Perspectives on the Role of Materials in Sustainable Product Design Education

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This paper discusses present and future roles of materials in sustainable design with a focus on design education. With a multifaceted understanding of materials, from an educational perspective, the challenge is to ensure that students are able to navigate within the materials in the design field and to reflect on its potentials and limitations in the process. Moreover, when further targeting materials within a design for sustainability agenda that is complex in itself, it has been observed that students find it overwhelming. Accordingly, the paper unfolds ways of understanding the role of materials in sustainable design education as a way to demonstrate the positions they can take as future designers.

Based on a study conducted during a materials course in a sustainable design engineering program, research was done on how students perceive the role of materials in sustainable design. This was done by extracting statements from students’ final assessments that were framed as essays on the topic.

The statements, clustered into categories, illustrated the diversity of approaches students take. For teaching, this underscores the necessity to not only apply a broad perspective in the field of materials in sustainable design, but also to emphasize the large degree of entanglement and interdependency between perspectives.

To further discuss this in an educational context and to facilitate developing teaching within this topic, a space unfolding two frameworks, one that considers key competences in working with sustainability and another that discusses the increasing number of approaches embracing design for sustainability, was introduced as a means to describe the complexity in the field.

The space was first used to position categories of students’ approaches from the empirical study, then expanded to propose four future roles of materials: as environmental impactors, as re-establishing connections, as moderators for social innovation and as media for critical and speculative design.

1
INTRODUCTION

The focus of this text is the boundary and the tension between materials and sustainability in the context of design education. Materials in sustainable design often become a matter of environmental concern for a given existing or future product. This, however, blackboxes the true potential that allows for broader considerations of what a material is, how it can be valued and how it can play an active role in the growing attention towards sustainable transition through a multifaceted design discipline. The text takes an educational approach by considering how design education can support future designers in actively incorporating materials as part of working with sustainable design.

Based on the above, and to embrace the multifarious nature of materials as well as sustainability to prepare students to act actively with materials as professionals within sustainable design, it was relevant to ask, "how can the role of materials be explored and worked with in sustainable design education?".

The focus of this text is motivated by years of experience teaching within and around this specific topic in different learning environments. Presently, new resources for learning and dissemination are published at a high pace, making the topic highly accessible. However, drawing attention to what students actually 'learn', formally in courses and informally through literature, exhibitions, blogs, social media and so forth, gets less attention. This study is thus motivated by a curiosity to know more about, what students actually take with them from the classroom and, consequently, what might need to be further emphasised to enhance a holistic approach to materials.

1.1 Combining materials and sustainable design

The essential for discussing the role of materials in sustainable product design is to understand what materials and sustainability are (or can be) in a product design context. Therefore, to establish a common ground, the following will briefly elaborate on these two aspects.

Materials are said to be comprised of two worlds: a physical world that relates to a material's physical existence as the components materializing (or being) an object, and a social world that relates to materials' interaction with surroundings and in this, humans (Pedgley, Rognoli, and Karana 2015; Drazin and Küchler 2015).

In the physical world, a material is described by its properties, being mechanical, electrical, thermal, magnetic, optical and deteriorative (Callister 2006). In design, the physical world of materials partakes in creating links to natural sciences and engineering and disciplines such as mechanical engineering, physics, nanotechnology etc. (Michael F. Ashby, Shercliff, and Cebon 2007).

In the social world, a material is described by its characteristics, through interaction with humans through our senses, and the material understanding is therefore based on our experience (Hekkert and Schifferstein 2008). Through this relationship, the social world can be linked to, for example, *aesthetics* (Folkmann 2010; Hekkert and Leder 2008) and *emotional design* (Norman 2004) and in a spatial context, *atmosphere* (Böhme 1993; Pallasmaa 2012). It can also be related to *sensing* and *perception* (Merleau-Ponty 2013) and (material) *culture studies* (Vannini 2009; Woodward 2007) and *social practices* (Shove, Pantzar, and Watson 2012). From a *material perspective*, it relates directly to *materials experience* (Karana 2009; Karana, Pedgley, and Rognoli 2014).

Even though this dichotomy of the nature of materials has influenced how materials have been understood and worked with, in education, in research and in practice, in reality they are the products of each other, as in the materialization of an object (see Figure 1):

materials are chosen for the experience they are intended to create (prescriptive)

experience of the given object is defined by the specific materials used (descriptive)

In that sense, materials can be regarded as boundary objects that translate intentions back and forth between two worlds and understanding this tension between prescription and description is essential for the role materials are assigned in design (Hasling 2015; Hasling and Bang 2016). Here, the designer's role is to successfully translate or mediate meanings into a materialized object that embodies relational and performative needs required to fulfil the object's intention.

