum, brass, copper, linoleum and glazed brick. Category 3, with materials with 41-60% correct answers, contains cotton wadding [bomulds-vat], woolen felt, PMMA [Plexiglas/akryl], rubber and glass. The majority of the materials are placed in category 1 and 2. In Category 1, materials with 0-20% correct answers are included, while in Category 2 materials with 21-40% are included. The materials in Category 1 and Category 2 comprise respectively 50% and 26% of all materials in the questionnaire. In Category 1 three groups of materials dominate: textiles/fabrics, wood species and (prominently) newly developed materials (~emerging materials). Because unspecified textiles and wood samples were assessed as wrong answers they are also placed here.

Students were able to identify that materials were textiles, wooden or plastic and in that sense the results of the analysis do not entirely justify the difference in detail of the material samples. If the textile and wooden materials from Category 1 are removed, the remaining materials are carbon fiber, Teflon Zenxit, sugar-cane, Arboform Corian, PLA and fiber concrete. These materials are not all newly developed (for example Teflon was developed in the 1930's ("DuPont - Teflon" 2014) and Corian in the 1960s (DuPont - Corian, 2013) (both by DuPont)), but they are materials that have significant properties and/or origins that can make them difficult to identify and link to other well-known materials. On the contrary the materials in Category 4 and 5 are all somewhat traditional, recognizable and commonly used in consumer products. Therefore they are materials students can relate to and find easier to identify.

The quiz shows, how students recognize materials and can be used to discuss one of the challenges in materials education. From teaching experience it is evident that students are more attracted to emerging than conventional materials, but still they know less about emerging materials. People are often attracted and fascinated by unknown things, which makes it make sense. Many emerging materials possess functionalities that make them stand out from similar conventional materials and easier to remember. However, if students do not establish an understanding of materials based on conventional materials that have a higher degree of transparent material properties and meanings, it is difficult to grasp the full potential of the respective emerging materials. Methods-wise it can cause material practice to become unstructured and unreflective and content-wise it can cause an imbalance of focus if conventional materials are forgot and emerging materials are considered the best solutions for all projects.

The relation between conventional and emerging materials can be explored by looking at the mechanisms that establish students' ability to recognize materials.

Conventional materials are familiar and students have made sense of them as part of everyday life, while emerging materials are unfamiliar and students will have had limited opportunities to establish personal meanings to the materials. Students often learn about emerging materials from 'innovative' materials literature and physical with examples that presents the materials as part of, for example, high-technology solutions. Conventional materials are rarely included in similar literature and most libraries deliberately focus on new materials (such as for innovative and sustainable solutions). Consequently the bases for discussing and comparing the two kinds of materials are very different, which means that it is difficult to establish a common ground that considers conventional and emerging materials equally. This is further stressed by the fact that students have limited access to the latter, as they are not easily available and can be expensive.

How do students articulate materials?

In the fall 2014, a number of student interviews were conducted. Initially they served to give students, from those in their first year to those preparing their master projects in the fifth year, the opportunity to share their material practices and to give recommendations of materials teaching in the future. However, most of the students, who could take part of the interviews, were first or second year bachelor students. As I will get back to later in this chapter, the two materials courses that are studied in the project are held on respectively the first and second years. Thus the students had either not had their first materials course or were in between the first and second materials course. Based on the initial purpose of the interviews, it was unfortunate, but it gave an opportunity to explore materials understanding and materials in education based on expectations and initial experiences from relatively inexperienced students.

The interviews were divided in two parts. The first part focused on how the students describe and communicate materials and has been used to elaborate on, how students articulate materials. The second part focused on how students saw materials as part of their practice and on their expectations of the materials teaching they were going to have or what had been missing and has been used to elaborate on what students want to learn.

In total eight students were interviewed. A schematic overview with information of the eight interviewees is provided in Appendix [A4] that also includes Danish transcripts of the relevant parts of the interviews. All interviewees were female, between 22 and 26 years old and had graduated from high school (STX) with A-level courses in combinations such as language and drama, social studies, English and Spanish, Latin and mathematics and social studies. None of the students had taken A-level high school courses in chemistry or physics. This is mentioned, as the orientation and depth of the materials courses are influenced by the students' competences. The eight interviewed students are not necessarily representative of the students at the school in general or their opinions, and the students chose to participate in the interview, meaning that they may have had a special interest in materials or other incentives to take part of the interview. Nevertheless, the interviews served discover some apparent trends and tendencies among the students.

Interviews and exercises

The first part of the interview was structured as two small exercises where students were asked to describe materials in their own words. In the first exercise, students described a material they had brought themselves (for examples of materials, see figure 60) and in the second exercise, students described a material selected for the interviews (see figure 61). The material in the second exercise was the same for all interviewed students. In both exercises, students were asked first to describe the material while only looking at it and then to adding to the description when having the material in the hands.

The two exercises aimed to show how students approach familiar versus unfamiliar materials and to explore general characteristics of, how students approach and describe an unfamiliar material. The students' approaches are demonstrated by two examples for each exercise as well as generic observations based on the interviews. It establishes a foundation for discussing differences in articulations of familiar and unfamiliar materials and on how the comments and observations have benefited the development of a materials teaching methodology. The interviews were conducted in Danish and have been translated in the thesis. Here they are documented as quoted conversations, complemented by reflections and thoughts during the interviews.

Exercise 1 - familiar material

The first student [S1], a second year industrial design student had brought her phone and chose to describe the back plastic component of it (see picture to the bottom right in figure 60). The material was first described is as 'dark grey, hard plastic that looks rough' and 'like there is a foggy effect on it'. She continued saying that "it looks soft, but at the same time, especially considering the product, you know that it is hard (…). Still, because I know how it feels, I really want to stroke it" (she laughs). Hereafter she was allowed to take the phone in her hand and it was asked, if there were additional things wanted to add. She highlighted the contrast between the roughness and smoothness and said that "you get this feeling that it does not slide and it would not just fall out of your hands. I have thought about the fact that it is a relatively fragile object". It seemed relevant to make her elaborate a

Figure 60. Material examples from the student interviews.

bit more on her reflection on the company's incentives to make the surface rough and she was asked if she had though about the durability of the phone and how the material choice corresponds to its use. She answered "I have thought about, if the surface makes it more dirty. I believe it does. I'm often accused of having greasy fingers, so I thought 'ohh no!' However it is plastic and you can wipe it off if necessary. The holes that make it rough are not big, so even though there is some friction it is still relatively smooth". Being an industrial design student it was also interesting to explore if and, how much she had thought about the production of a component like this. To this she answered that she hadn't given it much thought and continued with "I do not know. Maybe it has been sandblasted. I do not know anything about it yet. You cannot feel this print (points at a detail that is less rough), so maybe it has been dyed. There are details that are smoother, so even though you get another impression you can feel that it is hard plastic. I wonder if the soft areas are just a surface that has been added".

The second student [S2], a second year fashion and textiles had brought a hairy textile (see picture to the left top in figure 60). She described the material as "a kind of fur or as an attempt to make a man-made fur that has gone so wrong. It looks very plastic and almost like a ball of yarn attached in lines to a basis fabric that make it shine and stick together". Having the material in her hands, the student added that "it is very soft and it separates when you touch it. The way the stripes are attached looks like a magnified head from a Barbie doll!" The student seemed to reflect on the appearance of the material she had brought with her.

Therefore the comment she added when a picture was taken of the material was interesting. Here she said, that she had just realized when entering the door to the room (my office, containing several materials), that materials are so much more than textiles. She had taken for granted that she should bring a textile, but materials could be everything from wood to rubber. This comment has been included as it indicates the typically limited assumptions made about the kinds of materials that are relevant for different design disciplines.

Discussion on articulations of familiar materials

From the interviews a number of general trends have been extracted. There was a great variety in the aspects students highlighted. Students were good at reflecting on sensorial and associative material aspects and in cases where materials had been applied in a product. This also included the experiential incentives for choosing the material. Nevertheless most students needed guidance with follow-up questions to go in greater detail into experiential materials descriptions. However in general students did not use technical vocabulary when they described their materials. I tried to guide students in this direction by asking how they thought the materials had been manufactured and processed, and the technical and functional reasons for using the material, but this did not seem natural to them. This indicates that students are well aware of and trained in articulating experiential material attributes, but not in articulating technical material attributes and how they relate.

In the interviews, fashion and textile design students seemed to put more emphasis on material construction and composition than industrial design students. In contrast, industrial design students put more emphasis on functional material aspects. Similarly the industrial design students brought materials that were applied in a product, while the fashion and textile design students brought materials (textiles) without any application. Hence, it seemed easier for the industrial design students to reflect on materials in a given context and as part of a product. This demonstrates one of the differences between the fashion, textiles and industrial design programs, the traditions they build on and the professions the students are being trained to follow It also demonstrates why it is risky to ‘black-box’ the learning environment in artistic design education as one homogeneous community with identical practices and mindsets. Textiles design is based on the practice of making textiles, requiring knowledge of the construction and composition of a material but not necessarily focusing on the application. Industrial design is by tradition using materials in products, requiring specific knowledge of the functionality of a material in a given application. In both disciplines materials can be used as drivers of development or as means to realize a product.

Exercise 2 - unfamiliar material

Figure 61. The two ZenXit samples used in the exercise. For more pictures, see http://www.gabriel.dk/en/business-units/zenxit-as/gallery/

In the second exercise the material given was ZenXit, a recently developed material from the Danish fabric manufacturer Gabriel. The material is an open-structured polyester web with high elasticity developed primarily for upholstery products (“Zenxit,” 2014). For the exercise the material was provided in two versions with different density and size. The material was chosen because its simplicity, being a white, airy mono-material yet with unexpected properties, often surprises people. Furthermore it can be applied in fashion, textiles as well as industrial design and it was thus expected to be a material that all students could relate to. From the interviews, responses from two students are included that pinpoint some of the common observations from the interviews.

The first student [S3], a second year fashion and textiles student, did not know the material in beforehand “I do not know this material. It is very shaped [formgivet] and not at all flexible as a material for clothing like this is (she points at the material she brought herself and just described). It is almost…it is composed of all these small threads…plastic…that are melted together. It is…it is not…there are something with these words…I am not really good with words and remembering some of those things, but it feels like something you would use more for construction than something you relate to in clothing and interior design. (…) Er, I guess, I would say it is durable [slidstærkt] in the way that the individual parts…yeah, you can tear them apart, but together they are shaped to resist more. It is a very funny and experimental material...very contemporary in the way we try to find new solutions to make…or maybe to replace former things. (…) You almost want to believe that it is a sponge. There is something sponge-like about the way it reacts. It kind of pops out again when you release it.”

To continue her reflection and elaboration she was asked, how she imagined the material had been made. She replied, “It is definitely something with heat that bonds these threads. But first…I would almost say that it is a kind of silicon that has been made first and thereafter shaped in long threads and mixed, heated and pressed. That is my first guess (…)”. Her guess was incorrect, but that was of little importance. However it was interesting to observe the strength of her argumentation and the effort she put into describing more technically oriented aspects of the material even though she already stated that she found it really challenging.

It was an interesting way of articulating materials and to gain more insight. She was told that one of places the material had been used was in hospitals and was asked, if she could come up with reasons for that. She answered: “it is because the material is yielding [givende]. There is some softness, but it also becomes solid again. It supports the body. And there is probably also a hygienic aspect in the way that bacteria maybe have difficulties in being absorbed in the silicon or plastic. It also makes really good sense that it is for a sterile environment, but it also provides some tactility. It is not just like…they have definitely thought broader than the things hospitals generally use (…) It also offers something other than (only) for mattresses. It gives some kind of life. It is pretty funny".

The second student [S4], a third year industrial design student, had seen the material before, but she did not know what it was and what is was used for. In her description of the material she said: "it is not so nice…but the organic feeling is very nice. It is very flexible, because it is so porous. But the fact that you can sense what the material is, makes it less pleasant to be in contact with. It is very plastic-like. I start thinking of some kind of mattress, because I presume that it needs some wrapping, if…well…I just think that it could be something you can lie on. I do not know why. But it is probably an inner material, an insulation material (…). It is a very light material." When being told that the material comes by the meter [metervare] she continued "when I try to imagine what it can be used for in larger scale and how it is sensed, I think about insulation or something to lie on. Or if you have something that you do not want to be damaged. (…) I do not know if it is more or less porous than a foam mattress. Spontaneously I think more material, because a foam rubber particle…no not foam rubber…what do you call that? A substance. Such a particle is maybe not as powerful, so it needs more volume to provide the same shock absorption. But here the material itself is more powerful and therefore less material is necessary to do the same…maybe."

Discussion on articulations of unfamiliar materials

The two interviews highlight an interesting and essential aspect when approaching unfamiliar materials. Whereas the first student [S3] was very straightforward in her thoughts and ideas, the second student [S4] was more wavering in her descriptions and seemed a bit insecure. Nevertheless the second student [S4] ended up with a very telling and precise description of the material, immediately reflecting on the material's performative aspects. This difference can originate in various things. One is that, being a third year student, the second student [S4] have had one more year's training than the second year student [S3], which very likely has developed her way of reflecting on things. Another is that people respond to unfamiliar situations differently.

In his work with methods use, partly in design education Daalhuizen has identified four types of students based on how they approach new methods (Daalhuizen, 2014). The categories are: 'on top of things' (1), 'swamped, yet striving' (2), 'indifferent and disconnected' (3) and 'lost faith' (4) (Daalhuizen, 2014: 136f). Describing an unfamiliar material is not a method, but the characteristics Daalhuizen describes can be linked to students' personalities in the same way as in the interviews. This means that it is necessary to acknowledge that students act differently and approach exercises and tasks in various ways and that the learning environment has to embrace all personalities and meet their needs. In general students found it easier to describe materials they were familiar with, as they could associate the materials to applications, techniques and raw materials more than for the unfamiliar material. Nevertheless, students were more open-minded in describing and reflecting on the unfamiliar materials. Because students had limited prior understanding of the material, they were forced to be imaginative and approach the material more objectively and analytically.

In addition to this aspect, other significant features can be extracted from the interviews. None of the students knew the material in beforehand. Some had seen it before, but did not know, what it was and what it was used for. When asked, they found it difficult to come up with potential applications and the ones suggested were primarily in the building industry, such as insulation. However, when being told that a material application was for mattress pads in hospitals, the students could argue for this based on physical and experiential material attributes. Hence, the students seemed able to translate their intuitive experiences to the material application.

What do students expect from the materials courses?

According to the interviews there are as many approaches to teaching materials, as there are students. Some students like lectures on technical material aspects, while some prefer to experience materials in practice and to increasingly be able to link materials and material attributes to specific applications. Some students would like to get more detailed information about materials, while others think they get too much information. Common to all students is that they find materials important for their design practice and they like to work with materials. The majority of students had either had or was about to have the first Materials Introduction course and they were not expected to have much prior knowledge on materials. It is difficult to know something if you do not know that it exists, so the enquiry served more to investigate the level of materials awareness among students and if and how they regarded the role of sustainability in materials teaching.

Based on the interviews it is evident that many students find the materials field overwhelming. It is not possible to make it less overwhelming, but it is possible to develop materials teaching that can help students navigate in it. From the interviews it was also evident that students find that they have to be attentive (in materials lectures) in order to obtain sufficient knowledge, and that they find technical material terms challenging to navigate. This points at the multifarious dimensions materials in design entail and this is introduced in the materials courses. Even though artistic design education puts emphasis on experiential aspects of materials, it is necessary also to be accustomed to the technical aspects in order to design products that function properly. Through their practice, students are used to consider technical aspects, but lectures with dense information flows are a different learning format. The above comments can be underlined by an example from the Materials Introduction course for fashion and textiles students in 2013. After a lecture I talked to a group of students about the relevance and importance of the lecture's topic being test standards and quality controls. During the lecture, it was evident that students found it difficult to keep concentrating. The students knew this, but they also recognized the importance of the topic and appreciated the lecture even though they found the lecture format challenging. The underlying concepts of material standards are usually relatively simple to comprehend. Tearing strength tests provide knowledge of how easy it is to tear a material apart; light fastness tests indicate, how colors change due to external stimuli; and fire tests reveal how materials respond to fire. The challenge is therefore to provide lectures and practical exercises that make students link material properties to test standards and material requirements relevant for their applications and to facilitate the construction of a vocabulary that enables students to communicate the common material properties.

Some students highlight that they would like to learn more about new materials and techniques that cannot be explored in the workshops. The use and challenges with emerging materials was briefly described in the enquiry on what students know (see p. 141ff).

Sustainability in education

Only a single student commented on materials teaching and sustainability in the interviews. She stressed that it is good to debate sustainability, but the focus often seems to be distorted and students are not always asked to question whether it even makes sense to consider sustainability aspects for the given project.

Sustainability is one the three pillars of the Design School Kolding's strategy, but there is a common agreement that it is still not well enough integrated in the curriculum. As input to a report documenting the 2014 Copenhagen Fashion Summit that was published in the spring 2015, it has been stated that Design School Kolding "believes that sustainable futures must be created through cross-disciplinary teamwork; thus a range of design methods and theories are introduced to encourage critical thinking as well as navigating between utopia and the reality of business" and that "the curriculum will in the future include sustainability issues in most courses" (Copenhagen School of Design and Technology, published spring 2015). The last statement has been evident in the recent modifications of the curriculum (as of the fall semester 2014).

In order to develop a sustainability teaching strategy a group of organizers, teachers, researchers and students from fashion and textiles design is holding ongoing meetings. In the fall 2014 there was one of these meetings. Here the main topic was how the curriculum can facilitate sustainability as a holistic perspective rather than keeping specific initiatives in different courses. One of the participating students commented that it felt difficult to take sustainability into account and for many students, sustainability paradigms were ignored soon after the courses (for example Materials and Sustainability) had ended. Another student, who was due to graduate in summer 2015, added that it was not until recently sustainability made sense to her. The result was that in her last project, she had developed a textile collection for children with emphasis on sustainability aspects especially concerning production and disposal of the materials included. Her comment pointed very well at one of the main challenges with the integration of sustainability in design education, namely that because sustainability can be approached in so many different ways (cf. the hierarchical perspectives model in Chapter 4), it requires substantial insight in design practice, experience with design processes, and having established an independent design identity before sustainable considerations are not too difficult to incorporate.

DEVELOPING METHODS FOR LEARNING MATERIALS

The three previous parts of the chapter have elucidated different angles on learning about materials and premises for teaching materials at Design School Kolding. They have identified challenges with the present materials teaching that have been the central focus for the subsequent progress of the project.

It is evident that, due to changes in the curriculum and the organization, that generate new conditions for teaching, it is appropriate to reconsider the format of the materials courses. The consequence of introducing more components in the modules is that all the components will get less attention. This also includes students' material teaching and practice. It means that instead of lecture-heavy classroom teaching or teaching based on individual dialogues with students, the materials courses should increasingly provide structures for students to explore and work with materials individually and in groups. The courses should prepare students to undertake systematic investigations of materials and applications of relevant materials in design projects.

To establish a more structural materials teaching methodology, it was essential to understand how the materials selection matrix had been used as a means to identify material requirements and materials, and how it had been used as an assessment tool. In Chapter 5, differences between tools and methods were described (p. 103). Here it was argued that tools are 'devices or implements used to carry out a particular function', while methods are 'particular procedures carried out to accomplish something' and here interpreted as the overall procedural frame for tools to be used. The assessment of the matrix is a tool, but the matrix as a structural procedure is a method that also include just as important components such as identifying relevant material requirements based on for example user studies, moodboards and idea generation and identifying relevant materials based on the ability to navigate in the material landscape. The acknowledgment of the matrix being a method and not a tool calls for a different use of the matrix that activates more reflective and explorative aspects of the material selection practice.

In Chapter 5 and Chapter 6 it was emphasized that methods have to be understood and supported in order to function properly. If not, methods can provide a 'false security'. In the further exploration and development of the materials selection matrix, it is emphasized that the process should be transparent and customizable for the individual student to contain the risk of uncritical use. It is further acknowledged that the method needs to be supported by follow tools and methods that can help students to for example discuss material requirements and identify relevant materials for assessment. A more defined structure of material exploration tools can strengthen combinations of tools that explore materials in different ways.

The next chapters cover the development of the matrix in two iterations. Chapter 8 describes the first iteration conducted in the Materials and Sustainability course at Design School Kolding in the fall 2013. As the experiment was conducted within the same domain as the preliminary study, it was possible to get first hand experience on the appreciation of the modifications. Chapter 9 describes the second iteration conducted in a 'Materials for Design' course at Faculty of Industrial Design Engineering at Delft University of Technology in the spring 2014. The experiment was conducted in a different domain (i.e. in another course and with different student profiles) and served to explore, how students with a more technically oriented design syllabus would use and appreciate the matrix differently.

Between the two studies the setup for the matrix was modified and further formalized. It was therefore not possible to perform a direct comparison between the two domains. The modifications of the matrix have been described between the two iterations in the end of Chapter 8 and in the beginning of Chapter 9.

CHAPTER SUMMARY

This chapter has covered the initial experience and observations about materials teaching at Design School Kolding and the materials selection matrix. First the empirical learning environment was introduced focusing on past and present materials courses. Thereafter the preliminary experiences with the materials selection matrix were discussed before continuing to consider its background and components. The last section expanded students' material competences and mindsets based on the three questions: what do students know?, how do students articulate? and what do students expect from the materials course? The initial experiences and observations have established the foundation and supported the further development of the matrix and the methodology, of which it forms a part.

Summary

- Students find it easier to recognize conventional than emerging materials.
- Students find it difficult to grasp experiential and sustainability aspects of materials and they primarily consider material attributes related to products' use phase.
- Students are in general good at describing materials, but they find it easier to describe familiar than unfamiliar materials.
- Students show different characteristics when communicating materials and can be categorized as either the straightforward student or the weaving student.
- Three design engineering models have inspired the materials selection matrix: the House of Quality, the Harris Profile and the Pugh Matrix.
- Understanding the material selection matrix as a method rather than a tool can strengthen structured material explorations.

8. MATERIALS EXPLORATION - FIRST ITERATION

This chapter is in two parts. The first considers the first iteration of the materials selection matrix and describes how the matrix has been approached, compared to the preliminary study from the year before, it identifies topologies of requirements, materials and grading and discusses the findings. The second part introduces supporting tools as means to support the matrix in materials teaching and is based on the findings in the previous studies. The tools serve to make students more aware of the multiplicity of material attributes used to assess materials, and capable of navigating the complex material landscape through reflective and exploratory activities. The supporting tools also bring along additional theories that supplement value creation and meaning creation processes in particular, as discussed in Chapters 4 and 5.

USING THE MATERIALS SELECTION MATRIX

The first section is partly based on the paper: 'Development of the Material Selection Practice in the Design Education - A Study exploring Articulation of Material Requirements' (Hasling and Lenau, 2014) [P2]. The study was conducted in two three-week long Materials and Sustainability courses for respectively industrial design and fashion and textiles design for third semester students at Design School Kolding in the fall 2013. Both courses were conducted as design projects emphasizing sustainable solutions for camp life situations and began with an outdoor one-day camp that aimed at making students experience camp life personally. In the industrial design course eleven students worked together in four groups and in the fashion and textiles design course 22 students worked together in eight groups.

Unlike the previous year, the Materials and Sustainability course had been split into fashion and textile design and industrial design modules to address the respective disciplines of the participating students as well as to put more emphasis on experiential material attributes, sustainability issues and how material attributes interact. The courses also introduced some of the supporting tools.

During the course and in following assessment surveys, students highlighted the influence of the camp for their engagement in and relating to the given assignment. The camp also gave them an opportunity to discuss sustainability aspects more loosely around a bonfire and for students to collect materials and ideas for their assignments. Additionally a sales assistant from the Danish outdoor products store Eventyr Sport (Eng. Adventure Sports) had visited the course. He brought a selection of goods and presented the main factors in product design for goods for outdoor use.

The materials selection matrix was introduced in the end of the first week with a short lecture on its concept, its process and with examples from previous projects that had used the matrix (for examples of previous matrices see figure 51-55). In the introduction both unfilled and filled matrices were covered and different ways to use the matrix were presented and discussed.

After a week, students were given the opportunity to present their initial work and preliminary matrices were collected for a guiding analysis. The analysis was used to highlight a number of aspects the students should pay more attention to in their subsequent use of the matrix.

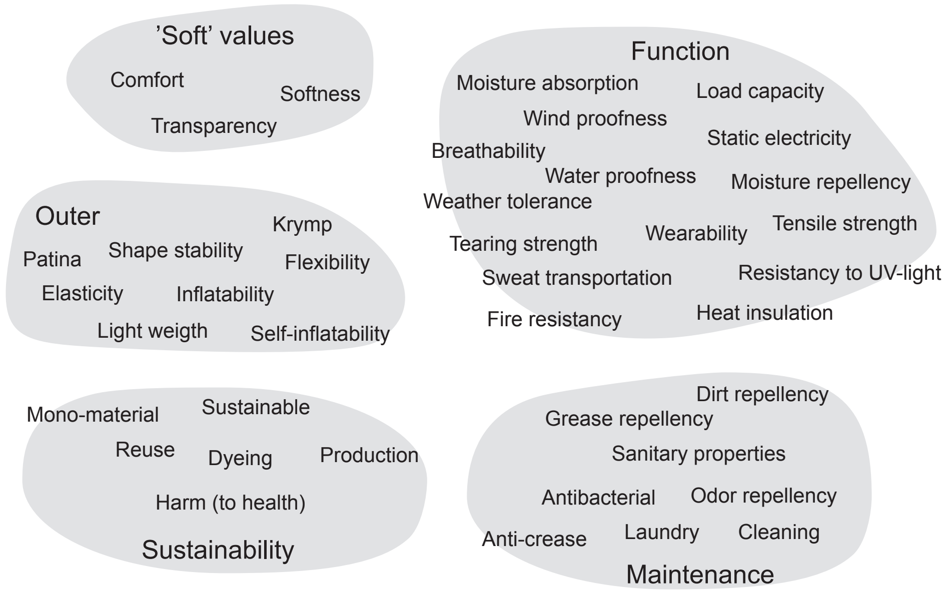


Figure 62. Cluster diagram with the 39 material requirements from the preliminary matrices in the fashion and textiles Materials and Sustainability course.