The design profession, historically from arts and crafts to critical and speculative design genres at present, is critiquing, challenging and framing society (Dunne and Raby 2013) and it can thus be argued that the essence of design is to create and embody values of a society's visions. Historical examples of this are the arts and crafts movement in 19th century Great Britain led by William Morris (Parry and Moss 1989) and the German Bauhaus School in the 1910s - 1930s that wanted to change society and to find a new way of living (Droste 2015; Fiedler and Feierabend 1999). From this perspective, many parallels between the core nature of design and sustainable development respectively can be identified.

In a design context, the term 'sustainability' is understood as the ability to maintain a certain rate or level, which can be translated into ensuring that any kind of system is viable and feasible when measured by parameters relevant for the given system. The term 'sustainable development', as it was originally framed by the Our Common Future report (United Nations 1987) and recently reframed in the United Nation's 17 Sustainable Development Goals (UN Sustainable Development Goals 2018), considers the overarching concept that deals with ensuring a sustainable existence for the world's current population as well for future generations. The Our Common Future report 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" (United Nations 1987).

Similarly, design "should shape and make the objects, communications, and systems that serve utilitarian needs and give symbolic meaning to life" (Heskett 2001) or, as a discipline, propose new futures answering needs based on knowledge and experience from the past and future, as Fry suggests (Fry 2009). Consequently, design as well as sustainable development can be understood as processes that aim to make the world better.

With this in mind, combining design and sustainable development can be understood in two ways (Bhamra and Lofthouse 2007):

one, often referred to as sustainable design, deals with making design more sustainable by focusing on a product's lifecycle and

two, often referred to as design for sustainability or sustainability by design, deals with ways of applying and operationalising design philosophy, thinking and methods within a sustainable development agenda.

The distinction between the two concepts is essential as it points to the relationship of power between the design profession and sustainable development respectively. Does the design profession need help to become more sustainable or can design be a means to propose alternative solutions in a more holistic manner?

1.2 Activating materials in sustainable design

Materials have a central position in product design, as all products are made of materials. However, in sustainable design, materials can be approached in various ways. To explore this, Mestre and Cooper's recently proposed framework for circular product design will be introduced (Mestre and Cooper 2017).

In the framework, Mestre and Cooper divide strategies into technical and biological material cycles determined by the nature of the material. In technical cycles, the intent is to keep materials as long as possible in systems based on either 'slowing the loop' or 'closing the loop' strategies (Figure 3, left side). Slowing the loop means designing for product longevity by understanding a product's lifetime (Ashby 2013: 80), while closing the loop means designing products and the systems around products for increased maintenance, reuse, recycling and recovery of materials and products (Bakker et al. 2014).

In biological cycles, the intent is to lower the impact of materials produced based on either 'bio-inspired' or 'bio-based' strategies (Figure 3, right side). Bio-inspired strategies adopt biomimicry and bionic approaches (Benyus 2002), while bio-based strategies focus on materials that are based on renewable resources that can be degraded into nutritious soil for new materials at the end of their life phase (M. Ashby 2015).

To further consider and unfold materials' potential roles in sustainable design, Ceschin and Gaziulusoy's Design for Sustainability framework can be highlighted (Ceschin and Gaziulusoy 2016). The framework incorporates a spectrum of approaches to working with design for sustainability that acknowledges the increasingly complexity of the concept (Keitsch 2015; Vezzoli and Manzini 2010) with approaches ranging from environmental concerns, to services and strategies beyond experiences and cultural interventions (Bhamra and Lofthouse 2007) and that are interdependent and interact (Michael F. Ashby and Johnson 2014; Mulder, Ferrer, and Van Lente 2011). The framework can be seen in Figure 4 below.

The framework presents a hierarchical design structure for sustainability strategies building on four levels: A product level, a product-service system level, a spatio-social level and a socio-technical system level, and two axes: an insular-system axis and a technology-people axis. Ceschin and Gaziulusoy argue that the potential for sustainability is greater higher up in the hierarchy, which is in line with Brezet (Brezet 1997) and Fletcher's (Fletcher 2008) former work.

The framework is not directly related to materials but can be used as a means to demonstrate how implementing materials in design can have a different impact and how opening up for new understandings of what materials can be and how they can be used can create new links between material use and sustainable transitions.

2
STUDY METHODOLOGY

To get actual insights on how students take into account and consider materials when working with sustainable design, an empirical study has been conducted. To assess a materials course taught in a sustainable design engineering program, students were asked to write a short paper discussing and reflecting on materials' role in sustainable design.

Design education can be framed in many ways, but this specific learning environment was chosen for its special focus on sustainability that makes it stand out from most other design courses. As the students can be assumed to be 'experts' in sustainable design, the hypothesis was that it would be easier for them to focus on the materials' role herein.