Figure 62 provides example of requirements used in the preliminary matrices from the fashion and textiles students. From the matrices 39 distinct material requirements were extracted and grouped in five clusters being: 'immaterial values', 'outer', 'sustainability', 'function' and 'maintenance'. The clusters were used to show to the students how they identified requirements relating to function and maintenance, and how they should emphasize more on experiential values and sustainability considerations for their final matrices.

In the final matrices, nine groups from fashion and textiles had identified 131 different requirements. Two of the groups had worked with products with more than one material component and had made matrices for each component. Consequently, averages of 14.5 requirements per group and 11.9 per component were identified. In the industrial design course 96 requirements were identified for four products, all of two components each. This gave averages of 24 requirements per product and 12 requirements per component. In the course in 2012, six groups identified 64 requirements for seven components (an average of 10.7 requirements per product and 9.1 requirements per component). From all the three courses, a total of 291 requirements, of which 120 were distinct, were identified. For an overview, see table 8.

Table 8. Overview of identified requirements in the course from 2012 and 2013.

	Groups / components	Requirements
Mixed course 2012	5 / 6	64 (average 10.7)
Fashion & textiles course 2013	9 / 11	131 (average 11.9)
Industrial design course 2013	4 / 8	96 (average 12.0)

Analysis

The following analysis of the matrices has focused on two aspects: 1) the kinds of requirements used and 2) the structure of the matrices. It was found that there was little difference between the matrices from the two years, which was partly expected, as the bases of the matrices were more or less the same However it was expected and hoped that students had put more emphasis on experiential and sustainability aspects. Because the matrices were similar, the results from the courses have been combined in a joint analysis and discussion.

Requirements

Modifications in the course curriculum did not seem to have an effect on the technical orientation of the requirements identified. Fewer than nine requirements could be characterized as non-technical. These were 'softness', 'comfort', 'tactility', 'Aztec appearance', Inuit appearance', 'smoothness', 'patina', 'signaling effect' and 'trend appeal'. A larger number (30-35 requirements dependent on how sustainability is approached) accounted for sustainability issues, typically combined with a product life cycle structured matrix. Requirements were predominantly related to either production (raw materials, energy consumption, manufacturing processes etc.) or practice in use in terms of durability and maintenance (such as mechanical, chemical and thermal properties).

Structures used

The majority of matrices show no structure and requirements are seemingly randomly selected and distributed, while few matrices have structured requirements based on the product life cycle, grouping requirements in terms of for example raw materials, production, use and disposal. Requirements in the matrices are commonly divided into functional/technical and sustainability assessments properties (also technically oriented) and only two groups have assessed materials using non-technical properties.

A more comprehensive analysis of the matrices was conducted and the study can be found in Appendix [A6]. Here supplementary findings are included such as that both conventional and emerging materials are identified for materials considerations and that the difference in kinds of materials do not vary much between respectively fashion and textile design projects and industrial design projects. In the study three grading strategies have been identified, being 'numerical grading', 'meta-numerical grading' and 'descriptive grading'. Numerical grading corresponds to using numerical values (such as 0 to5 or 1 to 10), meta-numerical grading corresponds to using signal values (for example green to red or emoticons such as unhappy to happy smileys) and descriptive grading corresponds to using descriptions as grading.

Discussion

The students were introduced to the matrix in a lecture that presented the purpose and structure and with examples of matrices from previous courses. It was emphasized that students should be encouraged and given freedom to customize matrices, to make them reflect on the components and functions of the matrix: what it does, and what it can be used for. Therefore many different versions of the matrices occur.

The general feedback from the course was that students find the topic 'materials selection and sustainability' overwhelming and being required to reflect on and discuss materials selection in a structured manner appears to be difficult. Students are challenged in multiple ways in the course. They are introduced to a structured decision-making method that forces them to explore new procedural ways and to reflect on their choices. Moreover they are introduced to a complex world of materials that can be fascinating, yet frustrating and chaotic to navigate. Finally they have to do this within the boundaries of design for sustainability, which in itself can be a challenge even for the trained designer.

Their difficulties correspond to Daalhuizen's studies on methods use that find that in non-routine situations, the need for guidance and structural methods is higher (Daalhuizen, 2014: 65). In fashion design education it can be further supported by Faerm, who writes that the future role of fashion designers will require the ability to perform deeper levels of research in order to support design proposals (Faerm, 2012: 217). The liberal and open-ended introduction to the matrix was appropriate for an era when the material landscape was less complex, when teachers had more time for the individual students in the courses, and when the emphasis on sustainability was different. In present design education the premises are different.

With a time limit of three weeks, students expressed the need to have time afterwards to reflect on using this method and further explore sustainability on their own. Their limited material knowledge and the small number of lectures given in the course are to some extent advantageous, as students are encouraged to be open-minded and explore different kinds of materials without being (too) restricted by prior assumptions. Nevertheless it is also a challenge, as students tend to hold on to what they know already. The setup corresponds to the active and interactive learning schemes and to experiential learning (see pp. 82-83). Here students are learning through experiences in the given learning environment through interactions with other students, lecturers and objects in practice. Nevertheless there seems to be a conflict in the way students are expected to learn and the content of leaning, and that active learning can be difficult to apply for technical setups before students have acquired a certain level of knowledge that enables them to navigate more freely. There is also a conflict in the time available in courses and the time students need to make sense of new methods and new topics such as sustainability. In the courses students start to make sense and gain experience, but there is insufficient time allowed for students to master these.

This suggests that the format for the materials selection matrix as a method should be revised to provide a structural frame that supports materials selection and that help students to identify requirements and consider materials. However the materials selection matrix should also allow students to make sense of the method and its components in order for them to see the value in it. This further includes a method that should support students in developing a vocabulary covering technical, experiential and sustainable aspects.

Based on the above considerations the materials selection matrix has been supplemented with supporting tools that serve to support students to overcome the identified challenges. This puts emphasis on the necessity of providing materials teaching that activates students' different mindsets with tools and methods that are developed to supplement each other.

SUPPORTING TEACHING TOOLS

The previous section demonstrated benefits and challenges with the materials selection matrix. The challenges implied that it was appropriate to refine the matrix itself or the teaching methodology it was part of. Focus has been put on a materials teaching methodology, where the materials selection matrix is one of the core components. Additionally it has been proposed to introduce a number of tools to support the materials selection matrix to provide a more transparent and reflective structure, to contextualize experiential and sustainable aspects better and increasingly to explore the material landscape and articulate material meanings.

The thesis proposes four tools that in different ways provide supplementary information to the matrix. The tools have been developed in accordance with the proposed materials teaching methodology. The first tools, a 'personal materials collection initiative' and 'educational materials descriptions' serve to enhance the accessibility and availability of materials, while the last two, the 'comparative material scale' and the 'Hanger model' serve to deepen students' ability to translate materials' meanings to provide more transparent understanding of materials. The tools have been used to a different extent and are based on differing theoretical foundations. This means that the following discussion will vary in detail.

Enhancing access to materials

The tools introduced to improve materials transparency explore the influence of more accessible materials and information in the learning environment and for the individual students. The tools build on the belief that a certain level of information has to be available in order to start making individual mental constructs and making sense of different kinds of stimuli. It means that students have to have access to base information that experience can build on, but also that they should given tools that can help them with making sense of the input.

The two tools have been introduced in the Materials Introduction course for three years. Each year the format of the course has varied and therefore it has been difficult to present coherent findings. The next sections will introduce the tools drawing on previous experiences.

The personal materials collection initiative

Materials access in learning environments can take different forms. Among organizers of disciplines [faglige fyrtårne], workshop managers and lecturers, the common agreement at Design School Kolding was that students should have access to a materials collection. Nevertheless, it was difficult to agree on the form it should take. The educational disciplines find various materials and information relevant, but the common agreement was that if there should be a materials collection, it should be established in-house. Such a collection should either embrace all disciplines or consist of smaller collections for each discipline.

Table 3 in Chapter 6 (see p. 114) presents a survey on four materials collections for design education with focus on five aspects: whether students could borrow materials, commercial interest, access to digital database, student integration and open access. None of these solutions was satisfactory, as all would require either too much space, too much time or too much money. Instead it was agreed to support students in making their own personal materials collections, initiated and developed in the materials courses.

The collections primarily serve to provide means for students to document and index materials collected and developed during the course. The collections were built on active and experiential learning strategies highlighting that the learner may shape inputs in order to ascribe meanings to the materials. This means that students should be able to customize and interact with the collection to become more familiar with it and to make it part of their practice. The personal materials collection should provide a framework to develop on and the desire to seek inspiration from it. As a result the personal materials collection has been introduced as a relatively minimalist template that students were encouraged to modify for their own needs.

The template was inspired by the four aforementioned educational material collections as well as physical and online-based commercial material collections and libraries such as Materia (2014) and MaterialConnexion (2012). A survey on selected commercial materials collections and libraries looked at the kinds of attributes used to describe materials (see appendix [A7]. These have also inspired the categories in the template. Using the template students can label, index and store materials in their own materials 'bank' to be used and developed, first as part of their education and later in their professional lives.

When students have been responsible for collecting their own materials, they have (consciously or unconsciously) considered why a given material was relevant and interesting for her/his practice. It means that students, just collecting a material, have acquired valuable (insights into) material meanings. This corresponds to the first two steps of Bloom's taxonomy of learning being knowledge/remembering (1) and comprehension/understanding (2) (see p. 85). Therefore it is also clear that students should be provided with tools that can support the use and development of the collection.

Collecting and indexing materials as part of design education are not new concepts. Establishing materials collections has previously been part of materials courses and in other, primarily practice-oriented, workshop courses, in which students have been required to document, how materials have been produced or treated. An example is a collection of organized knitted samples of basic models that students had made previously, as part of the introductory course in knitting, and this now has been reintroduced. Similarly in the past, students made structured weaving samples allowing them to experience the dynamics and influences of fibers, yarns, bonds and machinery on textiles. Also in print, samples of colors, materials and techniques were collected in a structured way. The previous systems were disturbed following reorganizations and cutbacks in budgets. Thus a new systems needs to be put in place.

Advantages of personal materials collections include for example, that students create materials collections customized for their individual needs and interests; and being encouraged to develop the collections, students develop their own structured ways to consider materials in their environment. The fact that students have a template to structure materials makes it easier to create links between materials and to communicate materials in courses and to other stakeholders. Thus working with the materials collection entails both internal sense making through personal mental constructs that link materials to experiences and external sense making through the negotiation of meanings with others. Students can include materials from their own projects creating stronger links between theoretical and practical courses based on personal values. Moreover, materials collections can function as a shared platform for materials that are introduced and created in other courses and therefore function as a part of the holistic use and understanding of materials at Design School Kolding.

However, there are also challenges. These primarily relate to how you make sure that students use the collections in their practice, that the right material information categories are provided and that you offer adequate flexibility in a template starting from first principles, but also addressing students with different interests and needs. You also need to make sure other lecturers and workshop managers encourage students to apply the template in their courses, if the value of the collection should be fully exploited. Until now the challenges have not been fully resolved, but they have been taken into account in the development of the template.

First time testing the material collection template

The materials collection template has been received both positively and negatively. Negative experiences generate just as much and valuable knowledge as positive experiences and in the presentation of the progress of developments both positive and negative experiences are included. The personal materials collection initiative in its present format was first presented in the first week of the Materials Introduction course in the spring 2013 with initial thoughts presented in the poster in [P6].

Despite the good intentions, the first introduction did not work as planned. The template as presented included information on the 'commercial/trade name', 'chemical name' (if applicable), 'manufacturer' or 'supplier', 'material category', 'physical properties', 'experiential characteristics' and possible applications of the materials. The template was provided with ten samples to establish a preliminary collection with. The ten materials were cork, two woven paper textiles, stone paper, 3M optical foil, Tyvek, plain cotton weave, PLA foil, PVC plastic tube and expanded polystyrene [Flamingo]. The selection provided students with both conventional and emerging materials as well as familiar and unfamiliar materials. Two materials were examined in plenary session and students were asked to continue to include and describe materials according to the template in the rest of the course.

After the courses, students' overall comments were that they found it relevant to be guided in establishing their own materials collection but they found it difficult to embrace the complex content of the template simultaneously with getting to grips with unfamiliar materials. Consequently many students had not described the materials or the information was inadequate. What happened can be described as a combination of different obstacles.

The template presented too many unfamiliar concepts that cause students to feel insecure and the necessity of understanding the concepts became a barrier for the future use of the template. The template was introduced with ten materials and that seemed to be too many, because the students did not have any relation to the materials and therefore found it difficult to describe it using the concepts in the template. The materials were deliberately both conventional and emerging. Nevertheless the textile students especially asked for a collection with fundamental textiles demonstrating different fibers and bonds, which was in contradiction to a hypothesis being that students are predominantly attracted to emerging materials with certain functions. This was further highlighted from the student interviews elaborating on knowledge, articulations and expectations, where it was discovered that students expect to be introduced to conventional materials in the materials courses. Here it was also stated that even though much attention is given to emerging materials, students are aware that they have to acquire a certain level of knowledge concerning conventional materials to explore more unconventional and emerging materials.

Second time testing the material collection template

In the next iteration of the materials collection initiative, the template was introduced less formally and served primarily as a way to collect materials from industrial visits and structure materials for the design projects in the industrial design Materials Introduction course in the spring 2014. The material collection was introduced by the lecturer in the course, so the main findings are based on the final presentations of the student projects and course evaluations. In the presentations, students had to present their work with the collection and propose how they would continue to develop it. In the course evaluation students were asked which parts of the course they would have like to spend more time on. Here 54 % of the students (seven out of thirteen) answered that they would have liked to have more time to develop their personal materials collections (Hasling, 2014). This can be regarded as good indicators for students' interest in using personal materials collections actively in their education and later on. Similarly, 54 % of the students would have liked to have more material lectures and many requested more focus on conventional materials such as wood, metal and ceramics as well as traditional manufacturing and fabrication techniques (Ibid.). Examples of preliminary materials collections are shown in figure 63. The examples were photographed at the students' work desks and were therefore not prepared for presentation.

Figure 63. Examples of material preliminary material collections in the industrial design materials course (spring 2013).

Third time testing the material collection template

In the recent iteration in the Materials Introduction course for fashion and textiles in January 2015, using the personal materials collection became part of the required learning output of the course. The template was simplified to adapt to the challenges experienced from the first iteration and was developed in collaboration with teachers and workshop managers in the school's textile department. In the modified version the template contains room for a physical material sample, an ob-

Figure 64. Examples of material collection cards made in the materials course.

jective description of the material, four check boxes indicating the construction of the sample (woven, knitted, warp-knitted or non-woven) and a subjective description of the material. Students were given to time to use and modify the template as part of the course, using textiles supplied specifically for the course (typically mono-materials and basic constructions) and with access to guidance from lecturers. It gave students the opportunity to reflect on what kinds of information they find essential and how they would like to use the collection in the future. Examples of filled in materials collection templates are shown in figure 64.

Materials descriptions

Simultaneously educational materials descriptions have been developed to improve the accessibility and user-friendliness of information available for common and explorative materials students work with. From teaching situations, dialogues and feedback from students, it appears that many students find it difficult to grasp the material information found in much literature and to distinguish between relevant and irrelevant information. To make information more accessible, it was therefore proposed that design students should make materials descriptions for other design students.

Materials descriptions have been introduced as a supplement to the personal materials collections and as easily accessible means to acquire materials information. As for the materials collection the format for the materials descriptions has varied over the three years it has been introduced. In all iterations it has been based on a formal template comprising ‘material name’, ‘material type’, ‘chemical composition (if applicable)’, ‘description’, ‘properties’, ‘production and process’, ‘examples of use’ and ‘pictures of typical applications’.

In the first year in the spring 2013, students had to hand in one A4 sheet each with a material description, which was then distributed to students in the class afterwards. In the second year students presented chosen materials as part of their final presentation. In the present material course for fashion and textiles, materials descriptions have become part of the overall assessment. As the amount of descriptions grows, the collection is to be found in the in-house area for materials and support published material information with material information customized for students, in a language familiar already used by the students and with relevance determined by another student.

In the first year, students were asked to described one of the materials they had analyzed or considered in their design project. The described materials included Greensulate (“Ecovative,” 2015), glass fiber, Agriplast (“Agriplast,” 2014), plywood, polyethylene, polypropylene, rubber, polyamide, ABS and aluminum. In figure 65, descriptions for glass fiber (left) and Greensulate) are included.

In the second year in spring 2014, students made descriptions on thermoplastic elastomers (TPEs), Arboform (“Arboform,” 2014), porcelain, carbon fiber reinforced polymers, Sugru (“Sugru,” 2015), aluminum, polycaprolactone (PCL), bio-PE and PA-6.10. The materials descriptions have now become parts of the final assessment of the course and have not been accessible for this study.

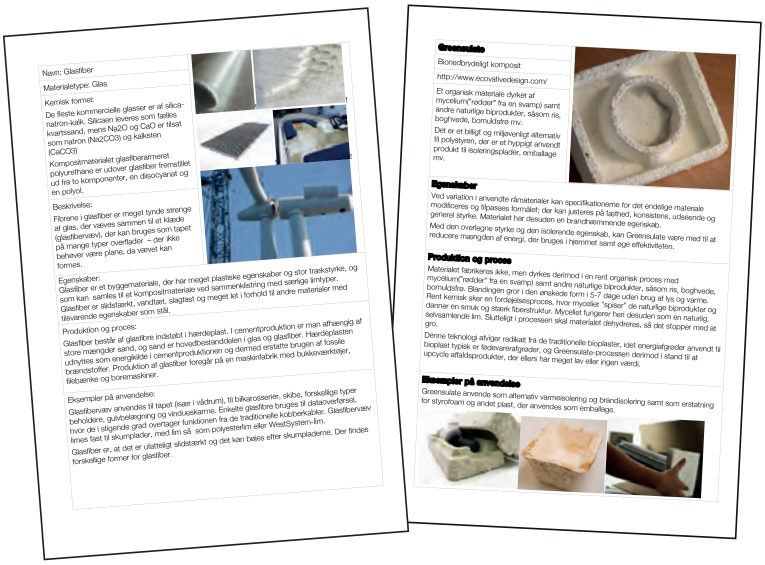


Figure 65. Examples of material descriptions from the course for industrial design (spring 2012). The two examples describe glass fiber (left) and Greensulate (right).

The descriptions showed to be a good way to introduce and communicate materials and comprise both conventional and emerging materials. The benefits are that descriptions are easy to integrate in the curriculum and they are applicable for materials as well as for techniques, functions and manufacturing methods. It means that materials descriptions can be used for a broad range of the practice-oriented courses in the curriculum. The main challenge has been that students seemed to be uninterested in making the materials descriptions, as demonstrated by their lack of engagement and enthusiasm observed in the courses and course evaluations. Lack of interest can further entail that the quality of the descriptions are not satisfactory.

The descriptions are meant to be open source, which means that someone has to check the content of the descriptions before they become accessible. In the course evaluations made after the course, only 15% of the students from industrial design answered that they would like to spend more time on materials descriptions in the course (Hasling, 2014). Reasons for this can be that many students resist being given written assignments and because the material information lacks context. Nevertheless, it is part of the intention of all staff to integrate theory into practice, to strengthen students’ oral and writing skills and that also applies for topics they find less relevant.

Design School Kolding faces the challenge of ensuring that students read mandatory literature for courses, which also influences the opportunities for introducing theories and methods requiring students to read more, in order to understand and use them satisfactorily. Mandatory literature is part of the academization of the school, but it is difficult to introduce literature into courses that are still practice and process oriented.

In Chapter 5, four knowledge dimensions that supplement Bloom's taxonomy of learning (factual, conceptual, procedural and meta-cognitive knowledge) were introduced (see p. 89) and can partly be used to expand this issue. It was stated there that for materials teaching in design education it is necessary to shift the focus from factual and conceptual knowledge to procedural and meta-cognitive knowledge. Here literature and many lectures (especially when introducing materials) are based on factual knowledge.

In the student interviews it was highlighted that (some) students find material science lectures demotivating and the content has to be exemplified with applications in order to make sense. It is however also evident that student's interests and competences are very diverse. It is therefore relevant to consider the role of disciplinary knowledge and what it entails by means of the social, institutional and disciplinary cultures in education as proposed by, for example Maassen (1996) and Breen (1999). The design practice was by tradition established on practical experience and it is relatively new that design is systemically studied and described. Thus, the role of written literature has been limited in design practice, which is still a practice- rather than theory-based discipline. In cross-disciplinary courses, such as the materials courses that also comprise components from natural sciences and engineering, the cultures collide.

Increasing materials transparency

The tools integrated to increase material transparency explore meanings of material creation in practice. They serve to make students reflect on how materials perform, primarily based on subjective means and to make students confident in exploring materials based on their own and potential user's values and requirements. The associative textile meanings exercise included in Chapter 5 also serves the same purpose and could have been a part of this section.

The means to increase materials transparency is two tools, namely the 'comparative material scale' and the 'Hanger model'.

The comparative material scale

Next to the materials selection matrix, the comparative material scale is the most elaborate and comprehensively described tool in the thesis. The tool originates in well-described theories and techniques and it has been relatively uncomplicated to integrate into materials teaching, as it is easy to understand and consumes little time. In three successive years, the tool has been used to explore material meanings, first year in the Materials and Sustainability course and the last two years in the Materials Introduction course.

The comparative material scale builds on relativity and subjectivity and is based on a Semantic Differential Technique as originally proposed by Osgood in the 1960s (Osgood, 1964; Osgood et al., 1975) and Personal Construct Theory and Repertory Grid techniques as used by Kelly (Fransella et al., 2004; Kelly, 1955). Repertory Grid techniques have been used by for example Bang to explore emotional values in textiles (Bang, 2010; Bang and Nissen, 2009) and Rognoli in her Expressive-Sensorial atlas (Rognoli, 2010). The comparative material scale was developed from observations and experiences in the first courses studied in the project and is primarily based on my understanding of what would make sense as a researcher. The tool served to shift the focus away from quantitative means, towards allowing students to activate and incorporate their own experience, preferences and values. The comparative material scale seemed to be an appropriate way to explore this. The references to the aforementioned theories, tools and techniques were made retrospectively, but they have been used to develop the tool further, to reflect on its use and to compare it with other similar learning tools.

Semantic Differential Techniques enable comparative studies of cultural phenomena that are strongly influenced by subjective and personal beliefs. By having "certain similarities underlying the phenomena as a frame of reference against with to compare them" (Osgood, 1964: 171) it is possible to compare phenomena. In a 'semantic space', a space with an unknown number of dimensions, the dimensions are defined by opposing meanings. Semantics can be based on for example pictures, sounds and even materials. Osgood primarily used the differential techniques with statistical factor analyses (1964). He proposed a measurement model in a series of bipolar seven-step scales (-3 to +3) defined by verbal opposites, now commonly referred to as Likert-scales (Likert, 1932). This technique is still in vogue and is used extensively for studying the usability of for example products, services and experiences in general (Rubin and Chisnell, 2008; Tullis and Albert, 2008).

Personal Construct Theory builds on relativity as in the Semantic Differential Technique (Kelly, 1955). Even though the two share characteristics, they do not seem to be directly related. From psychological human cognition theories, Personal Construct Theory builds on the belief that all human beings strive to make sense and give meaning to their lives by acting as kinds of scientists within a personal construct system (Fransella et al., 2004). Bang and Nissen elaborate on this stating that "we have expectations (i.e. hypotheses), we test them (i.e. bet on them behaviorally and take active risks), we live with the outcomes (i.e. observe the results) and change our minds or ourselves (i.e. modify our theory)" (Bang and Nissen, 2009). This means that humans, in their everyday lives, automatically construct (subjective) systems using their cognition. Constructs can be appropriated through comparison and triangulation and therefore, as personal constructs are influenced by the way each individual human being approach the world, personal construct systems differ.

The Repertory Grid and the Expressive Sensorial-atlas

The Personal Construct Theory has been operationalized with the 'Role Construct Repertory Test' (Kelly, 1955: 152), which today is more known as the Repertory Grid (Technique) (Fransella et al., 2004). It has been broadly applied in psychotherapy to collect information concerning user experiences, which has made it increasingly appreciated in human-computer interaction studies (Tomico et al., 2009). The Repertory Grid Technique is a semi-structured interview technique that explores, how individuals understand the world around them (Bang, 2010; Tomico et al., 2009). The traditional setup is a one-to-one interview between an investigator (such as the psychotherapist or researcher) and a respondent (such as the client or interview person) (Bang and Nissen, 2009; Fransella et al., 2004) but Bang has expanded the tool for dialogues in larger groups using a tripod approach (Bang and Nissen, 2009) that elicits bipolar constructs by triadic differences (Bang, 2010: 139). Based on three materials (in Bang's work textiles) it is possible to ask "How are two alike in some way, but different from the third?" (Fransella et al., 2004: 29). The tool enables and encourages the group to discuss similarities and differences based on personal constructs and thereby explores different material meanings articulated through verbal negotiations in the group. The Repertory Grid follows five steps being: defining a purpose (for example, the semantic bipolar scale(s) of interest), choosing the 'repertoire' (for example, choosing the materials to be included in the evaluation), eliciting bipolar constructs (for example, comparing three materials from the repertoire based on the bipolar scale), assessing according to constructs (for example, repeating the triangulation) and lastly analyzing the grid (Bang, 2010; Fransella et al., 2004).