2.1 Materials in a sustainable design engineering program

The sustainable design engineering program is taught in a university emphasising problem-based learning and project work. The study was made in a course called 'Knowledge on physical and material-oriented phenomena' and is taught during the sixth semester of the bachelor's degree program. The course is conducted as twelve classes over two months and runs concurrently with students working on their bachelor's degree projects. Prior to this course, the only material-specific course offered is during the first semester, combining aspects of mechanics, models and materials and predominantly emphasising a technical understanding of materials. The remaining curriculum is dominated by courses that develop students' competences within process management, systems design, co-design scenario building and so forth, all within a sustainability agenda. Therefore, even though sustainability is not articulated in the course description, it implicitly begins with sustainable design as a way to explore materials.

2.2 Teaching content

To provide an understanding of the basis of the course, the following will elaborate on the teaching content and what the students were expected to know at a minimum. The course structure allowed students to obtain a progres-

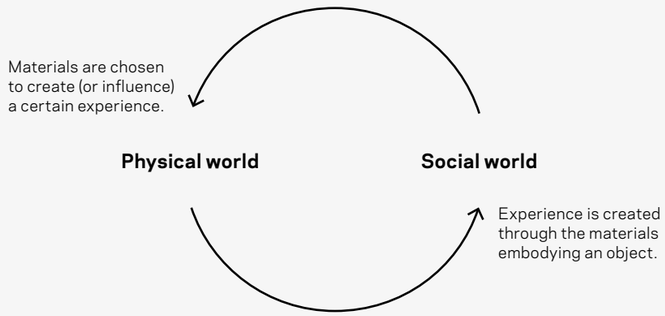


Fig. 1. The relationship between the physical and social world of materials in design

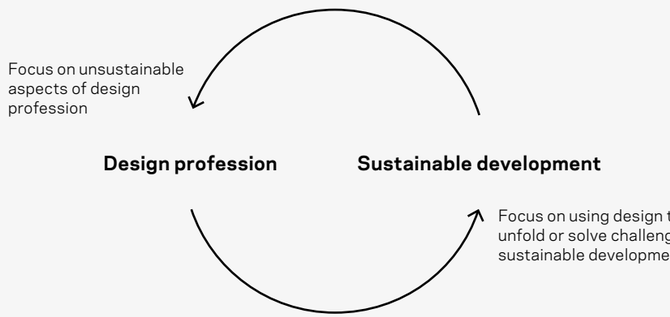


Fig. 2. The relationship between design and sustainable development

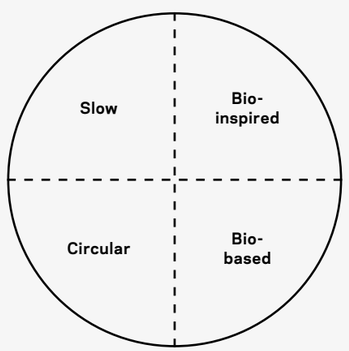


Fig. 3. Mestre and Cooper's division of material strategies (2017)

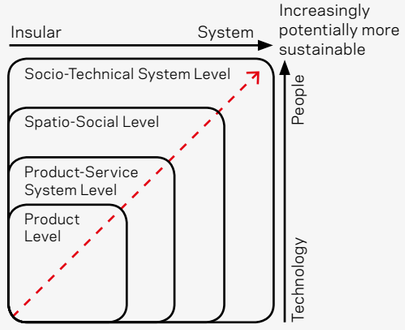


Fig. 4. The Design for Sustainability framework proposed by Ceschin and Gaziulusoy (2016)

sive cognitive recognition of the topic (Krathwohl 2002) based on 'materials accessibility', 'materials transparency' and 'materials approachability' (Hasling 2015). This means that the course content progressed from introducing materials from a physical and social perspective, to discussing frameworks that integrate materials in sustainable design, to considering material information and material selection methods, to introducing new materials and technologies. To ensure the involvement of teaching content such as literature and presentations, classes were a mix of lectures and student exercises in groups that asked students in different ways to reflect on their knowledge and ways of communicating about materials.

For the course, Ashby and Johnson's Materials in Design (Michael F. Ashby and Johnson 2014) and Karana, Pedgley and Rognoli's Materials Experience (Karana, Pedgley, and Rognoli 2014) were used as required literature. They were supplemented with relevant readings introduced in lectures to illustrate specific approaches, models and case studies. In this way, students were offered multiple entry points and methods to appropriating the topic as they preferred.

2.3 Data collection

In this study, the focus was on the students' final written assignments framed as short papers on materials' role in sustainable design. The assignment was given as a 'free' short paper (five pages), allowing each student to approach the field as he or she preferred. Papers by 19 students from this course were assessed.

As part of the assessment, the manner in which each student covered the topic was analysed in terms of:
Understanding of scale (detailing versus holistic aspects)
Understanding of broadness (physical versus social aspects)
Understanding of one's own role (reflection and appropriation)

From the assignments, quotes and statements that were considered representative for the narrative of the assignments were extracted based on content analysis (Berg and Lune 2011) and thereafter coded into clusters for further discussion (Burns and Burns 2008; Everitt et al. 2010). In total, 62 quotes were extracted, and the number of quotes extracted per student ranged from 1 to 9. In the following discussion, the student who wrote each quote can be identified by the number after the quote, e.g. (15) is student #15. The number and themes of the clusters were not determined before the session procedure and were framed by the quotes.

CLUSTERING RESULTS

To simplify, each quote was assigned to one category only, even though some quotes embraced aspects of more categories. Nevertheless, when identifying categories, they were believed to best elaborate on the multifariousness of the students' understanding of the topic. On the other hand, cross-over insights were used to bridge categories and build up the narrative for subsequent discussion. These cross-over insights and interacting categories will be further discussed in the reflection of the study.

The categories are, in alphabetical order [1]:
Consumption and practices of use (10)
Design education and profession (3)
Imperfection (2)
Product lifetime (5)
Material driven design (2)
Students' personal values and ethics (4)
Product experience (1)
Product lifecycle (7)
Role of materials (8)
Social values and responsibility (4)
Socio-physical relationship (5)
Thinking sustainability (6)
Sustainable systems (3)
User ethics, values and knowledge (3)

3
RESULTS AND DISCUSSION

The following section presents and discusses selected quotes from the student assignments based on the categories identified above.

3.1 Thinking sustainability

As sustainable design is the point of departure for the students, it makes sense to start with, what sustainability is and how students approach it. One student writes: "Sustainability is not a method or a guideline in how to make the World a better place (...), but many aspects exist that force the designer to make some important decisions." (7), while another states: "Sustainability is not a table value that can be found in a book; therefore the concept becomes very subjective, as you will get different answers on what it entails depending on who you ask." (19). Both of these elaborate on the complexity of sustainable design due to its high level of relativity and contextuality. Systems thinking is emphasised by a third student: "Sustainable development as a concept is challenging because it is related to a big and complicated system. When you deal which such systems with this level of complexity, it is not always easy to foresee how the consequence of an action will affect the system." (13).

3.2 Sustainable systems

Considering sustainability as a large system is further touched upon by other students. One student discusses this as: "These problems that primarily relate to the product level are becoming more relevant due to an increasing population and growing middle class. Even though we for many years have produced more climate friendly products, there is a rapidly growing demand that keeps emphasising the relevance of this problem." (10). Here, the student reflects on the fact that even though production has less environmental impact, increasing consumption means that the overall impact is still increasing in a 'rebound effect' kind of manner (Hertwich 2005). When introducing new materials or technologies, for example to lower environmental impacts, another student argues that: "The consequence with not considering (potential) side effects every time a (new) material

is used, is that the company is not aware of the side effects before the product is in production and then it is usually very expensive to change materials and processes." (8), which is in line with Mulder, Ferrer and van Lentes's concept of 'Dependence of articulations of sustainable technology' (Mulder, Ferrer, and van Lente 2011). The student further argues that: "Depending on which industry you are in, there are different approaches to and opinions about when a material is sustainable and there is (thus) great complexity in categorising sustainable materials." (8).

3.3 Product lifecycles

Seven students discussed materials with a focus on the product lifecycle and its opportunities and challenges. These touch upon the designer's role when defining the lifecycle as one student frames it: "When we design, it is our responsibility to be careful and thoughtful in every single step of the decisions we take concerning the design. We have to think about where the material comes from, where it goes, who should use it and how it should be treated afterwards." (5) as well as in more specific examples, such as from this student who used his own construction project as the case for the assignment: "To reuse a window that otherwise would have been discarded is more sustainable that producing a 'sustainable' window." (16). Another student reflects on this in more general terms arguing that: "An obvious way to limit material use is by reusing materials, but there is a challenge in the processes that are linked to collecting and processing reused materials and not appropriating the materials into new products. Therefore, using reused materials is not in itself sustainable." (19).

CONSUMPTION AND PRACTICES OF USE

More than half of the students link materials in sustainable design to the consumption phase and practices of use thereof. One student is straightforward when writing: "We need to adjust our respective consumption patterns." (13), a statement that is further elaborated on by other students in different ways. "The consumption we have today and that will continue to increase depends on a long list of factors that interact in a complex bricolage." (19), one student writes. Another student frames it as: "We are roughly changing as little (as possible) to our daily routines instead of the materials that presuppose access to our habits. (...) We strive for a world where our culture is maintained by sustainable materials." (9). Another student supports this when writing: "You have to look at materials as objects that in themselves shape our practices and not only as a tool for making products." (17). In relation to this, a student talks about a 'good' material as not being a matter of degradability, reusability or complexity when integrated in a product, but for the "'goodness' of a material, it is in the use phase, the largest potential takes place; in the interaction between material and user." (13). The same student further elaborates on this stating that: "(...) it is therefore important to go down in scale and consider the relationships we as consumers have with the products, resources and materials we consume. Here, it can be difficult to look beyond the existing and into what might be." (13), touching upon the necessity both to being able to consider different scales of focus and thereof initiatives, but also to developing scenarios for a future society that in a different way can incorporate more sustainable practices of use.