A similar tool, the Expressive-Sensorial atlas, by Rognoli (Pedgley et al., 2015; Rognoli, 2010, 2004), was developed to deepen "designers' knowledge and appreciation of materials' sensorial information and its effect on people's aesthetic and perceptive values" (Pedgley et al., 2015) and as a means to create correlation between phenomenological aspects of materials and their physical, chemical, mechanical and technological properties (Rognoli, 2010). The atlas consists of sensorial maps, each allowing the user to explore a sensorial aspect in combination with physical, chemical, mechanical or technological properties. Evidently the scales have been inspired from the Bauhaus School's tactile charts building on sensorial experiences through the work with various materials (Moholy-Nagy, 1947: 68). Being used in the first year curriculum at Bauhaus, the scales were here introduced as a method to create correlation between simultaneous ways of working with materials and techniques (Ibid.:69).

For educational purposes, the Expressive-Sensorial atlas is accompanied by eight different material samples (PMMA, PTFE, glass, stainless steel, titanium, aluminum, copper, lead) that have markedly different properties and sensorial qualities (Pedgley et al., 2015). Students are asked to rank material samples from one sensorial extremity to the other using three sensorial maps, light/heavy, cold/hot and soft/hard. These subjective perceptions can be compared with objective means, through the corresponding material properties 'density', 'thermal conductivity' and 'elasticity'.

The correlation between experiential and physical material attributes as used in the Expressive-Sensorial atlas could have been relevant to explore further, but it was explored rather late in the project, when it seemed more important to develop the comparative material scale as a tool on its own. The primary aim of the comparative material scale has been to encourage students to reflect and explore material attributes both through individual mental negotiations and as verbal negotiations between students in smaller groups. This makes the focus of the two approaches slightly different. Nevertheless, the two tools could benefit from each other, as they apply the same principles and it would therefore be relevant to combine them in a future project.

In materials teaching at Design School Kolding, the comparative material scale has aimed to make students explore and reflect on and discuss how individuals perceive materials. The studies have been based on the hypothesis that students become more aware of material meanings, when they are asked to communicate and document personal constructs. The studies have been assessed by analyzing identified features (in the first two years), the coherence of material scales (in the third year), observations and discussions with and in groups of students during the exercise. As the comparative material scale has explored two aspects, the following evaluation is divided in two. The first part explores the kinds of attributes used and the second explores coherence in selected attributes. The first exercises were conducted in the two Materials and Sustainability courses for respectively fashion and textiles design and industrial design in the fall 2013 and the second exercises were conducted in the Materials Introduction course for fashion and textiles students in the spring 2015.

Part 1 - identifying material attributes

Groups of two or three students were asked to compare five to seven material samples based on five attributes of their own choice. For the exercise a large variety of different materials was available. Of the five attributes, at least one attribute had to be a physical property and at least one had to be an experiential quality. Students were asked first to choose the five attributes and then to choose the materials.

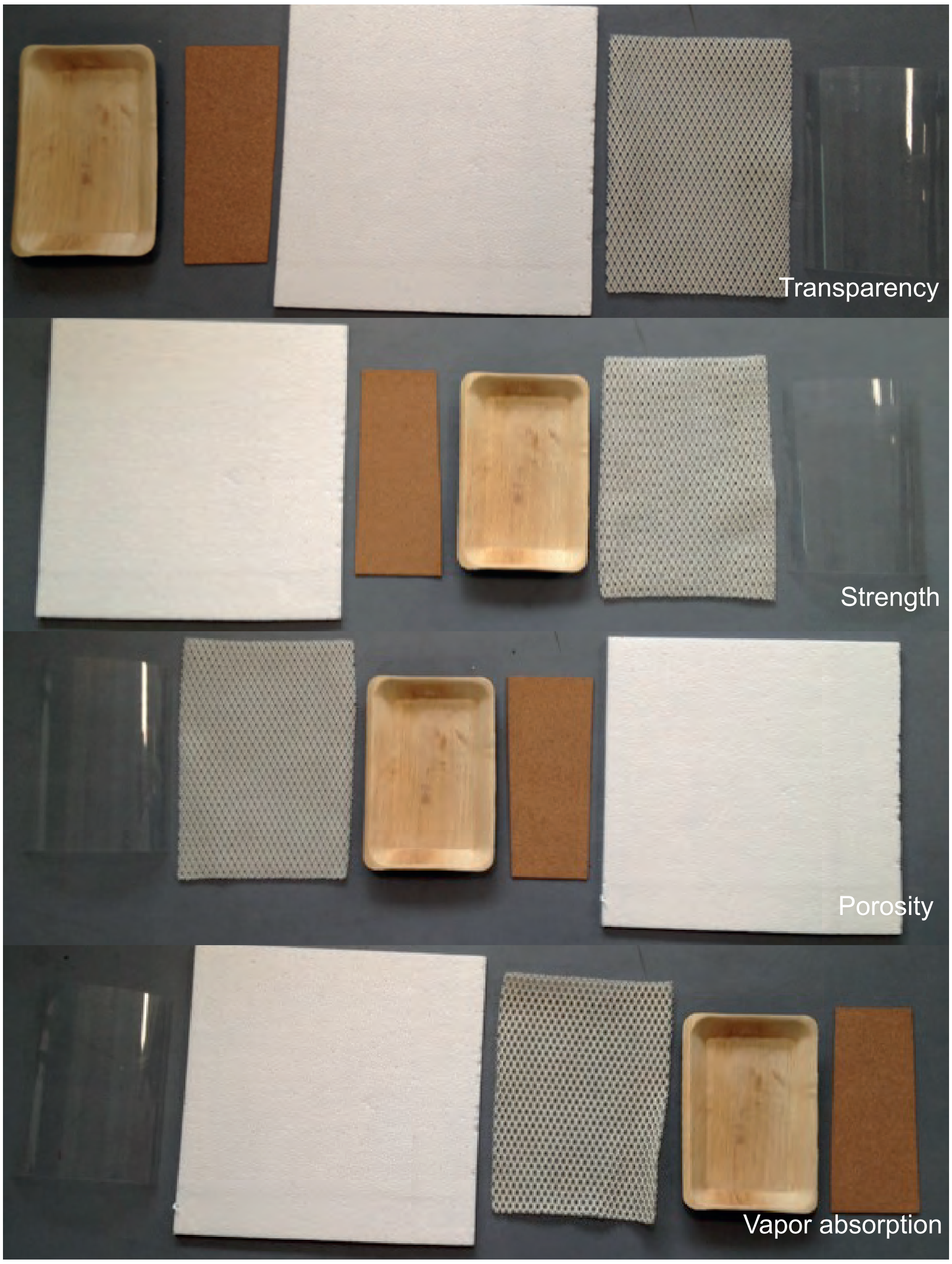


Figure 66. Four comparative scale constituting seven materials from the fashion and materials course conducted in the fall 2013. The four attributes were 'transparency', 'strength', 'porosity' and 'vapor absorption'. The materials to the left are the ones with the least associations to the requirement, while materials to the right are the ones with highest associations to the attribute.

Thereafter students were asked to make five scales based on the five attributes using the materials and take a picture of each of the scales including the name of the attribute the scale was assessing. For each scale, students had approximately ten minutes. The study has been based on exercises from ten groups, four from industrial design and six from fashion and textiles design.

In figure 66 and 67, two examples of comparative material scales are provided. Figure 66 shows four material scales from a group of fashion and textiles design students. They have used the attributes ‘water repellency’, ‘breathability’, ‘if I should design for Lady Gaga’ and ‘midsummer’. Similarly figure 67 shows four material scales from a group of industrial design students. They have used the at-

Figure 67. Four comparative scale constituting seven materials from the fashion and materials course conducted in the fall 2013. The four attributes were ‘water repellency’, breathability’, ‘if I should design for Lady Gaga’ and ‘midsummer’. The materials to the left on the scale are the ones most associated with the attributes, while the materials to the right are the ones least associated with the attribute.

tributes ‘transparency’, ‘strength’, ‘porosity’ and ‘vapor absorption’.

Analysis and discussion of part 1

The analysis explored how attributes corresponded to technical and experiential attributes respectively, and whether the scales could reveal potential differences between fashion and textiles design students and industrial design students. The attributes used in the scales were extracted, collected and placed in a two-dimensional matrix using a cluster analysis approach (Burns and Burns, 2008; Everitt et al., 2010). The attributes were placed in the matrix based on my interpretation of the attributes and have been assessed by two experienced colleagues. The matrix is included in figure 68. The x-axis corresponds to the degree of physical properties' significance and the y-axis corresponds to the degree of significance of experiential characteristics in the attributes. It means that the more to the right the attribute is placed, the more it can be associated with a physical property and the higher the attribute is placed, the more it can be associated with an experiential characteristic. Accordingly, the top right quadrant indicates attributes with strong links to both properties and characteristics, while the bottom left quadrant indicates attributes

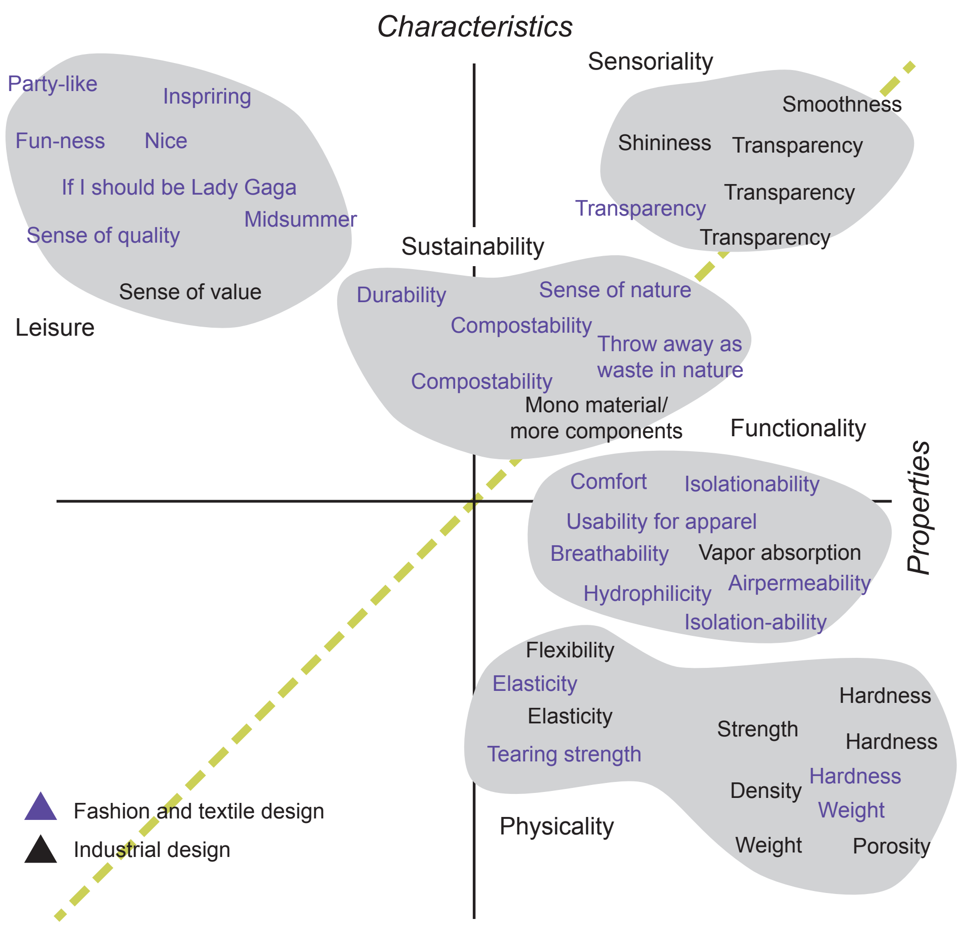


Figure 68. Two-dimensional matrix positioning material attributes extracted from comparative materials scales towards association to a property (x-axis) and character (y-axis).

with weak links to both properties and characteristics. This allows attributes to be related to both experiential and physical aspects.

From the scales, 40 attributes were extracted and transferred to the matrix. Of these, 24 came from scales made by fashion and textile design students (purple attributes) and 16 came from scales made by industrial design students (black attributes). The attributes could be divided into five clusters that have been titled ‘leisure’, ‘sustainability’, ‘functionality’, ‘sensorial’ and ‘physicality’. The color differentiation indicates, how students in the two courses had different focus. Attributes identified by fashion and textile students were predominantly found in three clusters: ‘leisure’ relating to attributes with strong characteristics and weak properties associations including criteria such as ‘party-like’, ‘fun-ness’ and ‘if I should be Lady Gaga’, ‘sustainability’ relating to attributes with medium characteristics and medium properties associations including attributes such as ‘sense of nature’, ‘compostability’, ‘throw away as waste in nature’ and ‘functionality’ relating to attributes with medium characteristics and high properties associations including attributes such as ‘comfort’, breathability’ and ‘usability for apparel’. Attributes identified by industrial design students could similarly be grouped in especially two clusters: ‘sensorial’ with high characteristics and medium properties associations including attributes such as ‘shininess’, ‘smoothness’ and ‘transparency’ and ‘physicality’ with low characteristics and high properties associations including attributes such as ‘hardness’, ‘density’, ‘porosity’.

The stippled line in figure 68 marks an imaginary boundary between objective and subjective attributes that corresponds to the continuous range of material attributes presented in figure 66-67. In figure 68, clusters with ‘sensorial’ and ‘sustainable’ attributes are in the boundary area. The above-example demonstrates that sensorial attributes can be topics for discussion among humans, but ‘shininess’ can also be measured based on specified standards. As it was highlighted in the discussion on sustainable design in Chapter 4, sustainability aspects can be difficult to grasp and black-box and aspects that concern sustainable design can vary from being highly quantitative and oriented towards processes and products to being highly qualitative and oriented towards holistic strategies and experiences. The attributes in the ‘sustainability’ cluster are predominantly related to recycling/degradability, which correlates to a product life cycle approach. However in the cluster ‘leisure’ the attributes ‘sense of quality’ and ‘sense of value’ are experiential aspects of sustainability, while in the cluster ‘physicality’ the attributes relate to prolonged lifetime and durability of a product.

Part 2 - creating coherence between material attributes

In part 2 groups of two or three students were asked to rank five defined material samples of equal size on comparative scales using five pre-defined attributes. The materials were a woven cotton fabric for furniture (striped), a woven synthetic fabric with a coating (black), a knitted synthetic fabric (black with flecks that folds on most pictures of the scales), a woven raw silk fabric (white) and a knitted cotton fabric (grey). The attributes were 'associations to Roskilde Festival' [Roskildefestivalsk], 'warmth' [varme], 'danceability' [dansevenlighed], 'suitability for windy weather' [anvendelighed i blæst] and 'water repellency' [vandafvisning] and where chosen to provide a broad range of both experiential and physical attributes. The students were allowed to use all their senses to assess the materials. Six groups and 15 students participated in the exercise. When making the scales, students were asked to argue for their rankings in the groups and to supply small keywords next to the scales and after the scales were made, they were attached to the wall in a matrix. In figure 69, the matrix with the thirty scales is shown. Scales from the same group are vertically oriented and scales with the same attribute are horizontally oriented. When all groups had finished, the coherence of scales was

Figure 69. Comparative material scales. Horizontally ordered are the attributes (from top to bottom) 'associations to Roskilde Festival', 'warmth', 'danseablility', 'suitability in windy weather' and water repellency'. The materials to the left are the ones with the least associations to the attribute, while the materials to the right are the ones most associated to the attribute.

discussed based on the students' discussions and own observations.

Analysis and discussion of part 2

During and after the exercise, students were surprised by the variety of material scales that were made. Most groups had taken a substantial amount of time before making the scales to establish a shared understanding of what the attributes meant and how they could be evaluated. The predominant part of the attributes had consciously been chosen to encourage this. Many students pinpointed the need to determine a context that established further conditions for the attribute evaluated, which is vital for material considerations. The more detailed the context is, the easier it is to identify how the materials should perform, how they should appear and what meanings they should generate. In real life designers usually have the context before choosing materials. However in this educational setting the exercise is to make student familiar with the role of the context when considering materials.

In assessing the coherence of the material scales, students elaborated on the difference between subjective and objective material attributes. To rank the material samples for the water repellency scale, most groups had intuitively performed hands-on tests investigating how drops of water were absorbed from the fabric surface. Even though the groups did not make the same scales, they had all discussed and reflected on the correlation between the composition and construction of the textile samples and their attributes. This was most apparent for water repellency, but also other attributes were highlighted for this. The woolen and the coated synthetic fabrics were generally considered as bad materials for dancing as they would get too hot or moist, while the synthetic jersey ranked high in all scales. The woven raw-silk fabric generally ranked low for 'associations to Roskilde Festival' as it would become 'dirty' and 'worn' and 'be too chilly', while the striped woven cotton fabric generally ranked high and was described as 'festive', 'colorful', 'suitable for both cold and warm weather' and 'durable'.

Supplementing exercise with blindfolded students

Some groups finished the exercise faster than expected and were given an additional exercise. The exercise explored, what happened if students were blindfolded when making the scales. Based on the Bauhaus design school, Moholy-Nagy has written that "a tactile chart, an illuminating, enriching exercise for the fingers, can be composed solely with the power of intuition" (1947: 67) and further writes that in order to shift emotional decisions into an organic relationship with the relatively slower process of the critical mind, it is necessary to activate and force other senses to coordinate. Of the five senses, the sight is dominant (see for example

Figure 70. The nine students that participated in the blindfolded comparative material scales exercise ranking materials based on ‘suitability for Roskilde Festival’.

Esslinger, 2006; Pan, 2007; Pocock, 1981; Smith, 2007; Wastiels et al., 2013), meaning that the first and strongest experiences are based on visual stimuli. As senses are mentally processed differently, the experiences they generate are not necessarily identical.

Consequently, participating students were blindfolded and given five new materials to rank. Each student made her/his own scales. The materials were a double-sided knitted cotton fabric (zigzag pattern), a light woven cotton fabric (check pattern), a jersey knitted synthetic fabric with golden print (dark brown), a dense woven hemp fabric (beige) and an interlock, woolen fabric (light beige). The attribute was chosen by the students and was ‘associations to Roskilde Festival’. Scales from the nine scales are included in figure 71.

Analysis and discussion on supplementary exercise

The attribute was probably not the best suited for identifying possible differences between ordinary and blindfold assessments, as peoples’ associations were highly subjective. Students used a range of different means such as ‘warm’, ‘windproof’’,

Figure 71. Nine comparative material scales based on the attribute ‘suitability for Roskilde Festival’ with blindfolded participants. The materials to the left are the ones with the least associations to the attribute, while the materials to the right are the ones most associated to the attribute.

‘soft’, ‘practical’, ‘flexible’, ‘comfortable’, ‘festive’, ‘durable’, ‘light’ and ‘stable’ to rank the materials. Even though the comparative result was less useful, the students’ behavior change doing the exercise was interesting in itself. While students made the scales, they stopped talking and focused their attention on sensing the materials. As it can be observed on the pictures of the nine students while doing the exercise (figure 70), their face expressions and body languages reveal that they are concentrated. Moreover after the exercise had finished, most students expressed, how difficult it had been not to see the samples when ranking them.

Overall the two studies on comparative material scales have given valuable insights in, how students compare materials. For students, it demonstrated to be an appropriate tool to explore materials differently than they would usually do and to make them discuss, how their value systems are based on attributes. The students found the components of the exercise intuitive, but the structured way of comparing different attributes and rankings increased their awareness of how important it is to consider material attributes widely, as well as specifically.

The mindsets applied in and the findings of the studies go very well in hand with other works at Design School Kolding. In the ‘Awareness Project’ Riisberg et al. explored, how tactile competences support the development of sustainable fashion and textile design (Riisberg et al., 2015; Riisberg and Bang, 2014). The project used the Repertory Grid technique (Bang, 2010) to explore tactile sensations in textiles with hands only. In a subsequent Garment Experiment, sensations were stimulated by the entire body rather than from hands only.

The Hanger model

The Hanger model is a tool to explore and communicate aspects of sustainability in product design developed by Laboratory for Sustainability at Design School Kolding (2013). It is based on a six-phase product life cycle and 52 means to influence the sustainability impact of a product. Designers, who work or want to work with sustainability can use these means to discuss how present or future designs can improve, and to determine how sustainability is valued. The tool bears resemblances to ‘articulations of sustainable development’ (Ashby and Johnson 2014; Mulder et al., 2011) that were discussed in Chapter 4 (see pp. 75-76) and can help to clarify, how sustainability is approached and how small efforts influence and interact. Examples of articulations from the tool are: ‘upcycling’, ‘water consumption’, ‘organic raw materials’, ‘use polyester’, ‘chemical consumption’, ‘reuse’, ‘zero-use’, ‘e-shop’, ‘mono-material’, ‘maintenance’, ‘bio-degradability’, ‘aesthetic lifespan’ and ‘local production’ (Laboratory for Sustainability, 2013).

For users with limited experience, such as undergraduate design students, the sus-

Figure 72. Presentation of the sustainability wheel tool in the Materials & Sustainability course for fashion and textiles students (fall 2013) (left). A group of students that uses the tool to discuss and develop their concept (fall 2013) (right).

tainability tool has the great advantage that articulations are already defined. It means that students can use the tool to explore different aspects of sustainability and be provided with a vocabulary that enables them able to communicate, how they have approached sustainability in projects.

The tool was first presented in the Materials and Sustainability course for fashion and textile design students in the fall 2013. In the presentation Brian Frandsen, who developed the tool, described, how it could be used and provided examples from companies in industry that had used to tool to clarify their sustainability efforts. Thereafter students were encouraged to find inspiration in the tool, to develop concepts further and to consider materials for them. The two photos in figure 72 show the introduction of the model and a group of students using the model to discuss their design concept. The tool was not intended to have a bigger role in the course, but for their final presentations in the course, many groups had used the sustainability articulations from the tool as keywords to base their designs on and in selecting materials, to support and feed the materials selection matrix. In the Materials and Sustainability course conducted in the spring 2015, the Hanger model and especially its articulation functioned as formal entries to considering sustainable design. The use of the model in teaching is further debated in the discussion using examples from the course in the spring 2015.

Discussion on the supporting tools

The four tools show different prospects and challenges but overall they appear to support materials accessibility and materials transparency and to develop students' continuous sense making process with material further when being forced to make structures and reflect on constructs. The discussion on the tools here served to illuminate their individual strengths and weaknesses and to elaborate on the theories, tools and other means from which they have been developed.

CHAPTER SUMMARY

The chapter has been divided in two parts. The first part presented findings from an iteration of the materials selection matrix. The analysis primarily focused on topologies of matrices based on identified material requirements, considered materials and grading strategies. From the analysis, observations from the course and the realization that the premises for teaching and learning in the course have changed, a refined version of the materials selection matrix as a method was proposed. As part of the proposal, supporting teaching tools should increasingly help students to use the matrix.

The second part presented four tools developed to answer 'materials accessibility' and 'materials transparency' (in accordance to the overall materials teaching methodology. These were the 'personal materials collection' and 'material descriptions' to support materials accessibility and the 'comparative material scale' and the Hanger model to support materials transparency. Studies on the tools were then presented.

Summary

_ The study on using the matrix propose a modified setup of the matrix due to more materials, less time for each students and higher emphasis on sustainability.

_ The study explored the matrices based on structure, kinds of materials considered and grading strategies.

_ As part of the refined setup, a collection of supportive tools is introduced to improve the components of the matrix.

_ The tools further answers to the materials teaching methodology with 'the personal materials collection' and 'education material descriptions' (for materials accessibility) and 'the comparative material scale' and the 'Hanger model' (for materials transparency).

_ The comparative material scale is based on theories of personal constructs and semantic scales that contribute to especially value creation and meaning creation processes.

9. MATERIALS EXPLORATION - SECOND ITERATION

The previous chapter proposed a modified version of the materials selection matrix with more structure and supporting tools to provide additional material information. This chapter further develops and tests the materials selection matrix in a new learning context with different premises. The chapter covers the modifications of the matrix from its previous use, describes the premises under which the matrix has been studied and discusses selected findings from the study. It is recognized that this study may seem to stand out, compared to the previous studies. However the study has been framed to correspond to the traditions of the learning environment it has been conducted in.

A DIFFERENT LEARNING ENVIRONMENT

In the previous studies, the matrix was tested in the learning environment of Design School Kolding. From experience, it was proposed to modify the materials selection matrix to meet ever-new conditions in design education.

The following study explores, the matrix a 'Materials for Design' master course for design engineering students at Faculty of Industrial Design Engineering at Delft University of Technology. The study was based on the hypothesis that students, who previously have used the matrix, find it easier to structure and reflect on material ideation without also having access to the specific matrix. The main goal was therefore to test the usability and appreciation of the matrix in a different learning environment, which is traditionally more technically oriented. In the study, the matrix was presented on its own (without supporting tools) to explore, how it would work standing by itself. The study has been based on the paper (draft version): 'Material Ideation in Design Education – identifying material requirements in product design' (Hasling and Karana, XXXX) [P3].

Modifying the matrix

Based on the findings that were discussed in the previous chapter, the matrix was designed with a higher degree of structure and control, in terms of procedural structure of the matrix as a method, and emphasis on the role of different categories of material attributes. The matrix was prepared as a paper template with associated guidelines in a pamphlet. The structure in the matrix served to:

1. Provide a higher degree of transparency of requirements and materials used,
2. Enhance use of experiential and sustainability-oriented material requirements and

3. Strengthen argumentation in the material selection.

Previous matrices were evaluated to identify common structures. These comprised eight steps similar to, for example, the Pugh Selection Matrix (Pugh, 1987, 1981) and material focused design process proposed by Ashby et al. (2007). The steps were:

(1) Sketch or describe the concept or component to be analyzed,

(2) Identify relevant requirements,

(3) Determine evaluation method,

(4) Identify relevant materials,

(5) Grade materials,

(6) Describe materials,

(7) Calculate scores and

(8) Evaluate results and determine final material choice.

The order of the steps highlights the importance of identifying requirements before materials. In cases where materials were considered before requirements, there was a tendency for the identification of requirements to be influenced by the materials, as students already had established a preconception of the 'correct' materials' Consequently in previous studies, students were often surprised by their final material choice, as they intuitively thought another material would fit better for the application. It was also important to allow student to evaluate materials by different means to accommodate their different ways of making sense of structures (for further details, see Appendix [A6]).

Requirements

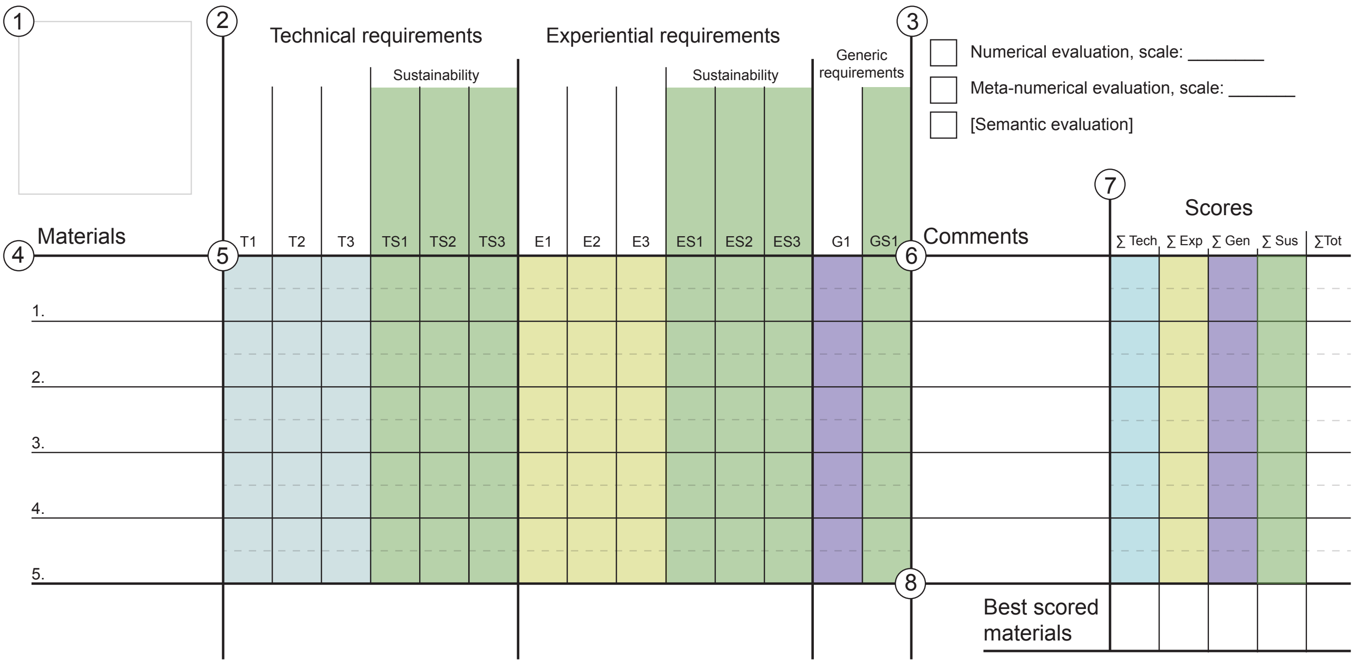
T : technical requirements
TS : technical/sustainability requirements

E: experiential requirements
ES: experiential/sustainability requirements

The matrix was modified to enhance recognition and appreciation of technical, experiential and sustainability attributes equally. Derived from the attribute triangle proposed in Chapter 4 (p. 79), a number of requirements should be designated to technical and experiential attributes respectively, meeting the dual nature of materials. Additionally, as sustainability attributes can correspond to both technical and experiential attributes, some of the latter attributes should relate to sustainability.. In the proposed matrix four categories of requirements are incorporated: technical requirements (denoted as T), technical requirements with sustainability aspects (denoted as TS), experiential requirements (E) and experiential requirements with sustainability aspects (denoted as ES).

Having established the basic format for requirements, the number of requirements was open to debate. In methods such as the Harris Profile, the fewer requirements the better, usually meaning 4-5 requirements (van Boeijen et al., 2013), as only the most important and relevant requirements should be included. In the previous studies the average numbers of requirements were respectively 10.7, 11.9 and 12.0 for three different courses (Hasling and Lenau, 2014), which seemed to be appropriate to ensure variety and still retain focus. Thus twelve requirements were evenly divided between the categories, with three requirements in each category. It encouraged students to put an effort in discussing and reflecting on relevant requirements rather than 'just' using the first one that popped up in their minds. Additionally, two requirements addressing generic material attributes were included where one was earmarked for sustainability. Generic material attributes are for example 'price' and 'production time'. The template as provided to students in the study is shown in figure 73.

Figure 73. The matrix template as used in the study at TU Delft. The numbers in the template correspond to the descriptive guidelines, where students could aqcuire additional information if needed.



Guidelines

Due to the higher degree of structure and information a 16-page pamphlet with guidelines was given to students when the first assignment was given. The guidelines provided information on structure, content of different steps and examples of material attributes and ways to grade and analyze materials.

Procedure

The template of the matrix that was developed for the study includes eight procedural steps of that are expanded in the following:

(1) The design proposal is sketched or described.

(2) Requirements are identified. Here different color codes indicate categories of requirements: T1-T3 are technical attributes (blue), TS1-TS3 are technical/sustainability attributes (green), E1-E3 are experiential attributes (yellow), ES1-ES3 are experiential/sustainability attributes (green), G1 is the generic attribute (purple) and GS1 is the generic/sustainable attribute (green).

(3) Students choose between numerical evaluation meta-numerical and semantic evaluation (cf. topologies of grading in Chapter 8 and in Appendix [A6]) and the scale is determined.

(4) Five materials are identified as a base for material assessment.

(5) The materials from (4) are assessed according to the identified material requirements (2) using the determined evaluation approach (3).

(6) Overall assessment comments can be added.

(7) The scores are calculated for each of the categories and in total.

(8) The results in (7) are evaluated and the final material candidate is chosen.

STUDY

The study was conducted under different premises from in the previous studies. Here the assignments were defined, the matrix template was fixed and it was conducted within a limited time frame.

The context for the study was a 3 ECTS point elective master's level course in Materials for Design held in the spring 2014. The aims of the course were to generate knowledge of technical and experiential aspects of materials considered and explored in an effective material selection processes, to create motivation to use tools and methods for material selection and to promote and develop the materials library in the faculty ("TU Delft, ID5413," 2014). Hence the course already built on and acknowledged interaction between technical and experiential material attributes. This was further stressed by the course literature that included books such as Materials for Design (Ashby and Johnson 2014) and Materials Selection in Mechanical Design (Ashby, 2007) and the PhD theses 'Meanings of Materials' (Karana, 2009) and 'Materials Selection in Product Design' (van Kesteren, 2008). These were previously introduced in Chapter 6.

Premises of study

The study included 29 students enrolled in the course. All participants had a bachelor's degree in Industrial Design Engineering from Delft University of Technology and they had similar educational backgrounds in terms of methods use, experience and materials knowledge. However, as the Materials for Design course was not mandatory, students enrolled in the course were expected to have some prior interest in materials.

The students had different educational profiles from the students in the previous studies. Being an engineering-oriented industrial design education, greater emphasis on technical subjects was expected than at Design School Kolding. Furthermore the students were master's students and were expected to possess prior knowledge on both materials and methods use.

Assignments

Students were given two comparable assignments on materials selection in two concurrent sessions. In one assignment they were asked to use the materials selection matrix in a fixed template format and in one they could approach the assignment as they preferred. An example of an assignment is:

> *You are given the assignment from a client, who manufactures interiors for kindergartens, to choose a material for an object to eat at there. You should use the matrix to choose the material".*

Hereafter the assignment with the matrix will be referred to as the restricted session, while the assignment with free approach will be referred to as the unrestricted session. Afterwards the approaches were analyzed based on templates, sketches and questionnaires filled in after each session to establish an understanding on the students' use and appreciation of the matrix.

The groups were divided in two tracks, Track A and Track B and were given the assignments in a different order. Students in Track A got the restricted assignment in the second session, while students in Track B got the restricted assignment in the first session. The different orders of sessions served to establish, whether Track A or Track B found it easier to ideate materials in the assignments. Based on overall hypothesis, it was expected that students in Track B would perform better in the unrestricted assignments than students in Track A.

	Track A	Track B
Session I	Context: Elderly care, indoor Unrestricted	Context: Playground, outdoor Restricted
Session II	Context: Kindergarten, indoor Restricted	Context: Elderly care, outdoor Unrestricted

Table 9. Assignments taxonomy in Track A and Track B.

Documentation

After each session students were given time to discuss and evaluate how the process went, and to answer a questionnaire linked to the assignment. In the questionnaire after the restricted session students were asked about their perception of the matrix. They did this by describing one good and one bad experience that could be used to make a cluster analysis, with six Likert-scales (-3 to +3) focusing on 'clarity', 'usability', 'value of answering assignment', 'representation of choice', 'potential future use' and 'potential introduction to peers'. In the questionnaire after the unrestricted session students were asked to describe their material ideation process by means of the final material choice, how it was chosen, requirements identified and how they could be grouped. In both questionnaires given after the last session students were asked which of the two sessions they preferred and why. The questionnaires were answered individually. After each session the matrix templates, paper sketches and questionnaires were collected and coded randomly the two sessions.

ANALYSIS OF THE STUDY

The analysis was based on a combination of qualitative and quantitative analyses. The quantitative analyses have been based on Likert-scales from questionnaires (see figure 74), while qualitative analyses have been based on multiple data inputs. In the questionnaires, students were asked to write down one positive and one negative experience from using the matrix. These were collected in a qualitative cluster diagram (see figure 75). In addition drawings, sketches and notes made in the unrestricted assignments (see figure 76-77) have been analyzed qualitatively to explore potential differences in structure, complexity and diversity of the material selections performed. The analysis of the study focuses on the topics 'usability' and 'appreciation on experience', and 'structure' and 'degree of reflection' in the ideation process sketches.

The 7-point Likert scale was applied with the extremes 'very poor'/'very good' and 'never'/'absolutely' for the numerical values -3 and +3. The odd numbered scale was used to provide students with a neutral benchmark and, for both negative and positive values, to highlight the likelihood of some having negative experienc-

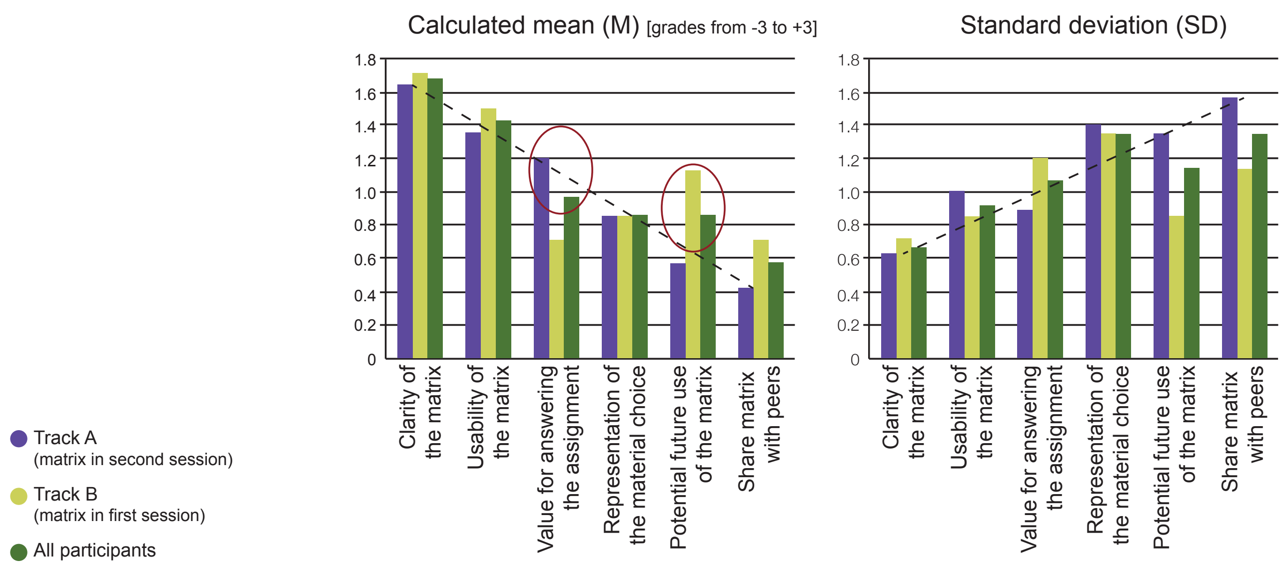


Figure 74. The calculated means of the Likert-scales. Right the standard deviation of the Likert-scales. Purple bars represent students from Track A (matrix in second session), yellow bars represent students from Track B matrix in first session and green bars represent all students.

es using the matrix. For additional information on Likert-scales, see p. 170.

Usability and appreciation of the matrix

Usability and appreciation were measured by means of Likert-scales concerning 'clarity', 'usability' 'value for answering the assignment', 'representation of choice', 'potential future use' and 'potential introduction to peers'. There were six questions: the first two covering the immediate matrix experience, the next two its contextual use, and the last two covering its potential future use.

In figure 74, the calculated means and standard deviations for the six questions have been shown. The purple bars represent Track A, which used the matrix in the second session the yellow bars represent Track B, which used the matrix in the first session and the green bars represent all participants. The percentage values indicated for some of the values correspond to the maximum score. When extremes are -3 and +3, the grade 1.5 corresponds to a percent value of 75%.

For 'clarity of the matrix', the calculated means were 1.64 (SD=0.73) for Track A, 1.71 (SD=0.63) for Track B, and 1.68 (SD=0.67) for all. For 'usability of the matrix', the calculated means were 1.36 (SD=1.01) for Track A, 1.5 for Track B, and 1.42 (SD=0.92) for all. The answers reveal that both tracks find the matrix equally clear and user-friendly and the scores are in the higher end of the scale (approximately ~75% of the maximum score).

The calculated means for the 'value of the matrix' were 1.21 (SD=0.89) for Track A, 0.71 (SD=1.20) for Track B and 0.96 (SD=1.07) for all. The calculated means for 'representation of material choice' were 0.86 (SD=1.41) for Track A, 0.86 (SD=1.35) for Track B and 0.86 (SD=1.35) for all. Here the value for answering the assignment was thus slightly higher (8%) for Track A than for Track B.

The calculated means for the 'future use of the matrix' were 0.57 (SD=1.34) for Track A, 1.14 (SD=0.86) for Track B and 0.86 (SD=1.15) for all. On the probability that students would share the matrix with peers, the calculated means were 0.42 (SD=1.55) for Track A, 0.71 (SD=1.14) for Track B and 0.57 (SD=1.35) for all. Here the calculated mean revealed that the probability of future use of the matrix was considerably higher for the track that was given the matrix in the first session (69%) than in the second session (56%).

The graph shows that in general, appreciation of the matrix decreased with the depth of questions and categories evaluated. In the 'immediate experience' category (Question 1 and 2), the assessment dropped to the 'contextual use' category (Question 3 and 4) and again to the 'future use' category (Question 5 and 6).

The standard deviations of Track A and Track B were similar for the 'immediate use' and the 'contextual use' categories. Here the standard deviation increases linearly. It indicates that there is an increasing divergence from the students' experience with the matrix from the immediate experience to the subsequent application of the method. When it comes to sharing the method or using the method again, the standard deviation differentiates between the two tracks and there is a larger disagreement from students from Track A.

The assessments from the Likert-scales have been linked to the appreciation of the sessions asked in the questionnaire after the last session. When asked, which of the two sessions they preferred, in Track A, 64% preferred the restricted session, 21% preferred the unrestricted session and 14% had no preference, while in Track B, the comparable values were 73%, 20% and 7% respectively.

Experiences and comments

The students' experiences have been based on the positive and negative comments they gave as part of the questionnaires given after the restricted assignment. The comments have been clustered with familiar comments in a qualitative cluster analysis (Everitt et al., 2010) provided in figure 75. The comments have been color-coded according to their charge (positive or negative) and their affiliation (Track A or Track B). Purple corresponds to positive comments from Track A, yellow corresponds to positive comment from Track B, bright green corresponds to negative comments from Track A, and dark green corresponds to negative comments from Track B.

The comments have been divided into two cluster sizes. The large clusters (six to nine comments in each) comprise general trends and overall topics for further discussion. These have been named 'scoring', 'process/method', 'attribute categories', 'comparison of materials' and 'requirements'. The small clusters (two to five comments in each) comprise topics that add a dimension to and/or overlap two or more large clusters. These have been named 'end score', 'surprising insights', 'context', 'time consumption using the matrix', guidelines/information', 'color scheme', 'overview', 'amount of criteria', 'amount of requirements' and 'weighted requirements'. The arrows in one or both directions indicate relations and interactions between clusters.

The generally positive responses (purple for Track A and yellow for Track B) were predominantly linked to the large clusters 'comparison of materials', 'process/method' and 'attribute categories', while negative responses (bright green for Track A and dark green for Track B) were predominantly linked to the large clusters 'requirements' and 'scoring' and the small clusters corresponding to the large cluster 'process/method' such as 'context', 'time consumption' and 'guidelines/in-

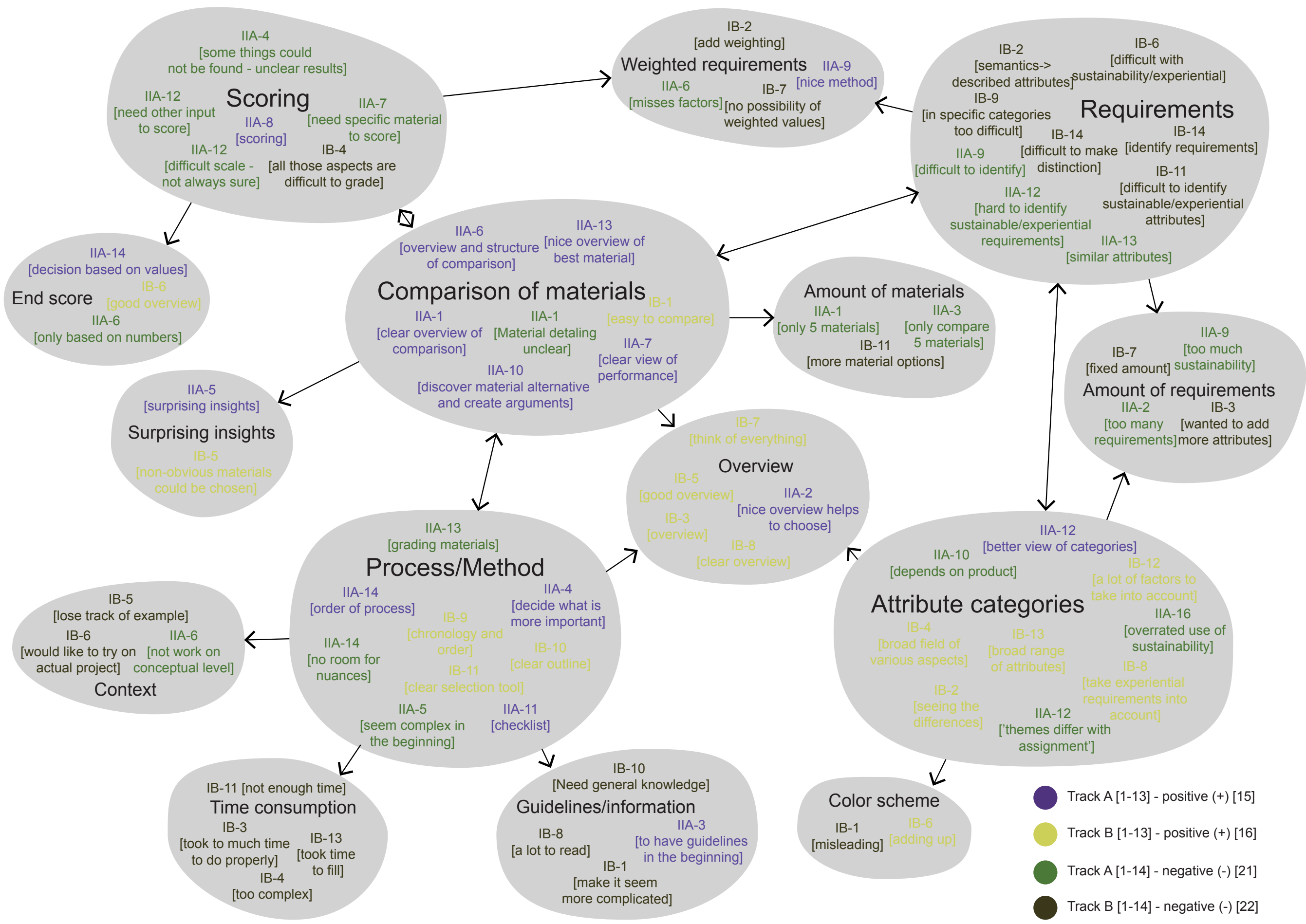


Figure 75. Clusters of comments from having used the material selection matrix.

formation' and corresponding to the large cluster 'requirements' such as 'weighted requirements' and 'amount of requirements'.

The large and small clusters have been used to locate tendencies in the appreciation of and frustrations with the matrix. The comments for the two tracks are not significantly different and therefore they have been considered as equal. It is however evident that the cluster 'comparison of materials' mostly consists of positive comments from Track A and the cluster 'attribute categories' primarily contains positive comments from Track B. Likewise the cluster 'scoring' got more negative comments from Track A, the small clusters 'time consumption' and 'guidelines' almost only include negative comments from Track B.

Structure and reflection in ideation process sketches

The influence of the matrix on structure and reflection was assessed by analyzing sketches and solutions from students' unrestricted assignments. The following focuses on how different approaches from assignments in Track A and Track B can be elucidated through these drawings, illustrations, diagrams and matrices. The

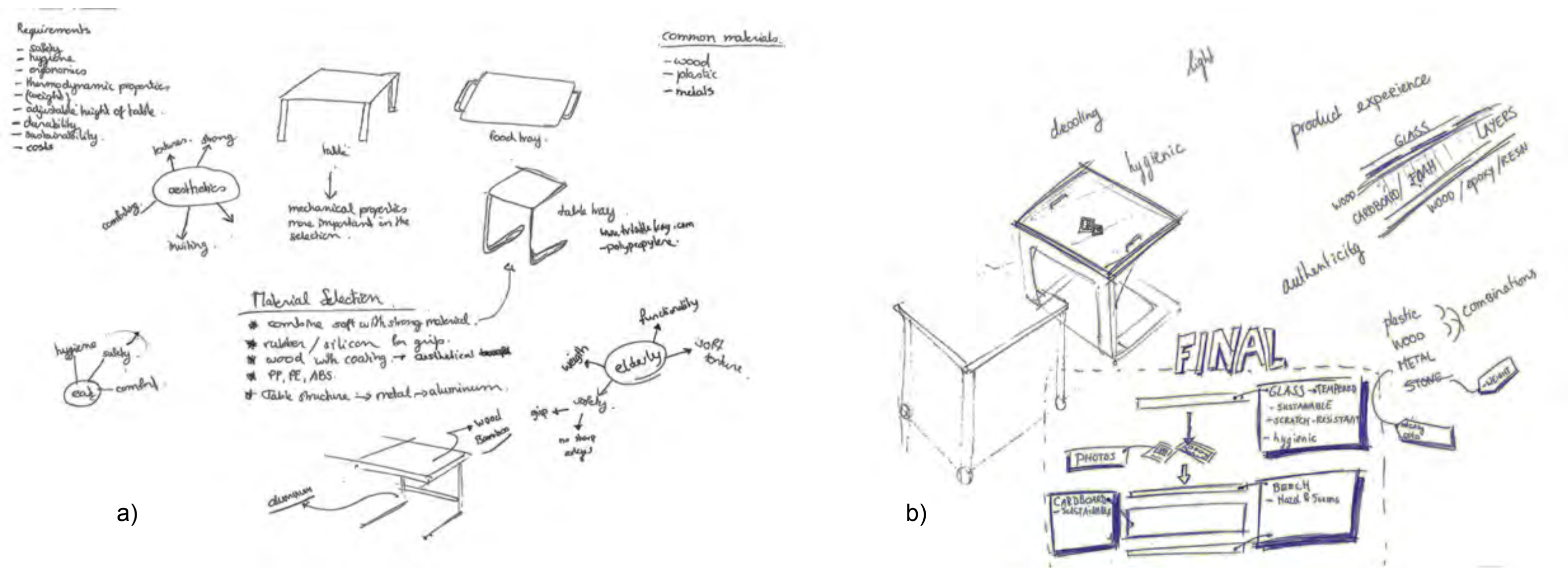
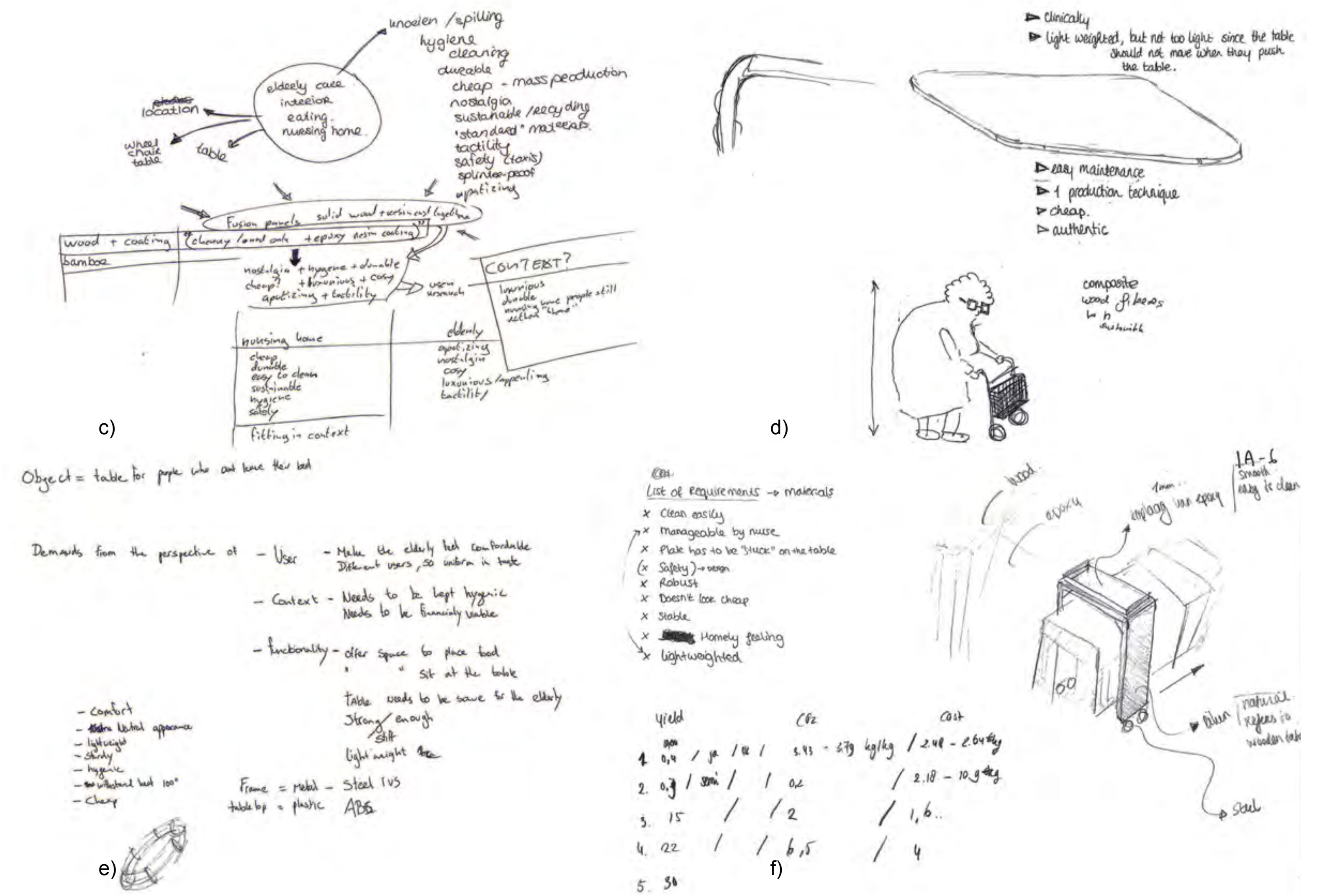


Figure 76. Six examples of material ideation structures made without prior introduction to the material ideation matrix. In the assignment, students had to propose materials for an object for elders to sit at while eating.