PRODUCT LIFETIME

Whereas students consider consumption patterns as a matter of consumers' practices of use, lifetime is linked to products' 'embedded' longevity in the use phase and how they as future designers can influence this. Here, students predominantly focus on technical means, for example this student who writes: "Designers deal with how maintenance and repair can be integrated actively in the design of product (...) One approach is products composed of modules where the individual parts can be taken apart. (...) However, maintenance and repair require an effort from consumers and that they see a value in the product." (6). Thus, the student both considers designing modularly to enable the exchange of broken components, but also the potential challenge of making consumers do the extra effort that maintenance and repair often require.

Two students highlight planned obsolescence in relation to lifetime. They write: "It is a societal tendency in a consumption driven society, where consumers want new and shiny products and where changing trends and rapid technology development make otherwise functional and useful products unwanted and therefore disposed and replaced." (15) and "Planned obsolescence thereby entails a use and dispose culture and we as designers should, as much as consumers, show materials respect and optimise their use in products." (6). These can be seen as comments on (some) companies' lack of responsibility in continuing to introduce products on the market with programmed durability, as this will force or make consumers buy new products influencing users' ethics, values and knowledge.

USER ETHICS, VALUES AND KNOWLEDGE

With attention emphasised on the consumption phase and users' responsibility, "It is central for being motivated to change behaviour and create change to understand which effect you have. By creating an incentive for experiences and value (...) we create personal motivation for people to care." (1), a student writes. Here the student elaborates on many people's lack of knowledge that, it could be argued, is the result of often absent or anonymous interaction between the production and consumption phases.

With the point of departure as his own house building project, another student reflects on the paradox of the present capitalist system in which we, as Papanek puts it, "work to make money in order to buy things that will distract us from having to work." (Papanek 1995). Concerning this, the student writes that: "A big house thereby transforms from being a symbol of wealth, freedom and surplus to being a symbol of the self's own constraints of freedom and this tendency is greatly responsible for the environmental impact of our lives." (16).

PHYSICAL AND SOCIAL ASPECTS

Taking a step back to the 'product lifetime' category, one student writes: "When we wish to design products to last longer (to lower consumption), it is important to be aware of all these factors (Ashby's six definitions of lifetime (Ashby, 2013: 80) in the choice of materials (...) Currently, this does not seem to apply in design practice, where especially the last factor concerning emotional durability (desirable life) is prioritised low." (3). Here, the student implicitly calls for increasingly considering both physical and social aspects of a product's lifetime.

Touching on this dichotomy, a student writes: "Even though we have learned to calculate materials' physical properties such as elasticity, tensile strength etc., there is an aspect where the technical engineering world meets the human's emotional and explanatory nature (...); this is where it becomes design." (5), while another writes: "(...) The question is whether the material association lies in the technical composition or in the abstract side describing how a material or product is perceived." (11).

Activating social aspects, linking these to physical aspects of materials and considering how both can be integrated in the design process, was fundamental for the materials course; therefore, some assignments reflect on this. Reflecting on the exercises made during the course, one student writes: "I realised how complex the interaction with materials is and we disagreed very much on some of the materials' associations." (5), which is supported by another student who writes: "Individually, each material cannot be assigned the same personality, as translations of the sensorial experiences are subjective." (15).

An example of the complexity of designing with social aspects in mind is that of ageing materials and imperfection. A student reflects on this when stating: "Generally, materials' surface plays an important role in design, as it shows the degradation process in a tangible and straightforward way, but you have to be aware that social value acquisitions are very subjectively grounded." (3). With reference to users' values, the student further argues that the: "Increasing interest in aesthetic imperfections in product design may be a response to the dominant perfectionism that is strived for in Western culture." (3).

THE SUSTAINABLE DESIGNER

In their papers, students are split between seeing themselves as civilians in society, i.e. acting as consumers in and users of the system, and professional 'experts' in society, i.e. acting as designers that partake in defining the system. To further delve into this, it has been divided into how they see themselves as individuals, reflecting on their own values and ethics, and how they see themselves as students, within design education and as future design professionals.

STUDENTS' PERSONAL VALUES AND ETHICS

One student reflected on his values by using his headphones as a case study; after having used them for a while, the materials started to look worn out and cheap. "I'm split between my design engineer persona and my consumer persona; as Dr. Jekyll and Mr. Hyde. I want to exchange them, because now they don't live up to the requirements I identified, before I got them." (15). However, because he knows about the lifecycle of the product, he feels bad and a tension between his societal self and his professional self emerges. Working within this field, it is probably something most can recognise and as another student frames it: "As a sustainable designer, when it comes to sustainability, I rarely take things for granted. To me everything can be reduced to whether it is a sustainable building block in this world." (9).