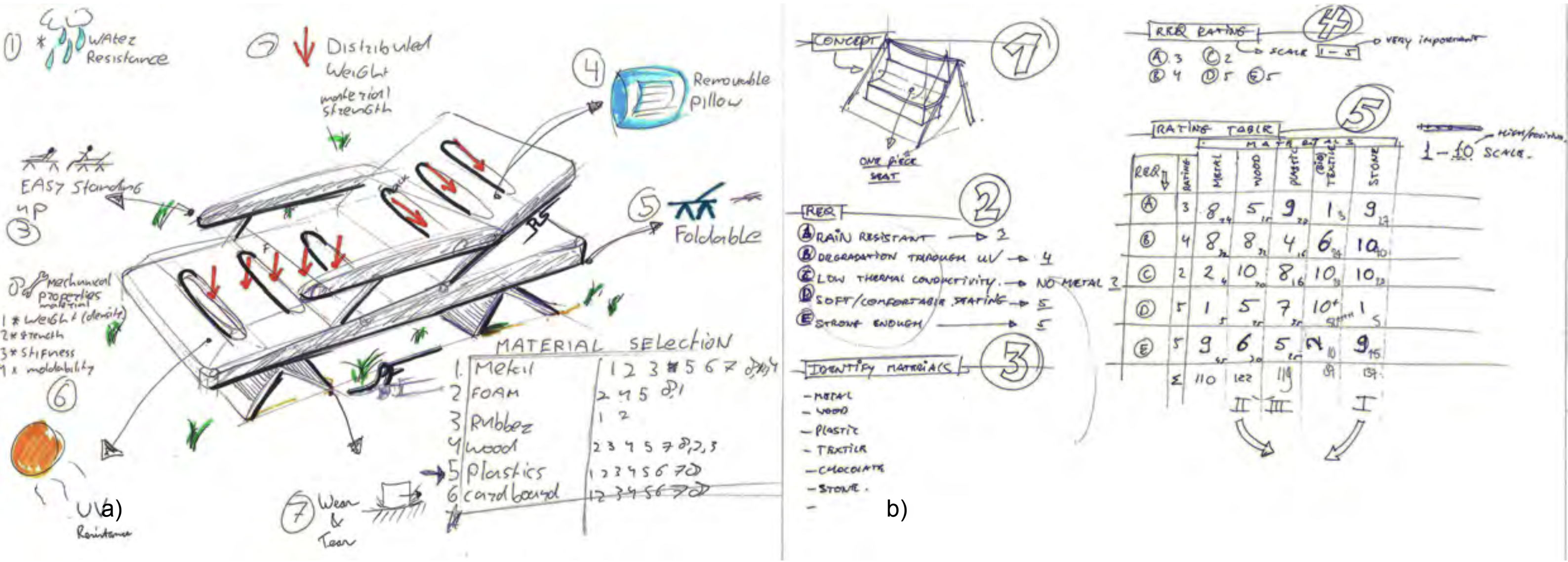
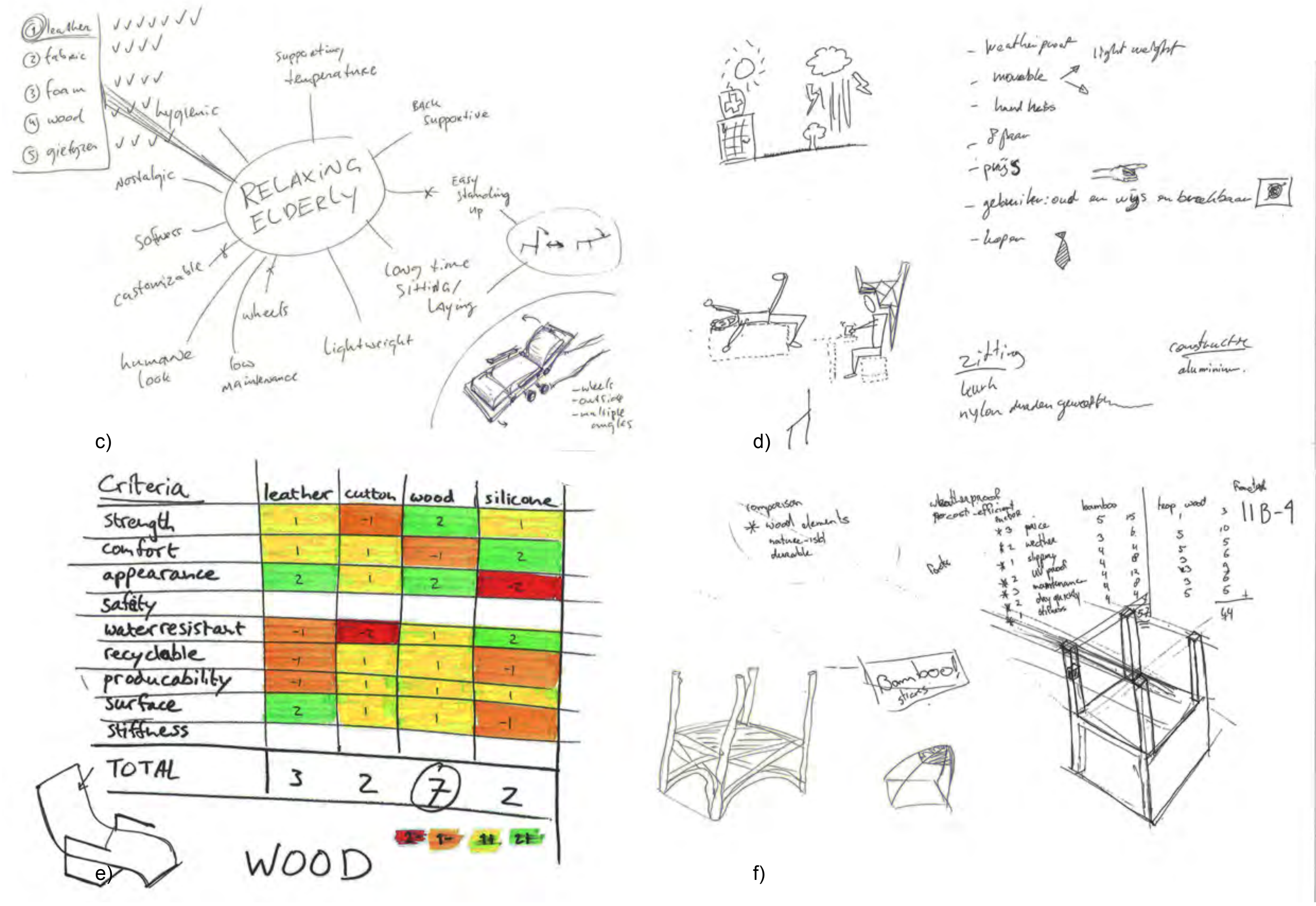


Figure 77. Six examples of material ideation structures made with prior introduction to the material ideation matrix. In the assignment, students had to propose materials for an object for elderly used to rest outside.



questionnaires linked to the unrestricted assignments have been used as further evidence.

Figure 76 includes six examples of material ideation approaches from the unrestricted assignment in Track A. Students had to propose a material to construct an object to assist older people in nursing homes with eating. In the following analysis I will focus on the two upper examples (approach '76a' and '76b').

In approach 76a a list of requirements has been made. The requirements have been grouped in the clusters: 'aesthetics', 'elderly' and 'eat' with supplementary material requirements. For each of the components of the design proposal, material requirements have been identified. In the questionnaires, the students have described their material choice as: (1) making a list of requirements and aesthetics, (2) selecting the most appropriate ones for 'elderly', 'eat' and 'aesthetics', (3) exemplifying products that could fit the assignment, (4) finding common materials and (5) finding materials that fit best for each component (such as metal, plastics or wood).

In approach 76b students have drawn a sketch of the proposed design, assigning a couple of keywords such as drooling, hygienic, product experience, authenticity and light. The sketch contains an illustration of the laminates the students propose to use, with examples of the material components. In their final proposal, the students have assigned material attributes to the materials they have chosen such as 'tempered', 'sustainable', scratch-resistant and 'hygienic' for glass, 'sustainable' for cardboard and 'hard' for beech wood. In the questionnaires, the students have described their material selection as: (1) making a small list of requirements based on product experience and mechanical properties, (2) making a design based on existing furniture, (3) assigning options, and (4) choosing a material from the Internet. The requirements were identified by making a quick design and brainstorming combinations of product experience and mechanical properties.

In figure 77, six representative examples of sketches made by students from Track B in their unrestricted assignments are provided. Students had to propose a material choice for an object for older people used to rest outside. Again, focus is on the two upper examples (approach '77a' and '77b'). Some of the remaining approaches will be highlighted in the discussion as they show some interesting features.

In approach 77a students have sketched the design proposal and have identified material requirements and functions clustered in seven groups ('water resistance', 'distributed weight', 'stability', 'removable pillow', 'foldability', 'UV resistance' and 'wear & tear'). Four desirable mechanical properties have also been identified ('weight/density', 'strength', 'stiffness' and 'moldability'). Six materials have then been assessed by indicating which requirements each material had lived up to. The material that lived up to most requirements were chosen as the choice. The students describe their material ideation process as making (identifying?) several requirements and marking them on different materials. The requirements were identified by previously used materials and imaginative use of the design proposal.

In approach 76b, students have applied a transparent and structured selection process in five steps. In (1) the design proposal is sketched, in (2) five requirements are identified, in (3) six materials are identified, from conventional material groups such as metal, wood and plastics, in (4) requirements are weighed from 1 to 5 and in (5) materials are rated from 1 to 10. The three materials that gained the three best scores have been highlighted. In the questionnaires, students describe that they have based their method on a matrix, where materials have been assessed according to various weighted requirements. In further detail the approach was described as: (1) identifying a concept and the part for investigation, (2) determining requirements, (3) rating requirements, (4) identifying material options, (5) rating each material according to the requirements, (6) counting scores by multiplying with rating, (7) adding up all scores, (8) checking if options differ much or not and (9) making the final choice. The requirements were identified through use scenarios, brainstorming and looking at images on Google. The approach showed many similarities with the material ideation matrix, and whether the students had found inspiration there, or whether they were accustomed to similar methods, the approach appeared clear, straightforward, structured and easy to use. In contrast to the matrix, the approach applies weightings of requirements, but does not consider diversity of material attributes.

More could be said about the approaches to the unrestricted assignments from respectively Track A and Track B. If two tendencies should be chosen for further elaboration in the discussion it would be the degree of structure, both mentally and graphically, and the integration of experiential and sustainability attributes. The students in Track B demonstrated more structured and elaborate selection approaches. Some approaches in Track A have been structured, but this was not evident based on the sketches alone. Similarly approaches from Track B did not appear to consider experiential and sustainability material aspects more than Track A.

Discussion

In the discussion of the study, three topics have been selected and covered. The topics of the following paragraphs relate to general discussions in the dissertation and highlight tendencies that were specifically apparent in this study. Thus the discussion builds on previous experience and anticipates the concluding discussion from page 218ff.

Appreciation and effects of structure

It is evident that students in Track B approached the unrestricted assignment in more structured ways than the students in Track A, demonstrating that the matrix played a role. Most groups did not copy the format of the matrix, but have provided alternative structured approaches. When the students provide alternative methods, they show that they understand how the matrix functions, and have reflected on how it could be improved to fit their requirements for a selection method, such as the ability to weight requirements.

First time use of the matrix

Students, as inexperienced users of methods, have previously been discussed as part of the challenges with in the use of the material selection at Design School Kolding. The use and development of methods form an intrinsic part of the industrial design engineering curriculum, and postgraduate students are expected to be able to navigate between existing methods and reflect on how methods are used. As master's students, they have previously had courses directly or related to materials such as mechanical engineering design ("TU Delft, IO1071," 2014) and manufacturing and design ("TU Delft, IO2040-13," 2014) in their bachelor studies. Therefore, separately working with methods and materials, the students were not experts, but they were not novices either. Nevertheless the combination of methods and materials with the matrix was a new non-routine situation (Badke-Schaub et al., 2011; Daalhuizen, 2014) and it was evident that they had not been required to consider physical, experiential and sustainability aspects simultaneously.

In a non-routine situation the user finds him/herself in a new situation. The path the user tends to go is based on prior experience of similar situations and if the user is not able to identify any similar situations from the past, new experiences have to be established (Badke-Schaub et al., 2011). The process of gaining new experiences is fraught with uncertainty. In materials ideation and selection it can be relevant to ask what an experiential attribute is, how the materials should be evaluated and how many requirements that should be included. Consequently, in modes of uncertainty, the need for methodological and structural support increases. The aim of the matrix was therefore to make the uncertainty phase and the establishment of new experience less troublesome, and, with time, to establish premises for making material selection a routine.

This can be monitored through scores in 'value for answering the (given) assignment' and 'potential future use of the matrix' in the Likert-scale statements. In the first statement, Track A (1.21) returned higher scores than Track B (0.71). An argument could be that because Track A had the unrestricted assignment first, they found it facilitated the following process. In contrast, students in Track B did not have anything to compare with when they evaluated the matrix. The scores given in the second Likert statement can support this argument. In the statement ‘potential future use of the matrix’ Track A (0.57) returned lower scores than Track B (1.14). An explanation could here be that because students in Track B were introduced to the matrix in their first assignment, they had the opportunity to get used to the matrix and thus were able to discover its potential for future use and for different assignments. The trend is similar in the statement concerning sharing a matrix with peers. This trend corresponds to the importance of having mental iterations that create value and increased cognitive knowledge. The development corresponds to Bloom’s taxonomy of learning (see p. 84ff). Whereas students in Track A have started to know and comprehend the materials selection matrix (step 1-2 in the taxonomy), students in Track B have become able to apply, analyze, synthesize and evaluate the matrix (step 3-6 in the taxonomy).

The responses from the students show some common characteristics when navigating an uncertain situation such as perplexity and narrow-mindedness. The students also demonstrated that they are not entirely novices and reflection at length on the method itself and how it affects the material selection in the end. As a student, in an unfamiliar and non-routine situation this can be overwhelming, and one’s knowledge seems insufficient. With the limited amount of time available for the students to use, reflect on and customize the matrix, it was not expected that it would become an integral and instant part of the students’ material practice. It was however a step in the right direction and demonstrates that the students in the study more easily could create new ideation and selection approaches that again can refer to Bloom’s taxonomy of learning.

Identifying experiential and sustainability requirements

According to the cluster diagram, the differentiation of requirements into categories was well received. However students found it difficult to identify requirements relating to experience and sustainability. Positive comments included that the matrix elucidated a broad field of various material aspects that needed to be taken into account; that it helped to discover the differences; and that it gave a better view of requirements. Negative comments included: that is was difficult to make a distinction between the categories; that the differentiation should be more flexible with respect to the number and grouping of requirements; and that there was too much emphasis on sustainability. Students showed few or no difficulties in identifying technical and sustainability-related technical requirements. However they found it difficult to combine experiential and sustainability-related aspects for design proposals. As the study was conducted on the first day in a course that emphasized experiential aspect of materials, students were not expected to have mastered these beforehand. The findings indicate that the course is relevant and provided an important aspect for understanding and using materials in design. However, it was expected that by the end of the course, students would find the matrix easier to use and thus assess it differently.

CHAPTER SUMMARY

This chapter presented a study that investigated the materials selection matrix in a materials course for industrial design engineering students. Based on previous findings, for the study, the matrix was modified to possess a higher degree of structure and put more emphasis on different categories of material requirements.

According to the study, students appreciated the materials selection matrix, and even though many had recommendations for improvements, they found inspiration in it to construct their own material selection approaches. However, even though the structure tried to put more focus on experiential and sustainability requirements, these were still underrepresented.

Summary

_ The study indicates that students find it easier to propose materials based on structured processes after they have been introduced to the matrix.

_ Students find the matrix useful for comparing materials and differentiating attribute categories, but they find the restricted requirements and the scoring approach useless.

_ The students found it difficult to identify experiential and sustainability requirements.

_ The study discussed topics such 'appreciation of effects and structure', 'first time use of the matrix' and 'identifying experiential and sustainability requirements' that supplement the concluding discussion.

10. TOWARDS AN IMPROVED METHODOLOGY FOR TEACHING MATERIALS

This chapter proposes a materials teaching methodology for design education. The methodology suggests a way to structure materials teaching to ensure progression of cognitive learning, make students able to reflect on and communicate material meanings based on physical, experiential and sustainability aspects and strengthen the transparency of material exploration and selection in design practice. In that sense this materials teaching methodology can be regarded as an attempt to establish a common pathway that helps shape students' relation to materials in design education.

The first part of the chapter is a reflection on the empirical studies from Chapter 7, 8 and 9. This departs from the role of learning environments and practices and considers the premises for teaching the topic of materials in different communities within design education. The reflection leads to a discussion on learning modes for a 'Learning through Materials' teaching methodology, contributing to the formal discussion that follows in Part IV_ Concluding discussion.

TWO ENVIRONMENTS, TWO DESIGN PRACTICES

The empirical studies in Chapter 7, 8 and 9 predominantly emphasize one learning environment at a time and focus less on how the environments differ, and how this influences a materials teaching methodology. Having worked with the materials selection matrix and been involved in and observed materials courses in the two learning environments the project is based on, it is evident that they build on different learning traditions and consequently also educate different kinds of designers. It is evident in the way students make sense and create meanings, referring to the sense making and sensegiving mechanisms previously discussed (see p. 93ff) and their value systems, being the aspects of design in which they are trained to establish their decisions (see p. 56ff). It means that even though students are all trained to become designers, practices within the design community vary, which influences how teaching methodologies should be structured. The following section provides a selection of examples highlighting how the two learning communities differ and how this results in different competences of working with materials as future designers.

Previously a community of practice was described as community with a shared understanding built through mutual engagement and a shared repertoire of communal resources (Wenger, 2000). Communities of practice are not fixed, static entities and have different structures of constellations depending on the perspective one adopts (Wenger, 1998: 127). This means that the design profession and design education will be regarded by some as one community, while others, most likely those involved in design will differentiate between them. In design education two questions can be formulated to delineate variations of practice communities:

‘How do students learn?’ and *‘What do students learn?’*

The first corresponds to learning as a social practice and the second corresponds to the content of learning being the ruling value system for the practice community in question.

Learning and practices

Learning as a social practice was introduced in Chapter 5 and emphasizes learning as situated actions that translate experience into knowledge. In social learning, meaning emerges through interactions between experiential learning and inspirational learning on a foundation of spiritual, conceptual and concrete worlds of experience. The two kinds of learning are regarded as sub-processes in a learning system (Bawden, 2010: 53).

Experiential learning is part of the active and interactive learning scheme (pp. 82-83) that puts emphasis on knowledge creation through the transformation of experience (Kolb, 1984). This can be done in either reflective observation or active experimentation and from a reality that can be grasped through concrete experience or abstract conceptualization. It means that experimental learning is “a recurrent process of adaption to change” (Bawden, 2010: 47), based on the cognitive world-view of the individual learner. Inspirational learning grasps reality through concepts or insights that are transformed through contemplation or application (Ibid.: 51). The learner is asked to engage with external factors from a conceptual world and transform it through internal contemplation, making the learner accept insights and apply them eventually in meaning-making (Ibid.: 52), based on a normative world view established by the community. The interaction between the subsystems of inspirational learning and experiential learning in meaning creation is illustrated in figure 78.

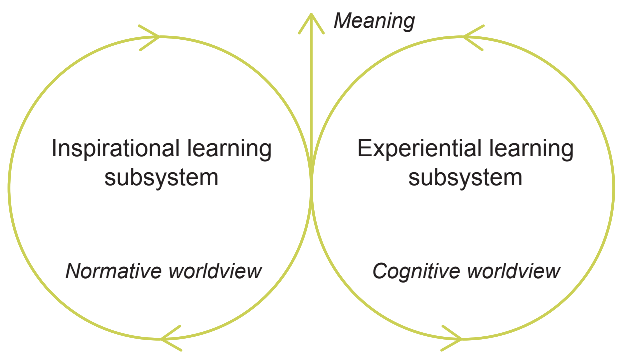


Figure 78. The subordinated systems of a learning system for generating meaning for actions (Bawden, 2010: 45).

Translated to the two learning environments of the empirical studies, inspirational learning is the dominating factor in the lecture-based learning modules, while experiential learning is dominant in workshop-based learning modules. In lectures, students are presented with concepts and insights, for example as overviews of materials, properties and product examples, while in workshops, students experience how materials act in practice. Consequently, differences in communities of practice within design education can be described through the emphasis on either of these two systems and how they balance each other. Here workshop-based learning modules dominate artistic design education, whereas lecture-based learning modules dominate engineering design education. This is illustrated in figure 79.

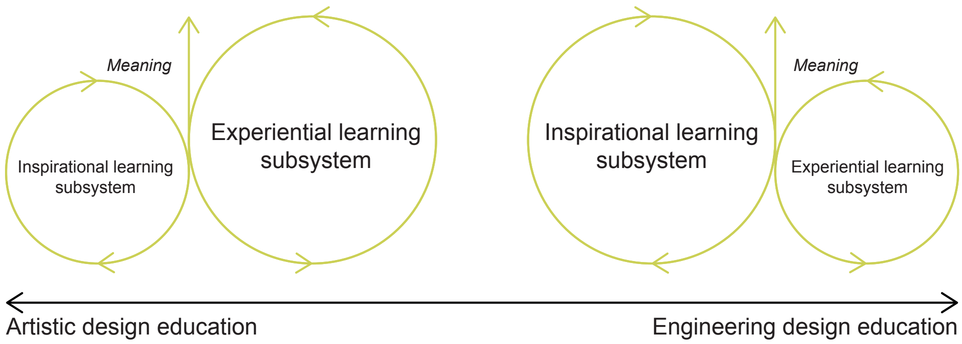


Figure 79. The balance between inspirational learning and experiential learning subsystems in artictic and engineering design education.

With reference to workshop- and lecture-based teaching the learning system described above corresponds to what can be called formal learning. Here this means the kinds of learning in the formal parts of the curriculum. However in design education, informal learning (e.g. Dewey, 1916) that occurs through observation and participation is also often present.

In Chapter 5 the notion of legitimate peripheral participation was used to describe the role of the master-apprentice relationship that was traditionally an important part of becoming a design practitioner (p. 87). Even though the master-apprentice practice is less applied in today's design education it still occurs in various ways. It is a requirement that students at Design School Kolding do internships to experience the professional aspects of their disciplines. This formalized practice is however very different from the master-apprentice-like relationships that can be observed among the school's students. Here it is common practice for undergraduate students to follow postgraduate students and receive help with practical work in return, in what Wenger calls 'learning-by-participating' (Engeström, 2007: 2). The less hierarchical arrangement of passing on knowledge, from student to student rather than from teacher to student in courses or from trainer to trainee in an internship, often creates deeper and more robust knowledge (Ibid.).

The common areas at Design School Kolding facilitate the continuous informal interactions between students and are important for inclusive and dynamic learning. In the workshops, students are exposed to other students' processes and work. The work desk areas, where each student has his/her own space, are open access and most student projects are exhibited in the school's common areas. Students are used to sharing experiences of materials and techniques as well as tools and methods. At Delft University of Technology students also learn from each other, but the premises are different, partly because there are more students and because the learning environment is quite different. Delft University of Technology puts a lot of emphasis on exhibiting student projects and the atrium in the center of the Faculty of Industrial Design Engineering is used for exhibitions. At the end of the semester, in some courses, students invite companies, academic staff and students to view their projects, often involving a physical prototype. The main difference lies in the accessibility of the processes taking place in the workshops and at the work desks, where the 'true' learning happens.

Content of learning

Without going into too much detail of the curricula, I will refer to Chapter 2. Design practice, education and research that highlights differences between the two traditions of design education. The different content of learning can further be elicited by looking at the kinds of design courses the schools offer. Here Design School Kolding teaches fashion, textiles, industrial, accessories and communications to designers, while Delft University of Technology teaches 'integrated product design', 'design for interaction' and 'strategic product development'. This indicates that Design School Kolding is grounded in traditional crafts disciplines with emphasis on practice, while Delft University of Technology puts more emphasis on design in a strategic and business perspective.

A FOUR-MODE MODEL TO STRUCTURE TEACHING METHODS

The previous section elaborated on variations in learning environments in design education, arising from different practices and value systems. From here it can be concluded that in order to establish a materials teaching methodology, different means of creating meaning and communicate materials are necessary. This creates the basis for proposing a model to structure teaching methods for materials, as well as other topics.

When researching for this project, it has been observed that several models are proposed to describe learning modes, including for experiential learning (Bawden, 2010; Kolb, 1984), inspirational learning (Bawden, 2010), competences and interests of students (De Nardo and Levi, 2014), cognitive learning (Bloom et al., 1956; Krathwohl et al., 1965) and learning processes (Illeris, 2002).

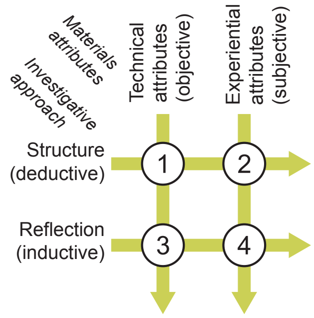


Figure 80. The Four-mode model that considers objectivity/subjectivity as well as struture versus reflection.

The proposed model addresses the construction and components of methods used for reflection and exploration based on two dimensions. One dimension considers the kinds of attributes that should be explored and the other considers the mode of exploration. For materials exploration and with reference to the previously used taxonomy, the first dimension differentiates between technical and objective attributes and experiential and subjective attributes; and the second dimension differentiates between structure and deductive reasoning and reflection and inductive reasoning. This offers a model to work with attributes and deal with technical, experiential and sustainable aspects of materials.

In the intersections of the two dimensions, four modes occur:

1. A mode that considers technical attributes by means of structural methods (objective and deductive)
2. A mode that considers experiential attributes by means of structural methods (subjective and deductive)
3. A mode that considers technical attributes by means of reflective methods (objective and inductive)
4. A mode that considers experiential attributes by means of reflective methods (subjective and inductive)

Figure 80 shows the two dimensions and the four modes. Modes that are horizontally aligned share approach (i.e. being either inductive or deductive), while modes that are vertically aligned address identical material aspects (i.e. being either subjective or objective).

Both dimensions relate to the value systems and attitudes of the users who investigate them. Most methods, including the materials selection matrix, contain both inductive and deductive components. Inductive components serve to open the exploration space, while deductive components serve to create coherence and rationality in the exploration. In the most recent version of materials selection matrix used in the study in Chapter 9, Steps 1), 2), 4), 6) and 8) embrace inductive thinking, while Steps 2), 3), 5), 7) and 8) embrace deductive thinking (see figure 73 on p. 185). Notice here that Steps 2) and 8) both comprise inductive and deductive thinking. In Step 2) relevant material requirements are identified. Inductive thinking (as reflection) is activated to identify relevant requirements based on the product and the context, while deductive thinking (as structure) is activated to ensure that the requirements cover whatever is found to be necessary. In Step 8) results are evaluated, based on an objective evaluation strategy from grading materials and calculating scores, but they should also be based on subjectivity and reflection on how materials rank compared to each other, and whether the evaluations are appropriate. Even though structural methods provide a systematized strategy to make decisions, it is important to remember not to use methods as automated processes with determined algorithms, but to be attentive, reflective and critical in every step and especially in the final result. There is no such thing as the perfect method for everything and everyone.

Four modes and communities of practice

The modes in the Four-mode model cohere with the two design education communities of practice of the project and can further be used to stress differences in their practice.

In the studies conducted at Design School Kolding, it was evident that students were unfamiliar with these kinds of structured methods use, resulting in difficulties in navigating between structural and reflective approaches. The materials selection matrix was introduced in a materials course that put emphasis on each of evaluating materials, identifying values of materials and choosing specific materials. This meant that students had to activate all four modes simultaneously and navigate between them, which was challenging.

In the study conducted at Delft University of Technology, students were accustomed to structures corresponding to Mode 1 and Mode 2. This was demonstrated through their approaches to the material selection matrices and to the unrestricted material selection process. They were further familiar with technical material aspects, which corresponded to Mode 1 and Mode 3. This was demonstrated by the diversity of material requirements identified. Accordingly tasks corresponding to Mode 4, reflecting upon experiential and sustainability material aspects were found especially difficult for students to understand.

Collection of tools

The Four-mode model calls for acknowledgment that different means to work with materials are essential in materials teaching to provide practices taking the physical, experiential and sustainability aspects of materials into account, as well as reflective and structured components. Therefore it is important to regard the materials selection matrix as part of a collection of means with different aims to work with materials in various ways. In materials teaching at Design School Kolding this includes moodboards, mindmaps, sketches, models and material tests among other things. It also includes the supporting teaching tools proposed and discussed in Chapter 8 (see from p. 142 ff.).

The materials selection matrix can be used as a framework to link and activate multiple exploration means in a more formal structure. In these studies, the materials selection matrix has not been used in a vacuum, but in interaction with many other inputs, and so it should remain. In the study conducted at Delft University of Technology, due to the limited time frame, students did not have much time to use supporting information. This resulted in more focus on the structures and components of the material selection itself. It was however the lack of contextuality, limited introduction to the categories of requirements, and the restricted process that were most criticized.

A new version of the materials selection matrix

Based on the above-discussed topics, I propose a new version of the materials selection matrix. The setup was tested in practice in the materials and sustainability course for fashion and textiles design students at Design School Kolding in spring 2015. The new version serves to expand the understanding of the matrix as a selection method, increasingly embracing it as a material exploration method and as a way to communicate reflections in the process.

In the new version the method is not presented as a fixed matrix template, but as a procedure that encompasses and highlights different aspects. The procedure contains six steps that in different ways encourage students to reflect on and structure their materials selection process. Some of the steps are identical to the steps in the previous versions, while others are new. In the design of the procedure, it has been stressed that it should provide an overall framework for considering materials, but each step should allow students to customize their own approach. The steps are:

(0) Sketch design brief,

(1) Identify material requirements,

(2) Determine evaluation method,

(3) Identify materials,

(4) Grade, describe and calculate materials,

(5) Evaluate results.

A sketch of the proposed procedure can be found in figure 81 (pp. 206-207) and in Appendix [A8] larger illustrations of Step 2) and Step 4) are included. The version has not yet been fully developed and needs to be refined.

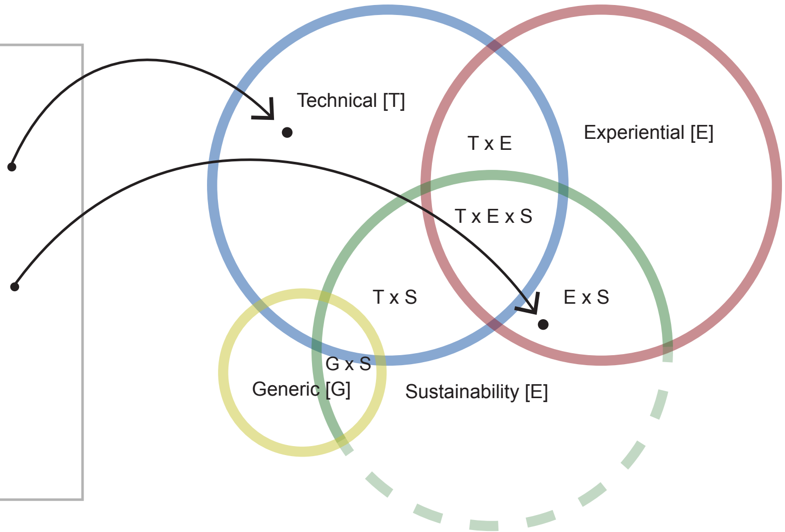
The steps in detail

In step (0) a design brief or assignment is sketched using drawings, descriptions

0) Sketch design brief

1) Identify material requirements

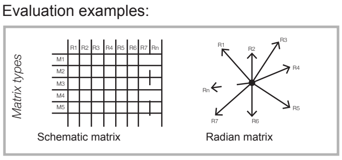
Material requirements



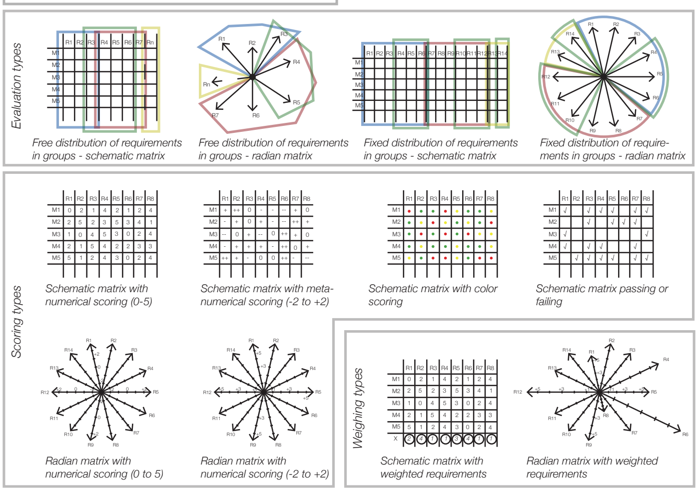
2) Determine evaluation method

Attach material samples, describe or sketch the materials in mind

Evaluation examples:



The materials can be evaluated in various ways. First decide whether to apply a schematic or radian matrix and how to evaluate and cluster requirements. Then determine what kind of scoring type you prefer. Finally decide if you want to weigh the material requirements.



3) Identify materials

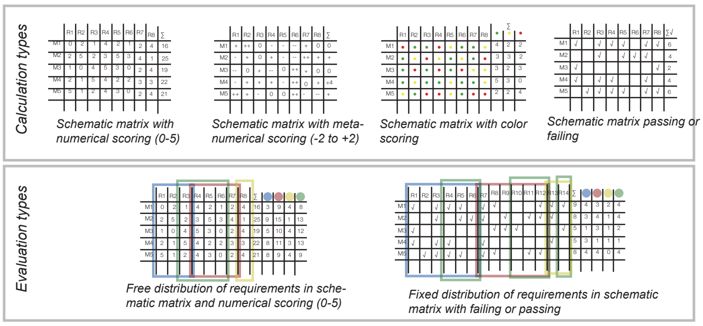
Attach material samples, describe or sketch the materials in mind

1.	2.	3.	4.	5.

4) Grade, describe and calculate materials

Base your grading, descriptions and calculations on the evaluation method

Calculating examples:



5) Evaluate result

Figure 81. The proposed modified edition of the material selection matrix as a method.

or other means.

In step (1), material requirements are identified. Modified from the previous version, the step includes two phases. In the first phase, relevant material requirements are identified using exploration methods such as brainstorming and mind mapping and are placed in the box to the left in step (1). Next, identified requirements are transferred and graphically distributed in their respective requirement categories in the circles to the right in step (1). These are: Technical attributes [T], experiential attributes [E], technical/experiential attributes [TE], technical/sustainable attributes [TS], experiential/sustainable [ES], technical/experiential/sustainable attributes [TES], generic attributes [G] and generic/sustainable attributes [GS]. Compared to the last version, some new categories have been included, derived from the P-E-S triangle introduced in Chapter 4 (figure 28 on p. 79). Accordingly, technical/experiential attributes correspond to attributes that relate to both technical and experiential material attributes (e.g. some sensorial attributes) and technical/experiential/sustainable attributes correspond to attributes that relate to technical, experiential and sustainable material attributes.

In step (2) the evaluation strategy is determined. The evaluation strategy is sketched and/or described in the box to the left in 2) and can be influenced by existing evaluation examples. These examples distinguish between a schematic and a radial matrix, free and fixed distribution of requirements in requirements categories, numerical, meta-numerical, color-coded and passing/failing scoring and weighted or non-weighted scoring (for details, see [A8]). The proposed evaluation types provide a range of different strategies that can be customized for the individual user and for different purposes.

In step (3) five materials are identified. To enhance the physicality of the matrix, it is proposed that physical material samples should be attached or alternatively described or sketched in more detail than in the previous studies of the matrix.

In step 4) the five materials are graded and described and the results are calculated according to the chosen evaluation strategy. The calculation system and the evaluation system are sketched in the box to the left. The phases of the step have been provided with explanatory illustrations to the right (for further details see [A8].

In step (5) the result is evaluated based on the previous steps and can be approached in different ways. In the evaluation it is important to determine, whether and if so, which of the categories of requirements are highlighted, and how non-numeric scoring strategies are assessed. Accordingly, in the evaluation of the result it is relevant to combine quantitatively and qualitatively acquired results to provide a sound argument for choosing the final material choice.

The supporting teaching tools presented in Chapter 8, relate especially to respectively step (1): tools that improve transparency, being comparative material scales and the Hanger model and step (3): tools that enhance material access, being the personal materials collection initiative and materials descriptions.

INTRODUCING A MATERIALS TEACHING METHODOLOGY

A materials teaching methodology for design education can facilitate and improve the relevance and coherence of materials in design practice and increasingly link value systems, vocabularies and methods used in materials teaching to the existing curriculum.

A methodology is proposed, established on three key aspects: 'Material accessibility', 'Material transparency' and 'Material approachability'. Material accessibility relates to the availability of materials in learning environments, material transparency relates to the understanding and translations of material attributes and meanings, and material approachability relates to means to transfer material knowledge and material information in present and future applications. In the methodology, each aspect includes strategies to explore and improve the material practice.

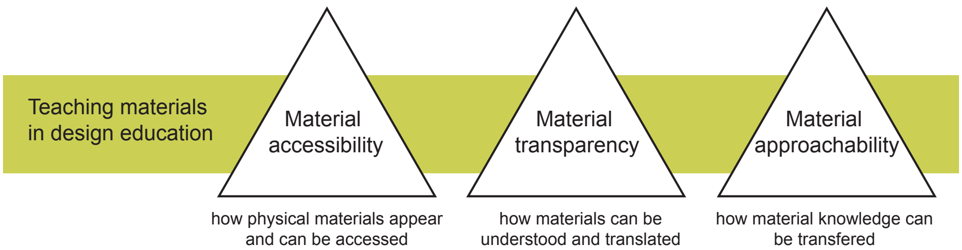


Figure 82. Schematic illustration of the materials teaching methodology.

The following elaborates on how educational material practice can benefit from using a materials teaching methodology, and provides a further introduction to the methodology and its components. It is partly based on the paper (draft version): 'A methodology for teaching emerging materials in design education' (Hasling and Lenau, XXXX) [P5], and uses references from relevant parts of the dissertation.

In cognitive learning theory (see Chapter 5), Bloom's taxonomy puts emphasis on building knowledge from the ground up, and to provide an expanding frame that can gradually embrace more complex knowledge systems based on the steps: remember (1), understand (2), apply (3), analyze (4), evaluate (5) and create (6). It means that the complexity of information provided and methods introduced should increase with time and experience. Many students expect materials courses to focus primarily on technical material aspects, which lose the focus on experiential attributes in the material practice in question. When materials teaching emphasizes experiential and technical material attributes equally from the outset, students become acquainted with the influence and roles of different material requirement categories that increasingly help them to construct personal meanings relations to materials.

The proposed materials teaching methodology has been build loosely on Bloom's taxonomy of learning and the three aspects build upon each other. Accordingly, tools that promote material accessibility primarily help students remember and understand materials; tools that promote material transparency help students understand, apply and analyze materials; and tools that promote materials approachability provide students with means to analyze, evaluate and create (from) materials.

Tools as the foundation of the methodology

Each aspect of the methodology is supported with tools and methods that provide reflection and structure on subjective and objective material aspects. In different ways the tools serve to develop students' cognitive comprehension of materials and to provide students with a set of shared means.

Tools that strengthen materials accessibility

In the first cognitive mode, materials accessibility, students should be given access to materials and technologies of all kinds to facilitate extensive materials exploration, and to allow students to start creating material meanings based on their own individual values. In the first phase it is essential that students gain interest and start reflecting on their understanding of materials, in order to create materials experiences in products for others later on. Thereby for the first cognitive mode, the personal materials collection and materials descriptions function as supporting tools.

In the personal material collection, students are provided with templates and inspiration for establishing their own material collections, with materials they are provided with as part of lectures, in practical workshops and while doing research for projects. In the materials descriptions students are requested to choose a material and describe it using keywords such as 'composition', 'description', 'production' and 'application'.

When students collect and describe materials, they are forced to reflect on and argue for their interests based on their existing understanding of materials. It converts students' materials awareness to socially established agreements, created through social interactions, when articulating material meanings and associations with others. This is in line with the interaction between internal and external pro-

cesses in meaning creation. While the process of making sense is internal, the synthesis through mediation of values and appreciations is external (Kolko, 2010b).

Even though both tools are presented with a template to fill in, students are not required to follow the template and the intention is more that it functions as inspiration and a foundation for the students' own work. With reference to the Four-mode model, the personal materials collection and the materials descriptions respond to mode 1 and mode 2 in the way that they provide structured overviews of selected materials and to modes 3 and 4 in the way that they require students to reflect on relevant material information. Consequently the tools facilitate both internal and external meaning creation.

Tools that strengthen materials transparency

In the second cognitive mode, materials transparency, students are trained in communicating materials in a continuous interplay with the surroundings and thereby challenging mental structures.

The comparative material scale is a tool to articulate and visualize mental structures of material meanings based on physical material samples and an attribute or keyword. It makes students explore materials using different senses that create awareness of how stimuli can be translated to associations. The scale further makes students discuss the coherence of associations of different kinds of material attributes among different people, which serves to create attention towards subjective and objective material means. With reference to the Four-mode model it means that the comparative material scale trains students in shifting between mode 1 or 3 and mode 2 or 4 when gaining knowledge on subjective and objective material aspects. When making orders of materials they create cognitive structures that refer to mode 1 and 2 and in discussions they reflect on their meanings and associations that correspond to mode 3 and 4.

The Hanger model is a tool to activate discussions concerning sustainable impacts in product design with emphasis on a selection of 'articulations of sustainable development' (using the terminology from Ashby and Johnson (2014) and Mulder et al., (2011) that previously has been applied in the thesis (p. 76)). The tool provides a foundation for considering sustainable design based on value systems among students and for potential costumers of sustainable design solutions. As it will be further debated in the discussion, making students choose three or four articulations as the departure for the development of sustainable product concepts appears to make concepts more strongly rooted in the holistic understanding of sustainable development. Thereby the Hanger model primarily develops students in mode 3 and 4 of the Four-mode model.

A tool that strengthens materials approachability

The third cognitive mode, materials approachability, comes with one method in the materials teaching methodology, being the materials selection matrix. The materials selection matrix has already been extensively discussed in dissertation and will only be briefly described here. It is used to assess a material candidate based on identified attributes within technical, experiential and sustainable aspects of materials. As part of the procedure of using the matrix both structural and reflective reasoning is activated, training students in making their selection process transparent, and providing students with the foundation for a materials selection practice that can be adapted to their preferences. The method embraces all modes of the Four-mode model in different phases of its procedure. For example, shifting between mode 1 or 3 and mode 2 or 4 is activated when positioning identified material attributes, mode 1 and 2 are activated when assessing materials using a specified assessment strategy and mode 3 and 4 is activated when identifying material attributes as one of the first phases in the procedure.

External supporting tools

Various external tools can support the materials teaching methodology. In the current methodology in the learning environment at Design School Kolding, two supporting tools are especially relevant.

The in-house materials collection provides a space for students to investigate various kinds of materials and become inspired. It further presents a way to structure materials that can be translated into the students' own personal materials collections.

Online-based material databases such as from the free access Materia and the subscription-based MaterialConnexion, Materió and Innovathèque enable students to explore materials in databases developed for designers and product developers, meaning that the structure and search criteria are customized for designers' needs and interests.

Furthermore it is relevant to acknowledge all other resources available in the learning environment such as the practical workshops, where students can manufacture and apply materials in different ways and the collection of materials oriented books in the library.

Tools that support each other

The methodology has been developed to ensure a cognitive progression when learning about materials based on procedure and meaning creation of a collection of tools. The following will briefly elaborate on, how the tools support and feed each other.

The overall frame of methodology is the materials selection matrix that provides a structured approach to evaluate materials. However to work efficiently with the matrix students need to have developed mental material meanings and a material language. The tools that enhance materials accessibility and transparency primarily create meaning and put little emphasis on materials application. Here students learn that materials are multifaceted and can be approached in many different ways. Adapting this mindset to otherwise restrictive and procedural material selection tools, a balance between reflection and structure in material selection is created.

The methodology and its proposed components have not been studied as a joint collection yet. However, as the materials selection matrix and the supporting tools have been used in materials teaching, it is possible to provide some indications of the appropriateness of a joint methodology. Selected advantages are for example:

- Materials collected in the personal materials collections can be used as potential materials in the materials selection matrix.

- Materials descriptions can provide information for used in the assessment in the materials selection matrix.
- The comparative material scale can be used as a comparative grading strategy in the materials selection matrix and
- The Hanger model can help identify sustainability articulations as requirements in the materials selection matrix.

Using the materials teaching methodology in other learning environments

The methodology has been developed for the first two years of the product design courses at Design School Kolding. The tools are relatively easy to approach and they focus on limited aspects at a time to make students feel secure in non-routine situations. The tools and methods have been developed to engage and encourage students to take ownership of the tools and the studies show that the tools can help students to understand and consider materials, because they involve their own subjective values and make them relate to the materials. From experience, it is apparent that students are motivated to establish their own materials collection after they have been introduced to the tool in the course. Moreover, students are more inclined to ask for and collect material samples, when they have been provided with a way to structure them.

It is however essential keep in mind that the methodology has been based on the learning environment and the course traditions at Design School Kolding. In order to apply the methodology in other learning environments it is essential to understand the underlying learning philosophy of the design course and thereby have insights in the community of practice in the learning environment.

The methodology does not judge whether artistic or engineering design is better, but provides a framework for structuring material teaching in design education. It means that the tools can be used with various emphases on technical, experiential and sustainable material aspects, but also that they can be used to give students alternative insights in materials aspects independent on the common way of considering materials.

To help others to use the methodology and tools, instructive guidelines have been made. The guidelines are based on the same structure, where the ‘objective’, ‘materials’, ‘time consumption’, ‘participants’, ‘procedure’ and ‘outcome’ are described. The guidelines can be found in Appendix [A8].

CHAPTER SUMMARY

The chapter consisted of two parts. The first debated on the influence of the learning environment on the practice of learning and the learning outcome. It led to the introduction of a Four-mode model that served to illuminate how methods and tools consider subjective or objective means using reflective and inductive or structured and deductive reasoning. Finally a new version of the materials selection matrix was proposed.

The second part introduced a proposed material teaching methodology that was based on the theoretical foundation and empirical studies in the project. The methodology is structured on three aspects: 'materials accessibility', 'materials transparency' and 'materials approachability'. The aspects framing the methodology have been discussed in two learning environments presented in Chapter 8 and 9. A 4-mode model has been proposed to help understand the logics of tools or methods based on subjectivity-objectivity and reflection-structure dimensions. The role of interaction of tools and methods and a modification of the materials selection matrix to highlight complexity and multifaceted options as a methodological procedure with different components rather than as a restrictive tool, is further discussed.

Summary

- The learning outcome is much dependent on the learning environment and the practice of learning that can be demonstrated through respectively instructional and experiential learning styles.
- The material selection matrix, a method to enhance students' materials approachability, has been presented in a new version.
- Methods for exploring and evaluating materials should navigate between physical/objective and experiential/subjective material attributes and between reflective/inductive and structured/deductive reasoning.
- A materials teaching methodology based on 'materials accessibility', 'materials transparency' and 'materials approachability' is proposed that contains tools and methods studied in the dissertation.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PART IV_ CONCLUDING DISCUSSION

Contents_

DISCUSSION

The following is a concluding discussion to elaborate on tendencies and findings from the project. It is concluding in the sense that it rests upon frequent discussions in the studies that have led to the proposed materials teaching methodology.

The concluding discussion first debates the five research questions and the hypothesis, predominantly focusing on the empirical studies. Afterwards a discussion is presented emphasizing various topics of the thesis, departing from 'Learning through Materials' and the research methodology that has been applied. The topics predominantly consider aspects that have been acknowledged late in the process and ones that revolve the procedural premises for the project and in the context it has been conducted.