DESIGN EDUCATION AND PROFESSION

"In sustainable design (the educational program), we talk about how we can design a product, so the materials used have a function in the end." (5), a student writes, meaning that sustainable materials here can be understood as appropriating materials used for a given function. However, as many different variations of design exist, as another student writes: "(...) Sustainability is something that always will be subject to discussion and based on that perspective, the concept is very defined by which background you have as designer. Therefore, it can be difficult to tell which role the material should have in this context." (7). According to a third student, this knowledge gap can be facilitated by processes using materials as communicative boundary objects: "To develop the best solution, we often apply co-design in multiple stages of the process. (...) In a co-design process with the user, materials are rarely described with technical terms, but with the perceptions the user assigns the material. (..) When we as engineers are interacting with these users, it makes good sense to talk the same language, so it is easier to share knowledge." (8). Here, the student talks about co-creation between the designer and the user, but similar ways of translating material understandings can be applied to, for example, communicating between stakeholders from different industries.

SOCIAL VALUES AND RESPONSIBILITY

Using a project of his own as a case in which he developed an open source kayak made from easily recycled materials, a student elaborated on the importance of social values. He argues that: "When making a functional kayak that people can build themselves and can pay for, we create a basis for more people having access to the sea and nature." (1). Thus, the primary sustainable argument here is related to the social value created in making a different experience accessible to people.

Similarly, another student also strongly emphasized the social aspect writing that: "It is extremely important that materials are strategically incorporated in our design processes to take advantage of the biggest potential. That especially counts for socially responsible products." (14).

MATERIAL DRIVEN DESIGN

Two students reflected on the potential of material driven design as an alternative to the otherwise often applied function-driven design process. With inspiration from Karana et al.'s framework (Karana et al. 2015), one student writes that: "There can be great profit in material driven design, as it can make a path for new innovative applications and push boundaries for the development of new materials." (8), thus linking the approach to the necessity of developing sustainable business models. Another student states that: "Material driven design is a more 'learning by doing' approach to product design and it requires the designer to explore and become familiar with the material's properties."

(17), and thereby touches upon the fact that different learning strategies need to be applied for activating materials in relation to sustainable design.

THE ROLE OF MATERIALS

In concluding, the final quotes consider the role of materials and thus embrace the essence of this study. Seven students specifically assigned parts of their assignments to a reflection on this. Here one student writes that: "What concerns materials, they are in centre of it all – they surround us and everything we interact with is made of material. To secure our future is to secure the future of materials and use materials consciously." (5), arguing for the necessity to act consciously and respectfully towards the materials that constitute our world. Another student writes that: "Maybe (materials have) an even bigger role than we assign to them. In everyday practices, we take them for granted as obvious props in the modern world, without much thought to what they consist of and how they have been processed." (10).

Two other students write that: "Materials are definitely important for the sustainability impact of what we design but using materials in a way that makes them active objects in the design process is a challenge." (18) and: "The use of materials is integrated everywhere (in design), but in sustainable design it depends on which approach you have (...) and which problems you try to solve." (7). Both statements touch upon having to negotiate the choices one must make in the design process and which direction one chooses to go therein.

As other students reflected on when going through the first categories, material choices in sustainable design are not as straightforward as one might wish. It is therefore, as the following two statements emphasise, essential to acknowledge 'relativeness' in the discourse on materials' role. The students write: "To have a sustainable material to me is not just about choosing a material; it always has to be more sustainable than an alternative material." (2) and: "It is the use of a material that makes it sustainable, and not the material itself." (8).

REFLECTIONS ON THE STUDY

The above quotes exemplify how students from an educational program on sustainable design engineering experience the role of materials within their future practice as design engineers. As the quotes demonstrate, the ways students approach this are quite multifaceted and vary greatly when it comes to the scale of detailing, the broadness of focus and how they reflect on their own role and responsibility.

Some students have chosen to develop their assignments based on a specific case, a project of their own or by someone else. Other students have reflected on sustainability at a higher level as a philosophical and existential phenomenon.

Some students have predominantly discussed materials' sustainable impact based on physical aspects from a conventional engineering perspective, some students have focused on materials experience as a way to engage interaction between subject and object and some students have discussed how designers can translate ways of understanding materials to enhance communication between different actors.

Finally, some students have approached the assignment human beings with personal values and ethics just as much as future designers, while some students have described challenges from professional perspectives and took into account the design profession as a whole.

This has been emphasised to argue that no approach is necessarily the right approach and that the role of materials in sustainable design education (and the profession) strongly rely on the individual designer and the field in which he or she works or intends to work.

4
A FUTURE PERSPECTIVE ON TEACHING MATERIALS

Based on insights from the study, a question that can be raised is: "How can we ensure that students obtain knowledge and competences in all these aspects, and be able to navigate between them, through curriculum development?"

In their framework, Wiek, Withycombe and Redman have identified five groups of key competences for working with sustainability in educational programs (Wiek, Withycombe, and Redman 2011). Through curriculum design work for sustainable design education (Ræbild and Hasling 2017), it has been further discovered that these competences can be hierarchically structured based on cognitive learning theories, such as Bloom's taxonomy (Bloom et al. 1956):

Normative competences. These relate to the ability to map, specify and negotiate values, principles, goals and targets.

Interpersonal competences. These relate to the ability to motivate, enable and facilitate collaborative research and problem solving.

Systems-thinking competences. These relate to the ability to analyse complex systems across different domains and scales, thereby considering cascading effects, inertia, feedback loops and other systemic features.

Anticipatory competences. These relate to the ability to analyse and evaluate and craft future scenarios.

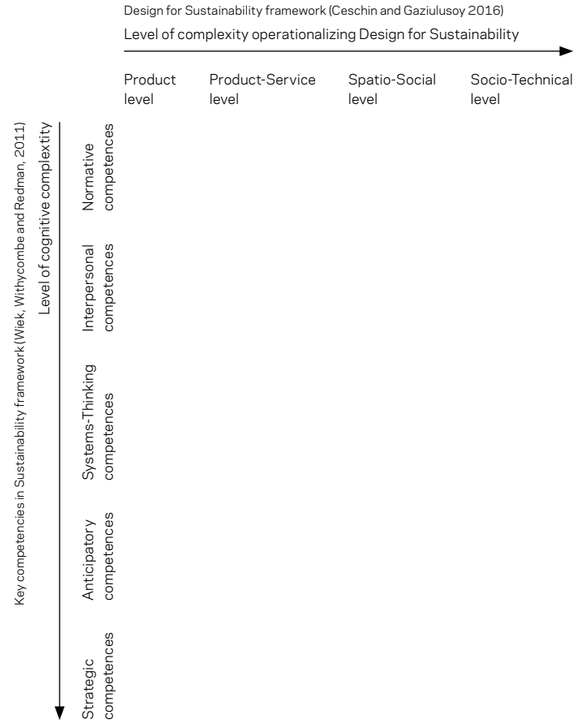
Strategic competences. These relate to the ability to design and implement interventions, transitions and transformative governance strategies.

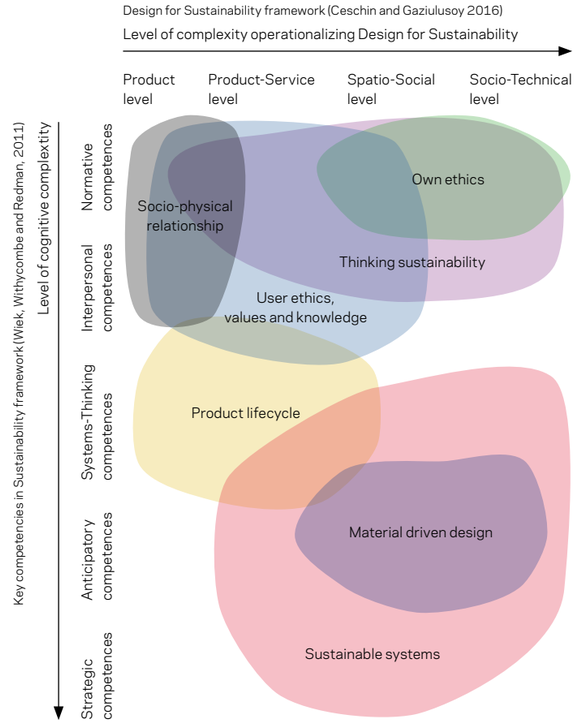
(Wiek, Withycombe, and Redman 2011; Ræbild and Hasling 2017: 7)

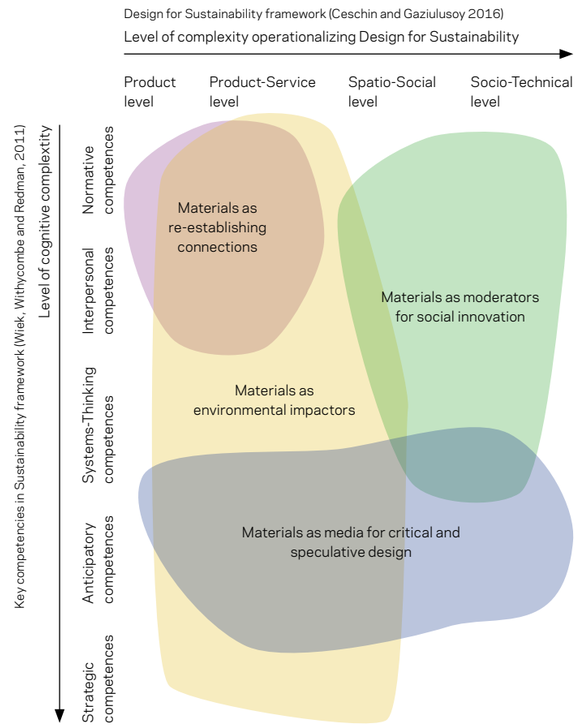
In curriculum design, the hierarchy of key competences can be used as a guideline to structure course content based on students' ability to cognitively deal with sustainability issues.