ANSWERING THE RESEARCH QUESTIONS AND HYPOTHESIS

The project has aimed to answer five research questions (RQ1-RQ5) to illuminate the hypothesis. When the hypothesis and the research questions were formulated it was recognized that it would be a challenge to go into detail with all of them. The same level of detail has not been reached for all the questions, but the questions have been maintained as guidelines for exploring the field and to question continually, how the various aspects could be approached. Furthermore, as each research question considers relations between multiple variables, the variables have been identified to structure the discussion.

[RQ1] Design education

> *"How can a stronger focus on materials understanding in the design education, help students to use new materials as a more integral part of the design process?"*

The question has been answered from different aspects departing from the variables 'materials understanding', 'design education', new materials' and 'design process'. Basically, it comes down to providing means for students to acquire knowledge and become familiar with materials. This has been empirically explored through studies on the comparative material scale and the assignment on translating associative meanings into physical material samples.

In the pedagogical tradition in artistic design schools, practical experience and social interactions between students and objects are essential as this helps students to translate and create meanings. In their interactions, students make sense of materials, helping to develop their ideas on material meaning. This correlates to sense making and sense giving mechanisms (Gioia and Chittipeddi, 1991; Klein et al.

2006; Kolko, 2010b; Orlikowski, 2007; Weick, 2005) and the reversible process of sense making and sense giving as a means to establish individual identities among design students (Fachin, 2014). Consequently, as students establish correlations between their use of materials and their identity as designers, they use materials as more integral parts of their work.

The studies indicate that the challenge is to provide students with a language to communicate. The mechanisms are activated, when students make for example moodboards and mindmaps, sketches and illustrate, but they are not verbally communicated. The comparative material scale translates materials to meanings, while the associative material meanings exercise translates meanings into materials (cf. taxonomies of material attributes in figure 16). With reference to the Four-mode model proposed in Chapter 10, the comparative scale creates mental structures through deduction, while the associative materials meaning exercise translates meaning through induction.

Both the research question and the PhD call emphasized 'new' materials, but the dissertation has not put much emphasis on differences between conventional and new/emerging materials. However this has been discussed in the paper (draft version): 'A methodology for teaching emerging materials in the design education' (Hasling and Lenau, XXXX) [P5]. It is here argued that teaching methodologies for emerging materials do not differ much from the ones used for conventional materials, if the teaching methodology in itself provides room and flexibility for students to explore materials and create a multifaceted understanding of materials performance based on physical and experiential values. The challenges are however that new materials can be difficult to access and process in the common workshops at design schools. Compared to conventional materials, emerging materials are often more complex and build on an alternative understanding. It is therefore fundamental to establish a strong material practice in design education that provides students with tools and methods to explore and evaluate materials based on reflection and structure.

[RQ2] Materials teaching

> *"Which tools and methods are used and needed for the materials education to satisfy requirements from stakeholders such as students, educational institutions, and the industry?"*

The research question has three variables: 'tools and methods', 'materials education' and 'stakeholders'. The discussion will primarily consider 'tools and methods' and its relation to relevant stakeholders. The requirements of the stakeholders are inherent parts of the value set of the respective stakeholders.

The premises for teaching materials in design education have changed, which means that teaching methods should be revised. It was shown that students found it difficult to use the materials selection matrix in its present format. The teaching methodology provides students with procedural structures to frame material exploration and with supporting tools that individually and together provide additional insights. This aims to make students more active, individual and autonomous, and less reliant on support from teachers, workshop managers and other educational staff in exploring and working with materials. The tools should help students to gain materials knowledge based on experiential and physical aspects. As Daalhuizen (2014) and Badke-Schaub et al., (2011) have stated, students need methods and defined frames to navigate in unfamiliar processes to cope with uncertainty.

Tools and methods that challenge students' world-views function as boundary objects (Star and Griesemer, 1989) and continually stretch the boundary of students' comprehension and knowledge. Therefore it is in meeting with unfamiliar ways to understand the world that meanings are created as they have to negotiate a shared basis of meaning with the actors they interact with. Deduced from Daalhuizen (2014), students are more inclined to internalize things they are familiar with. Therefore it is vital to provide materials teaching that corresponds to the students' level of cognitive learning. The proposed materials teaching methodology has been developed to challenge students' comprehension of materials increasingly, based on accessibility, transparency and approachability. Materials teaching based on this methodology will thus increasingly help students to consider and integrate materials as part of their design practice.

From study of the matrix in Chapter 9, it was evident that students will consider using tools, if they find them interesting and immediately relevant. It means that tools have to be transparent and easy to use. Furthermore it is better to develop many tools that work together in flexible networks than one composite tool that must be used from beginning to the end to provide a result. As a result the methodology is on a procedural and yet flexible frame, where different supporting tools can supplement with inputs.

It can be stated that the tools have been well received, as they provide surprising outcomes for its users. This can be exemplified with the comparative material scale and the materials selection matrix. Students were surprised at the instant insights the comparative material scales provided on material appreciation, contextuality of attributes and subjective versus objective means. Similarly when students used the material selection matrix, they were surprised when this indicated that another material was more suitable than the material they first considered.

From the educational institution perspective, the project has primarily focused on, how material learning tools can interact with the remaining curriculum and how they can take part in lifting the curriculum as a whole. The methodology has been developed for materials teaching, but can also be applied for other courses. The tools and methods serve to make students acknowledge the value systems they make decisions on, and provide procedures that can give structured insights, when they evaluate phenomena. These phenomena can be materials, but it can also be products, services, concepts and so on. Materials teaching and what it brings with material exploration tools and methods should not be regarded as a solitary component in the design education curriculum, but as an integrated part that brings alternative aspects and diverse understandings.

The industry has not gained much attention in the project as the circumstances made it difficult to do this satisfactorily. The project has focused on students in the process of developing a material practice, which is a different premise from that which designers in industry would experience. In industry, designers and product developers are (usually) more experienced and they are expected to be able to navigate between the different aspects of materials presented in the dissertation. A workshop for industry to test and explore the materials selection matrix was planned, but was omitted for two reasons. As the project increasingly acknowledges the role of a joint methodology, rather than individual tools, studying the matrix used by practicing designers would be inconsistent and partly irrelevant for the topic. Furthermore, after studying the materials selection matrix at Delft University of Technology, it was realized that it is worth more, if users have time to work with it as well as having a specific concept to develop. Even though the study at Delft University of Technology provided other insights than those expected, they were very valuable as it dealt with students' appreciation of the method. In a potential workshop with industrial stakeholders the anticipated insights would be different and it would be necessary to modify the tools.

[RQ3] Material meanings

> *"What kinds of material meanings are essential for design students to strengthen their material awareness? - and how do they communicate materials'*

In the discussion of the question variables 'material meanings', 'material awareness' and 'communicating materials' are considered. All three variables can have different meanings for different stakeholders. Therefore to establish a common ground, 'material meanings' is the meanings actors embed in materials, 'material awareness' is the spoken and tacit considerations of material meanings and 'communicating materials' is the means actors use to transfer material meanings such as verbal descriptions and sensorial stimulations in design practice.

Meanings are more or less subjective and contextual and are up to the individual person to decide. It is therefore not about specific kinds of material meanings, but more about being able to navigate in the range of material meanings and being aware that different meanings are important for different stakeholders. It means that in understanding, which meanings are important, students should understand the value and appreciative systems of the stakeholders they design for (Schön,1983; Vickers, 2010) and be aware of the dynamics between sense making and sense giving in their work. Furthermore when designing for sustainability, students can create stronger concepts when understanding the interactions between physical and experiential attributes within a frame of sustainable development founded on environmental, economic and social aspects.

This 'awareness of material meanings' is challenged and growing when actors are interacting with other human actors, such as other students, companies, customers and non-human actors such as materials, techniques and products. Awareness is thus created between actors with different values and appreciations. In design education students with similar values, being part of the same community of practice often have esoteric communication. When students are presented to different ways to approach materials that offer systematic ways to construct supplementary meanings, they are challenged in their understanding of materials

Consequently the proposed tools and methods in the materials teaching methodology have been developed especially to make students aware of the meanings they embed when choosing or constructing materials. The comparative material scales are introduced to make students explore and develop their value systems. Similarly the Hanger model is used to give students a selection of sustainability articulations they can use as inspiration when they develop concepts.

According to the studies in the project, students predominantly communicate evaluations of materials based on objective means. However, in interviews students primarily used subjective means to describe materials, based on senses, emotions and associations. The two contradicting approaches to communicating materials often cause descriptions of materials to be inadequate. Thus the materials teaching methodology also serves to prepare students to communicate materials from both a physical and an experiential perspective and to build a bridge between the two means to communicate materials.

[RQ4] Material choices

> *"How do design students perform material choices? - and if this could be improved, how could it be approached?"*

The research question contains the variables 'design student', 'material choices' and the actions ‘perform’ and ‘improve’. It means there are aspects of a present situation such as in the beginning of the project and of a future situation such as now in the end of the project.

The preliminary studies in materials courses and interviews with students that had had the materials courses indicated that students predominantly consider materials based on their own experience, which makes good sense. With the materials courses that introduce more technically oriented aspects of materials, students are provided with an alternative way to understand materials. The challenge is to ensure that students’ subjective material meanings are well integrated with the objective material meanings from the materials teaching. This challenge is further stressed by the fact that students expect materials teaching to be focusing on technical materials teaching. This means that often students do not make links between their subjective interpretation of material performance and objective material performance such as physical and chemical properties. A consequence is that the materials courses in some ways risk to be cut off from the remaining curriculum, which is undesirable.

According to the empirical studies, tools and methods can improve the transparency of material choices in materials teaching and provide more robust outputs. The influence of tools and methods in materials choice can for example be demonstrated in the study conducted at Delft University of Technology, where students, who had been introduced to the materials selection matrix, applied more structure in a subsequent assignment (see figure 77 and 78 on pp. 192-193). However studies conducted at Design School Kolding also indicated that students sometimes use the materials selection matrix without reflecting on its components resulting in inadequate choices. Consequently tools and methods should encourage students to reflect and involve themselves more. This also includes recognizing that materials selection is based on multiple aspects that all have to be mastered.

From combinations of the studies conducted at Design School Kolding and Delft University of Technology, it was evident that the previous methods used influenced the reflection level and general use of the materials selection matrix. Students at Design School Kolding are not yet familiar with structural methods such as the materials selection matrix, which meant that students spent the course becoming acquainted with the method and structure of the matrix rather than reflecting on, and discussing, what the matrix is good for and where it has limitations. On the contrary students at Delft University of Technology are familiar with similar methods and they were able to identify benefits and shortcomings of using the matrix even within quite a short time.

In general students perform material choices predominantly based on objective means. It has been previously highlighted that subjective means figure prominently in artistic design education, but they are poorly acknowledged in the (articulated) selection process. Design is about understanding the experience of the object designed, and this includes experiential material attributes. The challenge seems to be that formal methods are linked to objective requirements, leaving vital subjective aspects out of the formal part of the decision-making process. To overcome the challenge, it is necessary to emphasize the multi-faceted nature of material requirements and to provide a vocabulary that works for both physical and experiential aspects.

[RQ5] Sustainability perspective

> *"How can a stronger material awareness improve the sustainable impact in product design?"*

The research question includes the variables 'material awareness', 'sustainable impact' and 'product design' related through the actions 'stronger' and 'improve'.

In Chapter 4. Understanding materials, it was stated that sustainable design can be articulated through many different aspects with focus on both quantitative and qualitative values. It was also stated that sustainable design can be many different things, as long as the (positive) 'articulation' (here meaning a specific action that lowers an environmental impact), considers related articulations and thereby establishes better conditions overall for actually making a sustainable design. This means that it is necessary to know how to navigate between sustainability articulations and understand how one articulation affects others, focusing on environmental, economic and social sustainable aspects.

The relevance and appreciation of sustainable design correspond to the value system that is attached to the application of the material or product and its intended users. Thus in order to provide a sustainable design and to evaluate whether there is a need for the product it is essential to understand, how the material or product is used.

If material awareness is understood as the spoken and tacit consideration of material meanings, being aware of meanings embedded in materials can enhance the 'quality' of the material in an application. This corresponds to both technical properties and experiential characteristics. Gaining knowledge of, for example, production processes and technologies can improve technical aspects of sustainable design, while gaining knowledge of consumptions patterns and emotional affiliations can improve experiential aspects of sustainable design.

In the materials teaching conducted at Design School Kolding, tools and methods to discuss sustainable design have been the materials selection matrix and the Hanger model. The Hanger model (Laboratory for Sustainability, 2013) can help communicate established sustainability articulations, and students use the model to define and specify sustainable aspects in projects. In the most recent materials and sustainability course held in spring 2015, students were required to choose three to four articulations from the Hanger model to base their sustainable design concepts on. They were also required to discuss, how the chosen articulations corresponded to each other and how they interacted with other articulations. Because students were obliged to depart from selected articulations, part of their concept development dealt with identifying a need and justifying the chosen solution, which in the end created concepts that considered different aspects of sustainable design in depth.

However, it was observed that students often find it difficult to express sustainability articulations related to experiential attributes. Therefore tools and methods should improve the tangibility of contextual material meanings and provide structure and reflection for exploring and evaluating as means to develop students' sustainability awareness. This has influenced the development of a third year course called Design for Change for fashion and textile students that puts emphasis on the emotional aspects of sustainable design looking at the past, present and future.

Hypothesis

> *"A stronger emphasis on materials teaching in design education can strengthen awareness on materials among (product) design students and can enable students to perform stronger and better-founded material choices in a sustainable perspective".*

The hypothesis consists of the five variables 'materials teaching', design education', 'awareness of materials', 'choices of materials' and 'sustainable perspective' that each has been the outset of one of the subordinated research questions.

The following will present some additional arguments that support the hypothesis and aspects that suggest adjustments to the hypothesis.

The project builds on the belief that materials teaching should allow physical, experiential and sustainability concerns to be assessed equally and jointly. The approach has been to develop a platform with the materials selection matrix in the center that increasing allows students to consider all means simultaneously. As it was emphasized in Chapter 4 and 5 teaching in materials is challenged by a traditional dualist way to understand and communicate materials.

The emphasis on diverse material aspects in the present curriculum is satisfactory, but a joint platform can improve students' ability to create holistic understanding of how materials perform. To provide a holistic approach to materials, it is essential that both technical and experiential aspects of materials are included in materials teaching and that students learn, how they correspond and interact.

Holistic thinking also applies for the role of materials in design education. In design courses that emphasize reflection and practice-based knowledge creation, materials teaching that predominantly focuses on technical aspects risks being divorced from the remaining curriculum. It means that considerations for choosing materials with the appropriate properties such as strength, elasticity and density as well as the chemical composition are not necessarily linked to the properties' influence on for example 'drapability' and 'dyeability' that in materials and products can be used to provoke emotions and create associations.

Consequently awareness of materials use (and of sustainable design) relates to understanding how material attributes affect each other, somehow similarly to the cause-effect relations in the learning schemes used by Beck et al. (2014) (see figure 30 on p. 82). Here the relation is between physical properties and experiential characteristics. As it was shown in the exercise on associative material meanings, multiple means to obtain the same key-phrases could be observed, suggesting that if an experiential characteristic is the cause a number of different effects can occur. Similarly if a physical property is the cause, a number of different effects can be obtained. As a result awareness of materials use corresponds to understanding this network of cause-effect relations.

The hypothesis was formulated in the initial stage of the project and my own understanding of materials has developed. Therefore as a supplement to the original hypothesis I will therefore add that:

> *''Materials teaching' is here understood as an activity that investigates materials based on physical and experiential values using structural and reflective means'"*

Material awareness is improved, when students actively consider, how materials perform based on physical and experiential requirements, which in combination with tools and methods make material selection transparent. Sustainable material choices are appropriated, when material requirements are based on both technical and experiential considerations, dealing with a given and defined articulation of sustainability.

TEACHING MATERIALS IN DESIGN EDUCATION

De Nardo and Levi argue that a dominant challenge in materials teaching in design courses is that students and lecturers have different competences and interests (De Nardo and Levi, 2014). Students are mainly interested in product applications, while lecturers, often educated in natural scientific or engineering subjects, tend to focus more on raw materials and technologies. Consequently it is necessary to create a platform, where lecturers and students understand each other.

In a topic such as materials, it is easy to lose students' attention if the approach gets too technical. It is however also important to remember that we are not all supposed to approach materials similarly, but that our various understanding can complement each other's. This means that artistic design students are not required to acquire the same technical understanding of using materials as engineering design students; and that engineering design students are not expected to go as much in depth with experiential aspects and to work as much practice-based as artistic design students are. However, to work with product design and especially when working with sustainable design, it is necessary to approach design as holistically as possible and consider both technical and experiential aspects equally. Hopefully the project provides insights that increasingly prepare students to use and appropriate materials based on physical, experiential and sustainable means.

The materials teaching methodology has been developed to facilitate the appreciation and use of physical, experiential and sustainable material considerations and to challenge students' boundaries of what materials are and what they can be used for and to provide a structure to explore materials. The methodology is therefore also preparing students to challenge other actors' understanding of materials and thereby continuing to grow and strengthen their own practice.

The project builds on a decade-long experience in materials teaching incorporating tools to develop students' understanding and awareness of materials gradually, which means that an informal materials teaching methodology has been customized for the students over time in the learning environment at Design School Kolding. Thus the material teaching methodology has been developed as a pedagogical toolkit, which provides a learning perspective that activates students in their learning process and force them to reflect on their choices. It is more important to know, how particular materials have been chosen, than what they actually are, and it is in the process of using and comprehending methods that 'real' learning takes place. The methodology thus provides a broader approach to consider materials and develops students' ability to perform structured and considered decisions.

Sense making and experience in design education

The materials teaching methodology builds on interaction between inductive and deductive mindsets in what can be described as abductive thinking. As previously mentioned by Kolko, design synthesis is an abductive sense making process (Kolko, 2010a) (see pp. 43-44). The design process is an iterative process incorporating 'thought', 'action' and 'decision' (Roozenburg and Eekels, 1995) and synthesis is part of the design process as the 'creation of possible solutions' part (van Boeijen et al., 2013). In materials teaching, design synthesis corresponds to the step where students appropriate and work with materials in order to become experienced with them.

Abductive thinking underlines the need for operating with different mindsets to challenge continuously the preconceptions students have when working with materials. In a constantly iterative process, shifting between inductive and deductive thinking students are prepared to create material meanings in internal processes based on their experience with materials, and to translate material meaning into external processes, when discussing how material meanings are embodying meanings into materials use and development (inspired by Kolko, 2010b). Thus one of the strengths of a coherent methodology instead of just individual tools and methods is that it ensures that students are challenged and trained in working with different modes of thinking. During the progression of the courses it can be observed that students become increasingly accustomed to gaining and analyzing information in different ways, improving their reasoning and decision-making.

It also means that a tool has stronger impact if it applies both deductive and inductive thinking and where students are forced both to create internal cognitive structures and to realize them verbally or practically. Consequently it is essential for working with comparative material scales, that students are given the opportunity to discuss their individual values and appreciations with others and thereby mediate and exchange values and experiences. The role of internal and external meaning making was evident in the exercises where the comparative material scale was used. It was observed that in the last exercise, which systematically shifted between internal and external meaning creation, the outputs expressed by students were generally more positive and reflective than in the previous exercises.

Similarly, students, who customized their personal material collections (which is a way of externalizing meanings), found it easier to describe materials for the collections and see the prospects in them.

An 'analogue' teaching methodology

It may seem strange to base a teaching methodology on analogue tools and methods in a society, where more and more is digitized. In the three years the project has lasted, an increasing amount of new means to explore materials have emerged such as literature, materials collections and tools. Chapter 6 presented the two digital tools, CES EduPack (Ashby et al., 2012) and the Rapid Design Module (SAC, 2015) to assess materials for respectively industrial and fashion design. The CES Edupack is widely used, especially in design engineering courses, and the Rapid Design Module, developed by the Sustainable Apparel Coalition as part of the Higg Index, encourages professional designers to investigate sustainability impacts of textiles and garments. Both work well for their purpose and some could wonder, why the material teaching methodology has not been based only on digital tools. The answer is rather simple. Unless users have spent a considerable amount of time understanding the data behind the program, there is a substantial risk that it may provide a false sense of security.

In the Materials and Sustainability course for fashion and textile design students took in spring 2015, a combination of the Hanger model, the Rapid Design Module and the materials selection matrix was introduced. The Hanger model (see pp. 102 and 159) served to exemplify sustainability articulations and how they interact (see p. 61), the Rapid Design Module (see pp. 102-103) helped students investigating the environmental impact of raw material and production choices, while the materials selection matrix provided a procedural frame for identifying material requirements, considering relevant materials and performing material assessments based on physical, experiential and sustainable criteria. It was deliberately chosen to keep the matrix as a hands-on method, that in contrast to digital tools available could be customized and modified to fit the students' products and their design challenges.

SENSE MAKING, EXPERIENCE AND SUSTAINABLE DESIGN

Previously Börjesson was quoted for saying that "product attachment is a precondition for the sustainability of products which highlights the designers' ability to create strong user-product bonds" (Börjesson, 2006) (p. 106), which links experience to sustainable design. Also in the hierarchical perspectives model proposed in Chapter 4. Understanding materials, experience is an aspect of sustainable design.

Experiential attributes in sustainable design education

From both learning environments in which the materials selection matrix was tested, students found it difficult to identify attributes that correlated to the combination of experience and sustainability. Moreover during dialogues and group discussions with students in the Materials and Sustainability course conducted in spring 2015, the topic was often focusing on positioning 'experience' in the triangular sustainable development framework. This indicated that students increasingly became aware of experiential aspects of sustainable design and started questioning, how they could contribute. After the course I reflected on sustainable development in design practice and consequently ended up asking:

> *"Where does experience fit into the models that describe sustainable development?"*

The Triple Bottom Line (TBL) was originally developed as part of a management tool for organizations to frame innovative initiatives and judging by how often it is referred to, it has proved to be a good way for companies to communicate sustainability initiatives. It is however dominated by the rational world-view of its developers, and therefore concepts such as 'experience' have difficult premises. However, as it was highlighted with the fifth perspective in the hierarchical perspectives model, cultural interventions and experiences have been incorporated as aspects in the philosophy that support sustainable development (figure 22, p. 72). This means that the Triple Bottom Line is not necessarily a proper or sufficient model to be used in sustainable design when aspects of experience are acknowledged.

Recently Fleming and Sherman have proposed a 'Quadruple Bottom Line' that adds an experience dimension to the original Triple Bottom Line (Fleming, 2013, 2014). It means that if experience is regarded as the cognitive process that incorporates reflection and meaning creation, as it was presented in Chapter 5, it can function as an independent entity and support the three remaining aspects. This also corresponds well with the idea of interaction between the aspects in the Triple Bottom Line approach.

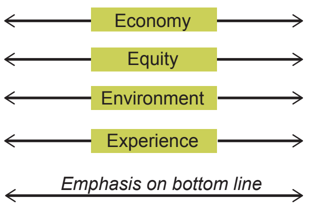

Figure 83. The four bars of the Quadruple Bottom Line as proposed by Fleming and Sherman (2013)

In their representation of the Quadruple Bottom Line, Flemming and Sherman apply four bars that each puts emphasis on an aspect (see figure 83). Nevertheless the model presented here builds on the original triangle where an extra dimension has been added. This creates a pyramid with a triangular foundation, as it has been illustrated in figure 84. In a triangular structure interrelations between the four aspects are maintained through positive and negative implications as it was demonstrated with 'articulations of sustainable development' in figure 25 in Chapter 4 (pp. 75-76).

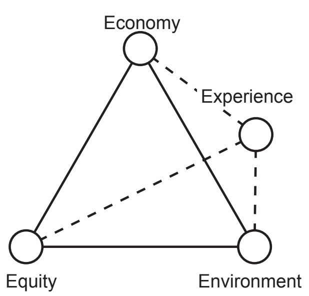

Figure 84. An interpretation of the Quadruple Bottom Line (QBL) as proposed by Fleming and Sherman (Fleming, 2013)

The model can be connected to Fletcher's anthropology inspired user study 'Local Wisdom' that explores 'the craft of use' in fashion consumption ("Local Wisdom," 2015). The study investigates consumers' relation to clothing through notions such as 'sharing', 'multiple lives', 'storytelling' and 'adaption' (Ibid.).

An example of a string of sustainability articulations starting from 'experience', could be that if a woman has strong positive associations with a knitted sweater, she keeps it and repairs it instead of buying a new. This result in less raw materials usage and thus lower consumption of energy and water in production process, but also lower earnings for companies that sell similar sweaters and possibly less demand for people working with raw materials production unless the selling price is higher.

The Quadruple Bottom Line has not been explicitly applied in the materials courses of this project, but as it is further discussed in the following section, it is suggested that the added dimension provides a space for designers to incorporate sustainability as an intuitive way of thinking, corresponding to design as a practice and discipline, and to the learning environment of design schools. This also means that sustainability considerations find their way increasingly into the remaining curriculum. This is on its way in the fashion and textiles programs at Design School Kolding, where sustainable aspects become more explicit in courses. Here the third year course, Design for Change becomes a natural progression of working with experiential sustainable issues after students worked with materials and the dual natures of materials, in the Materials and Sustainability course.

Sustainability taxonomies in the materials teaching methodology

The project applies two taxonomies to integrate and discuss sustainable design aspects in the materials teaching. The first taxonomy differentiates between physical and experiential material attributes rooted in objective/physical and subjective/social values, as illustrated in figure 16 in Chapter 4 on p. 62. The taxonomy was for example used to identify relevant attributes in the materials selection matrix in Chapter 9. The second taxonomy departs in the Triple Bottom Line and was introduced as a means to approach sustainable design. However, as was stressed in the previous section, students in artistic design education are likely to find sustainable design and the use of the model more relevant, if a fourth and more relational aspect such as 'experience' was added. The two taxonomies share some characteristics so:

> *"Is it relevant to use both taxonomies or does this risk making students more confused (than necessary)?"*

Experiences from the courses described indicate that it is relevant to use both taxonomies, because they touch upon different ways to approach materials and sustainable design and that they can support each other. Thus they accommodate students' different mindsets as well as different 'design problems' such as functional and symbolic aspects.

The Quadruple Bottom Line considers sustainable product design as a holistic activity, whereas the physical/experiential scale specifically corresponds to materials choices in the materials selection matrix. Thus the physical/experiential scale puts emphasis on primarily two aspects in the Quadruple Bottom Line, namely environmental and experiential aspects. In the materials selection matrix students are asked to identify physical, physical/sustainability, experiential, experiential/ sustainability and generic material attributes, meaning that economic and social aspects are more or less eliminated. It does not mean that these are not important, but the range of attributes has been simplified to make the matrix easier to use.

The holistic philosophy applied in the Triple (or Quadruple) Bottom Line has inspired the Hanger-model that was developed by Brian Frandsen and Laboratory for Sustainability at Design School Kolding. The Hanger-model is visual and thus easy to grasp and work with for design students. It puts emphasis on highlighting various dimensions of sustainable development in a Cradle-to-Cradle framework. In the recent Materials and Sustainability course in spring 2015 students were required to use three to four aspects from the Hanger-model as the foundation for a sustainable design solution. Using the aspects, they had to discuss how they interact and interfere with each other, as in the 'articulations of sustainable development' (pp. 75-76).

Formalizing the Hanger-model to establish a foundation for sustainable design concepts was inspired by an impulsive and intuitive use of the model by students in previous courses. In the courses students found it easier to articulate design intentions and sustainability strategies after an introduction to the model.

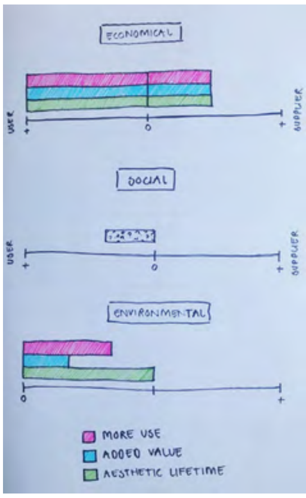

Figure 85. Operationalizing the Quadruple Bottom Line approach and creating links from economic, social and environmental to experiential aspects using 'sustainability obstructions' (from the Materials and Sustainability course in the spring 2015 by Line Nygaard Jensen, Anine Svane Olesen, Lotte Hahn Koefoed and Anne Hagsten).

The output of mandatory use of the model was that students increasingly acknowledged that concepts within sustainable design become stronger, when time and effort have been used on identifying a need and prioritizing how the need could be fulfilled. The use of the Hanger-model also initiated discussions in the groups of the role of experience in their designs, which refer to the aforementioned critique of the Triple Bottom Line.

Some groups developed their own systems to incorporate their aspects from the Hanger-model in the Triple Bottom Line, of which one is included in figure 85. The students, Line Nygaard Jensen, Anine Svane Olesen, Lotte Hahn Koefoed and Anne Hagsten studying fashion and textiles design used a bar version of the Triple Bottom Line to indicate, how their concept influences 'more use', 'added value' and 'aesthetic lifetime' for the user and the supplier in what they call 'sustainability obstructions'. The obstruction, here their concept, serves to illuminate and challenge relations between environmental, economic and social aspects, thus being comparable to articulations of sustainability. The three aspects all belong to the 'experiential' aspect of sustainable design suggesting that the students have used intuition and reasoning to operationalize the Quadruple Bottom Line. The sustainability obstructions were identified for the specific project, but it is a good example of the need to enable students to modify models and tools to fit their individual ways of creating meaning.

Artistic design education as a promoter of sustainable design

In different ways the studies show that students increasingly become better at reflecting on and articulating the dynamics between technical and experiential material attributes and their relation to sustainable design. By differentiating between sustainable considerations that relate to technical and experiential aspects respectively, students were forced to reflect on the concepts of sustainable development and sustainable design and in their various levels and perspectives.

In the last Materials and Sustainability course in the spring 2015 it was thus interesting to observe, how students increasingly were able to navigate and use sustainable thinking as a driver instead of a barrier. Instead of regarding sustainability as something related to predominantly energy consumption, waste water and gas emissions, they linked sustainability to their future profession and to the competences they already have. It meant that students allowed themselves to be creative and 'designerly' because they felt more familiar with the assignment.

Based on the above it can therefore be suggested that students in artistic design education increasingly should be introduced to sustainable design in relation to their competence. It must also be stressed that objective means to approach sustainable design, such as those based on technical and physical aspects, are also important and should be considered as part of a solution. It is however reasonable to say that in an artistic design approach to sustainable design, it makes sense to consider technical and physical characteristics as part of a system supporting experientially oriented sustainable design. This means that in experientially oriented sustainable design, the experience of users should be the driver for change, while more environmentally oriented aspects become positive side effects of it.

THOUGHTS ON THE RESEARCH METHODOLOGY

The present version of the research methodology was formalized during the course of the project, when a preliminary understanding of the problem area had been established and the first materials courses had been conducted. The research methodology was developed based on the available conditions and with the knowledge and insights, which I, as a researcher, had at that time. Even though the methodology has served its purpose, some aspects can be discussed with hindsight.

The use and the relations between the motivation, the hypothesis and the primary and subordinated research questions were discussed in the end of Chapter 3 (p. 40ff) and will therefore not be further mentioned.

Use of theories and notions

Theories and notions have been used to support empirical findings and as inspiration for some of the structures and taxonomies that are proposed in the thesis. As it can be derived from the network of theories and notions provided in Chapter 3. Design methodology (on pp. 33-36), several theories, concepts and notions have been used to describe the phenomena the thesis builds on. The theory presented in Chapter 4 serves to establish the understanding of materials both as physical and social objects, and the role of sustainable design in materials practice, while the theory presented in Chapter 5 serves to frame the context of the studies for understanding the premises for materials teaching. It means that the project has had three main theoretical departures. The theories have origin in similar epistemological traditions, which means that many concepts overlap, but also differ slightly. The project was deliberately structured so as not to be restricted by a few theories and concepts, as it aimed to embrace multidisciplinary views. However it is also recognized that this may have caused some ambiguous and vague definitions of some concepts and may have caused the reader to juggle between many concepts at the same time.

The use of theories and concepts has also been influenced by the fact that when searching for explanations for an observed phenomenon, it was necessary to consider theories that I, as a researcher, was unfamiliar with. The use and combination of different theories forced me to put much effort into understanding how these theories relate, how they differ and how they can be combined to provide the best overall understanding of the field. Consequently theory use in the project has predominantly been inductive.

Working with students in a dynamic learning environment

The primary empirical studies have been conducted in the two mandatory materials courses at Design School Kolding, which influenced the consistency of output. When a live situation is used as a research context, unexpected events occur, and it is not always possible to control how experiments develop. The materials courses changed during the project, modifying the premises of the experiments. It has therefore been difficult to provide a consistent and unambiguous narrative of the progression of studies and how they relate.

It is important to mention that the learning environment at Design School Kolding in general has contributed with vital inputs to the progress and findings of the project. Having taught in the two materials courses, students have become familiar with my competence as a teacher, my interests and most importantly, this project. Consequently it has been possible to follow, informally, how students develop their material practice after the materials course. Some of the greatest discoveries in the project have happened when time has been spent in the workshops discovering what students were making and how they worked. Therefore the challenge of being able to conduct structural studies in the materials courses has paid off, by being given the opportunity to experience the 'real materials practice'.

The role of experience

The primary studies are based on first and second year bachelor students. This arose because I was assigned to teach in their respective courses. Nevertheless, it turned out to be optimal research conditions, as students in this phase of the studies really 'learn'. They are subjected to so many new things and concepts and in the development of individual designer identities, they progress rapidly. Students were eager to learn, and had not been (too) influenced by other courses, thus providing good conditions to study 'learning through materials'. Working with considerably inexperienced students further means that the initiatives you present in teaching will appear to have comparatively higher impact.

Limitations and prospects in the empirical data

The premises for conducting experiments in the project have influenced the availability and impact of the empirical data. The empirical data have predominantly been collected in two materials courses at Design School Kolding, where between 10 and 36 students have participated. Moreover the courses have consisted of various groups of students from different design disciplines. It means that it would be misleading to analyze the studies quantitatively. Although quantitative approaches have been used to identify tendencies in observed phenomena, the study should not be regarded as quantitative. Similarly the interviews with eight students should not be interpreted as representative of all design students, but as providing insights into these students' current material practices.

Because the empirical data has been collected in materials courses, iterations have been restricted to follow the curriculum. Thus within the time frame of the project it was possible to conduct experiments in the materials introduction course in two consecutive years and in the materials and sustainability course in three consecutive years. As the tools and methods have developed, it has not been possible to test two identical versions after another. This is also the reason for not having been able to test the materials teaching methodology as a whole.

From the above limitations it can be argued that the reliability and credibility of the study is questionable. The project has investigated a broad topic based on specific research objects, a narrow group of research subjects in a closely defined context. The intention has not been to provide universal knowledge, but to create 'point' knowledge immediately applicable for the given learning environment, as well as to illuminate trends that appear in the study, and should be further studied to become generalizable. Because the project has focused on one specific learning environment, the proposed tools have been developed with this in mind. This means that they may be difficult to appropriate directly into other learning environments. The tools guidelines in the appendix are included to ease this.

Having double roles in a research project

The one main aspect that may raise some questions about the reliability and creditability of the project is the double role, of having been both the researcher and the lecturer, as this affects the ability to remain objective. However the double role has not seemed to cause evident problems and since it was a premise from the beginning, it has been utilized to become part of the investigative method.

In the two materials courses at Design School Kolding students have been informed of my double role and that observations and student feedback could end up as inputs into the project's findings. Students have found it exciting learning that they were the focus of the project and they have been open-minded and eager to take part in discussions that related to the scope. The two courses are pass/fall courses meaning that students could not get measurable preferential treatment, restricting the benefits for students to general interest.

The eight students interviewed voluntarily participated and the interviews were not conducted simultaneously with any of the courses. The materials 'pop quiz', used to extract data to evaluate material knowledge, was conducted in another learning environment without me being there. Finally the workshop at Delft University of Technology was conducted in a course, where I was not in charge, and I therefore did not have any influence on the students' final results.

The primary strength of the double role has been that I, as a researcher, have had access to actual materials teaching and have gained the students' trusts as me, as a lecturer, to establish a longer lasting learning environment where different material perspectives could be investigated. The teaching part has had first priority all along, which means that common research methods such as having 'control groups' have not been considered. The strength of the double role became evident after the workshop conducted at Delft University of Technology. The workshop itself provided useful information on approaches to and outcomes of the materials selection matrix, but it provided limited knowledge of what happened before and after using it. At Design School Kolding I, as a lecturer, have been present from the beginning to the end of the materials courses taking active part in teaching and supervising students in their process meaning that to students I was a lecturer more than a researcher. It created dynamic relationships that generated knowledge beyond what was experienced in the workshop.

Prospects

The very narrow scope has also provided valuable insights that less contextual studies would miss out on. It was deliberately chosen to focus on a specific primary context. The courses and the learning environment at Design School Kolding have functioned as an appropriate initial setting for establishing a materials teaching methodology. It has created a project that is strongly linked to the educational institution and the participating students that would have been difficult to create, if the project had been less contextualized.

Because the project has been developed with one particular learning environment in mind, it means that its findings are easy to integrate in the curriculum. Therefore it is also acknowledged that it is necessary to conduct further studies to understand the methodology and its tools as a holistic system that can be used in learning environments that are not at Design School Kolding, for instance, national as well as international, design-related as well as not design-related and educational as well as corporate learning environments.

CONTRIBUTIONS

The core contribution of the project is a materials teaching methodology that builds on three steps: ‘Materials accessibility’, ‘Materials transparency’ and ‘Materials approachability’. It incorporates objective and subjective aspects of materials to consider physical and experiential attributes increasingly as joint means in material considerations for sustainable product design. The core contribution corresponds to the PhD call, stating that the project should “contribute to building knowledge of new materials in a broad design sense (…)” and “strengthen creativity and innovation in terms of education and practice, contribute to renewed self-understanding, and support design solutions to the many future challenges of product design” (“PhD call,” 2011).

The project has been built on experience and knowledge from the existing materials teaching at Design School Kolding and contributes to an expanded understanding of material teaching aspects used to improve teaching in changing conditions. The methodology has incorporated tools and methods to prepare students to work with materials individually, and in groups, and to take responsibility of future material explorations, including sustainable aspects in the early design phase.

EDUCATION

Established on both design engineering and artistic design research, the project can contribute to building bridges between different approaches to understanding materials in design. In that sense it can contribute to better communication and knowledge sharing in the design field. Within design research, the project can contribute with insights into the multidisciplinary fields of learning and materials.

Even though the primary context for the project has been Design School Kolding, the project has been based on issues that apply to other design courses as well as other disciplines in academia and industry. The project suggests a teaching methodology for materials, but it could also be applied to other parts of the design curriculum. It has been established on a generic model to provide progression in cognitive learning and to accommodate changing conditions in learning environments that can support the academization of artistic design courses to train students to articulate, what they do and how they make choices.

The structural approach to a teaching methodology can help ensure that learning is progressing, and in design schools currently transforming into universities, the methodology can provide a structure to develop curricula from. With this it is suggested that the methodology can contribute as a framework to understand teaching in general, and can be customized for specific purposes and aims.

The strong emphasis on experiential material attributes generated through sensorial experiences, associations and emotions can be valuable for more technically oriented design courses and can help to create value and appreciations for materials in use.

PROFESSION

For the design profession and industry, the dissertation can contribute to expand and structure material explorations as part of product development. Even though the methodology has been developed for students with differing experience levels from those expected for design practitioners, insights from the dissertation can help to put emphasis on physical, experiential and sustainable material aspects and how they interact. The work can strengthen strategies thereby, for instance by clarifying sustainability strategies in a company or for specific products. It can also provide valuable insights in user experiences of materials considered for products.

Design practitioners can find inspiration in the methodology as a whole or in the specific tools and methods to explore different aspects of product development. The materials selection matrix may be used to investigate materials choices in a procedural structure. Materials collections may be used to overview available and needed materials; comparative material scales may be used to explore tacit meanings of materials based on subjective preferences, and the Hanger model to explore and articulate sustainability articulations.

RESEARCH

Within design research, the project can contribute with insights into the multidisciplinary field of learning and materials.

In the Introduction the project was positioned within 'research in, through and for design' and it can also contribute to these communities within design research. With its focus on materials, the dissertation can contribute to the research communities working with materials experience, such as communities within 'Materials for Design', 'Human-Computer Interaction' and 'Interaction design' and 'Design semantics'. It can also contribute to the 'traditional' design engineering community, with its emphasis on stronger relationships between physical and social aspects of materials, by applying reflective thinking, and also to the artistic design community by applying a higher degree of structural thinking in the decision making process. Finally the research design can contribute as a methodological example of combining methodologies from artistic and engineering design research.

When looking beyond design research, the project may contribute in a couple of research fields. With its focus on learning process, the dissertation can contribute to research into learning processes, especially those within ‘active and experiential learning’. The dissertation can also contribute as a methodological example of ‘action research’.

FUTURE WORK

It is acknowledged that the thesis leaves some unanswered questions and provided some speculative models, procedures and methodologies that point to future research.

The project has identified different aspects of materials teaching in design education and as part of the project, a methodology for teaching materials has been proposed, including selected tools and methods. The methodology has been developed on the basis of three years studies, but as it was condensed in the last stage of the process, it has not been fully explored in teaching situations. It means that it is necessary to explore how it works in practice and how its integrated tools and methods function together.

The tools and methods have been tested and developed simultaneously in the project. They need to be further studied to refine and optimize their functions. This means testing the latest version of the materials selection matrix and exploring how the different steps work individually and interact together. It also means to explore further how comparative material scales can explain how different senses act. It was superficially studied in the Materials Introduction course conducted in January 2015, which provided some interesting insights. The comparative material scale could appropriately be combined with the Expressive-Sensorial atlas (Rognoli, 2004) and the Repertory Grid technique (Bang, 2010) to explore further material meanings across the continuous scale of abstraction levels in material attributes.

As part of the contribution a Four-mode model has been proposed to create methodological awareness on the two dimensions: objectivity/subjectivity and structure/reflection. This two-dimensionality should be further investigated to understand, how present tools and methods function and how they can be improved.

Finally it would be relevant to explore, how the teaching methodology applied in the two materials courses influences students' material practice; not only during their studies but also in their future professions. Due to the limited time frame only the material practice of design students has been considered. I am well aware that I eliminated very important actors thereby it would be relevant to study how established actors in the design profession approach the materials selection matrix and the methodology behind it.

Photo by Diana Lovring

POSTLUDE_

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INDEX

SUMMARY

This dissertation documents a PhD project concerning learning about materials in design education. The project has aimed to understand, how design students approach materials in their design practice and to propose modified teaching structures that can accommodate a stronger focus on materials in their design practice.

The project has been conducted at Design School Kolding, a Danish artistic design education rooted in arts and crafts, with emphasis on hands-on experience. Using different theoretical viewpoints, the project has explored how materials understanding and teaching materials, traditionally focusing on objective material attributes, can integrate and consider subjective and social material values to a greater extent. In the project objective material attributes have been referred to as physical material properties and subjective material attributes have been referred to as experiential material characteristics.

In recent years sustainability has become increasingly discussed and challenged, in the society as well as in design discipline. This project has engaged sustainability as a means to establish meaningful material requirements when developing and selecting materials in product design. It has been stressed that sustainability issues should be related to both physical and experiential material attributes.

The project has departed from the hypothesis that "a stronger emphasis on material teaching in design education can strengthen awareness of materials among [product] design students and enable students to make stronger and better-founded material choices in a sustainable perspective". To explore the validity of the hypothesis, the dissertation has been divided in three parts.

The first part presents the conditions and premises for the project, including developments in the material landscape and in design practice, learning environments in design courses, how the projects has positioned itself in design research and towards adjacent research communities and finally the research methodology that has been applied.

The second part discusses materials and learning from a selection of theoretical viewpoints, stressing meanings of materials, learning materials as a social practice and the role of reflection and experience in meaning creation. Viewpoints stem from as varied disciplines as science and technology studies, anthropology, learning theory, engineering and organizational theory.

The third part constitutes the empirical contribution of the dissertation. Based on experiments conducted in materials courses and interviews with students, it has been studied, how students value, communicate and select materials. The primary object used in the studies is the materials selection matrix that during the project

has been iteratively modified to optimize students' benefit from using it. Other objects have been the comparative material scale and the personal materials collections initiative. The objects have been analyzed using a combination of structured analytical methods and observations in courses and interviews.

The findings of the project are multifaceted. It has been shown that students find it difficult to relate to, communicate and consider experiential and sustainability-related material attributes. Therefore it is necessary to rethink, how these aspects can receive more attention in the practice of materials education. It is evident that students find it easier to approach materials, when they have been provided with tools and methods developed to articulate material meanings and structure material selection in design projects.

Based on the findings, the dissertation proposes a progressive materials teaching methodology that builds on three pillars being materials accessibility, transparency and approachability. With accessibility, students should be provided with tools and methods to access and explore materials, with transparency tools and methods to translate and identify material meanings and with approachability tools and methods to approach and structure materials investigations for material selection in product design.

This dissertation wants to address researchers and lecturers involved in materials in design education. Additionally researchers and lecturers that work with materials in other disciplines and other disciplines within design education can find inspiration in the work. The considerations of experiential material values can benefit more technically oriented courses and the emphasis on a teaching methodology rather than distinct tools and methods can be used as inspiration for other parts of design education. I have valued to make the dissertation accessible to the students it has focused on. It is hoped that design students will find inspiration in this work and make use of the views on materials and the approaches to evaluate and develop materials in includes. Finally, I believe that design and production companies could use this dissertation to gain new insights for discussing and communicating materials when materials are developed or explored.

Core contributions of this dissertation include a materials teaching methodology that incorporates interactions between physical, experiential and sustainable material aspects based on value systems, and the individual tools and methods it includes. The methodology further contributes with approaches to embrace structured and reflective means towards understanding materials.

RESUMÉ

Denne afhandling dokumenterer et ph.d.-projekt om læring om materialer i designuddannelsen. Projektet har haft til formål at forstå, hvordan designstuderende arbejder med materialer i deres designpraksis og at give løsninger på, hvordan materialeundervisning i stigende grad kan imødekomme et større fokus på materialer i designpraksissen. Projektet er blevet udført på Designskolen Kolding, en dansk designuddannelse med rødder i kunsthåndværk og med stort fokus på praktisk erfaringsdannelse. Med udgangspunkt i udvalgte teoretiske tilgange har projektet undersøgt, hvordan materialeforståelse og materialeundervisning, der traditionelt har fokuseret på objektive materialeattributter, i højere grad kan integrere og tage hensyn til subjektive og sociale materialeværdier.

Bæredygtighed får voksende opmærksomhed og bliver diskuteret og udfordret i samfundet generelt såvel som i designfeltet. Projektet har integreret bæredygtighed som en måde at skabe meningsfulde materialekrav når materiale skal vælges og udvikles i produktudvikling. Der har været lagt vægt på, at bæredygtighedsproblemstillinger skal relateres til både fysiske og erfaringsbaserede (experiential) materialeattributter.

Udgangspunktet for projektet har været hypotesen at ”et øget fokus på materialeundervisning i designuddannelsen kan styrke materialebevidstheden blandt [produkt]designstuderende og gøre studerende i stand til at foretage mere solide og velfunderede materialevalg indenfor bæredygtige rammer”. Hypotesen er blevet udfoldet og undersøgt gennem afhandlingens tre dele.

Den første del af afhandlingen præsenterer den ramme projektet er blevet skabt i og de vilkår og præmisser, der har styret projektet. Det inkluderer ændringer i materialelandskabet og i designpraksissen, læringsmiljøer i designuddannelser, hvordan projektet har positioneret sig selv i designforskningsfeltet og i forhold til omkringliggende forskningsfelter og hvordan forskningsmetodologien er blevet udviklet og har formet projektets forløb.

Den anden del af afhandlingen diskuterer materialer og læring med fokus på materialemeninger, læring om materialer som en social praksis og betydningen af refleksion og erfaring i meningsdannelsesprocesser. De teoretiske tilgange har oprindelse i discipliner såsom ’science and technology studies’ (STS), antropologi, læringsteori, ingeniørvidenskab og organisationsteori.

Den tredje af afhandlingen udgør det empiriske bidrag af projektet. Med udgangspunkt i eksperimentelle studier fra materialekurser er det blevet undersøgt, hvordan studerende værdisætter, kommunikerer og vælger materialer. Det primære forskningsobjekt har været en læringsmetode kaldet ’The materials selection ma-

trix', der gennem projektet er blevet udvikling for at optimere studerendes udbytte. Andre forskningsobjekter har været en 'komparativ materialeskala' og et 'personligt materialesamlingsinitiativ'. Forskningsobjekterne er blevet undersøgt og udviklet gennem en kombination and strukturelle analytiske metoder og observationer i kurser og interviews.

Udbyttet af projektet har mange dimensioner. Det er blevet vist, at (design) studerende har svært ved at relatere til og kommunikere erfaringsbaserede og bæredygtighedsrelaterede materialeattributter. Det er derfor nødvendigt at nytænke, hvordan disse aspekter kan få mere opmærksomhed i materialepraksissen på designuddannelser. Det fremgår således også, at studerende finder det lettere at tilgå materialer, når de er blevet introduceret til værktøjer, der er udviklet til styrke formidlingen af materialemeninger og strukturere materialevalg i designprocesser.

Baseret på projektets resultater, præsenterer afhandlingen en trefoldig metode til materialeundervisning, der bygger på materialetilgængelighed (materials accessibility), materialetransparens (materials transparency) og materialefremgangsmåde (materials approachability). Gennem materialeadgang får studerende værktøjer til at udforske materialer, gennem materialetransparens får studerende værktøjer til at identificere materialemeninger og skabe værdisystemer, og gennem materialefremgangsmåder skal studerende have værktøjer til at strukturere materialeundersøgelser til materialevalg i produktdesign.

Afhandlingen henvender sig til forskere og undervisere, der er involveret i materialer i designuddannelsen samt materialer i andre discipliner og andre discipliner indenfor designuddannelsen. En erfaringsbaseret materialetilgang kan være til gavn for tekniskorienterede designuddannelser og den udviklede metode vil med fordel kunne inspirere og tilpasses til andre dele af designuddannelsen.

Det er blevet vægtet højt, at de studerende som projektet har haft fokus på også vil kunne få noget ud af at læse afhandlingen. Jeg håber at designstuderende kan finde inspiration i og anvende de vinkler på materialer og tilgange til at udforske materialer som afhandlingen præsenterer. Sidst vil jeg mene, at design- og produktionsvirksomheder vil kunne bruge afhandlingen til at få nye indsigter i, hvordan man kan diskutere og kommunikere materialer i materialeudvikling eller –forskning.

Kernebidrag inkluderer tilgange til at bygge bro mellem tekniske, erfaringsbaserede og bæredygtige materialeaspekter baseret på værdisystemer, indsigt i, hvordan designstuderende arbejder med materialer og en metode til at undervise i materialer, der favner strukturelle og reflekterende måder at forstå materialer.