Combining the Key Competences in Sustainability framework and the Design for Sustainability framework by Ceschin and Gaziulusoy (2016), the solution space is shown in Figure 5. In the space, the horizontal axis considers the output (what?) and the vertical axis considers the competences needed (how?).

Even though the axes indicate different aspects, they are symptoms of the same complexity, but they are not linearly dependent on each other. It is, for example, possible







↖ **Figure 5.** The space unfolded by the Design for Sustainability framework (Ceschin and Gaziulusoy 2016) and the Key Competences in Sustainability framework (Wiek, Withycombe and Redman 2011).
↗ **Figure 6.** Selected categories from the study with students incorporated in the space embracing the two sustainability frameworks.
← **Figure 7.** The four examples of the roles of materials in sustainable design education in the space embracing the two sustainability frameworks.

to discuss normative competences from a socio-technical level aspect, such as the justice of laws and regulations, as well as to discuss strategic competences from a product or product-service level aspect that can relate to the strategy itself of introducing a new product-system on the market.

Nevertheless, the space can help to demonstrate how materials can play different roles and be activated in different ways. It is a challenge to position all the categories used in the study, but the most significant and applicable ones have been integrated in Figure 6.

MATERIALS' FUTURE ROLES

Based on the study and considering the present development of sustainable design, in a future perspective, it is appropriate to further emphasise the diversity of materials' role. Below, four overall future roles for materials are described.

Materials as environmental impactors and the effort towards minimizing the environmental impact of processing, using and disposing materials, focusing on, for example, life cycle assessments and technology development.

Materials as re-establishing connections between humans and objects, for example by emphasising the origin and use of materials through material narratives and need recognition, such as communicating material (and product) journeys and materials' embedded values therefrom.

Materials as moderators for social innovation as a way to empower users (both designers and end-users) (Manzini 2015), such as in maker spaces (Smith 2017) and when used in welfare design.

Materials as media for critical and speculative design (this could be called material speculation) as a way to raise awareness of the consequences of actions in society (Dunne and Raby 2013), for examples through designer-oriented Do it Yourself approaches (Rognoli et al. 2015) and Material Driven Design (Karana et al. 2015).

In Figure 7, the four future roles for materials have been tentatively positioned in the space unfolded by the two frameworks. As different kinds of prior knowledge are needed for different roles, this can be used to understand which competences are needed for different roles.

From a design education perspective, this can help create awareness and structure course content as well as linking material approaches to an overall discourse on design's role in a sustainable transition. From a design professional perspective, it can help empower the role of materials as it allows designers to appropriate materials in different ways and with different levels of complexity depending on interests and needs within a sustainable agenda. Thus, it speaks into the diversity of professionals working within a design context, but from different perspectives, having different mindsets and using different tools and methods in their processes.

5
CONCLUSION

The role of materials in sustainable design education is multifaceted, which can make it complex, challenging and frustrating to actively consider them in the design process. Nevertheless, understanding the potential of working material-oriented or material-consciously in sustainable design can also open up new possibilities that can help design students as well as practicing designers to frame their identity and position themselves as designers.

This paper's central question: "How can the role of materials be explored and worked with in sustainable design education?" has been answered by multiple sources.

It has been answered by an introduction to the topic, the nature of materials and the concept of design for sustainability, combined in a design education context.

It has been empirically answered by statements on the role of materials in sustainable design from final assignments in a course on materials in a sustainable design engineering program. This was done as a way to explore what students take with them from courses and what might need to be further emphasised or reframed therein. This can, for example relate, to scale and the level of reflection when discussing specific issues and challenges and how these take part in a larger holistic system. It can further relate to how students navigate and translate meaning between physical and social aspects of materials and how they are able to consider their own role and responsibility when working with materials as future sustainable design engineers.

Finally, with the introduction of four future perspectives of materials' role in sustainable design education, an advance discussion has taken place on how ways of teaching materials in design education can support sustainable activities in different ways. This should further assist in highlighting and communicating the different roles materials can have in a sustainable transition agenda as a way to help designers interested in materials to position themselves not only in the materials in the design landscape, but in the design landscape itself.

> "It is the use of a material that makes it sustainable, and not the material itself."

FOOTNOTES

1 The numbers in brackets are the number of quotes assigned for the given category. The categories will be further described using a selection of the quotes extracted.

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