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TOWARDS SUSTAINABLE TEXTILE MATERIALS: POTENTIAL PATHWAYS AND DIALOGUES BETWEEN DISCIPLINES

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ABSTRACT

The need to take care of our material environment has become urgent. New types of scientific collaboration have emerged, and designers are being invited to collaborate with top-level scientists. Several examples have shown that the creativity of designers can be brought into different kinds of scientific collaboration to enhance existing approaches and ways of working. This study investigates various design-science collaborations in the context of material research, all aiming to create sustainable textile materials. The empirical basis of this study consists of five material research and development projects. Our data identified five different approaches to materials; *Transforming, Reinventing, Recycling, Biofabrication and Designing new materials*. We investigate the projects to understand not only the approaches to producing sustainable textile materials, but also to map the differences in the scientific dialogues. By opening up these dialogues, this paper describes how knowledge can be build between disciplines.

INTRODUCTION

The way in which we use textile materials has changed dramatically over just one generation. In four decades, the amount of global textile fibre production has increased from 24 million tons (1975) to an annual consumption of 105 million tons (2017) per year (Sundqvist 1988, Lenzing report, 2017). Population growth and the dominant fast fashion system are maintaining this development, and the textile industry remains responsible for severe ecological and ethical problems. The increase in textile waste tells the same story; fast material throughput in the system and a dramatic increase in consumption (e.g. Niinimäki, 2018). However, a change is slowly emerging: more and more consumers are asking for sustainable options, and the textile business is awakening and reacting to these requests. As part of the development towards a sustainable world of textiles, raw materials need to be considered more carefully than today: precious natural resources only can be used in a responsible and durable way. Renewable material sources offer an obvious solution, and this turns our attention towards the bio-economy. Furthermore, new fibre sources are needed to substitute virgin materials such as cotton, and therefore the textile industry is looking for totally new material sources such as algae or agricultural waste. In addition, the increasing textile waste streams need to be treated in a closed-loop manner, while also aiming for the circular economy approach (Niinimäki, 2018). Thus, a new, more holistic approach is needed in which collaboration between disciplines enhances knowledge about textile materials in the context of sustainability.

TEXTILE DESIGN IN DIALOGUE

Oicherman (2018) argues that turning into tradition is more acceptable in textile design than in other design or creative areas. She also highlights that textile design has a negative connotation; an ancient, craft ‘aura’, which means that innovation is not a label easily placed on textile design. Innovation is mostly used as a marketing message in the commercial textile area (ibid.). Yet we

argue that winds of change are blowing into textile design and textile research, aiming for new sustainable material development in a collaborative setting with other disciplines. The need for wider collaboration to further enhance sustainable textile material innovations is obvious. Carole Collet (2018) is one of the pioneering researchers in this context. She started in 2012 by using a speculative design approach in connection to biotechnology. Collet's *Biolace* series from 2012 is a pioneering example of this. Currently, these wild explorations are shifting from speculative design towards commercial reality through new collaborative settings. Biotechnology companies are collaborating with designers and design brands: for example, recently they worked with fashion designer Stella McCartney to produce 'the first dress made from bio-fabricated silk' (Collet, 2018, 89).

Accordingly, change is emerging in the perspectives of textile design and textile material research. Hundreds of designer-led small-scale DIY experiments and several research projects are being conducted around the globe, both to explore potential raw materials and to develop new fibre production or recycling methods for new and existing raw or waste materials. Here, new collaborations between different disciplines make an important contribution. A recent study by Niinimäki (2019) shows how experimental co-design processes and innovation involving textile waste has added a new, soft knowledge layer to technology-driven materials research. 'Through an experimental approach and especially through "playing" with material samples (touching, feeling, describing the haptic experience in co-design sessions) and through co-imagining material attributes, a new layer of material understanding has been added to technology-driven materials research' (Niinimäki, 2019). This important dialogue between textile design and materials research uses methods from experimental research, the particular aim of which, according to Redström (2017, 101) is to push boundaries and explore alternatives. In the research and development of new materials, both the skillsets of deep and sector-specific design (e.g. textile design) and new design are needed. These skills enable crossing over disciplinary borders (Niinimäki et al., 2017), which further enables visualizing and showing scientific knowledge in its future application sectors.

To study these emerging dialogical phenomena, and to make sense of the broad array of ongoing developments and collaborations, this paper presents five potential pathways towards more sustainable textile materials: *Transforming, Reinventing, Recycling, Biofabrication and Designing new materials* and discusses these approaches through our ongoing multi- and interdisciplinary materials research projects.

This explorative investigation takes a descriptive and interpretative approach towards future directions in textile materials research. The paper aims to open different pathways towards new sustainable material developments, and while doing so, to show the potential of different kinds of dialogues between textile design and textile materials research. It also maps textile designers' new roles in this context. The paper discusses renewing textile design research in this specific context and through these explorative and experimental collaborations.

DATA, METHODS AND FRAMING

Five collaborative cases form the data of this study (see Table 1). These cases were selected as they have been key initiatives for multi- and interdisciplinary collaboration in the context of material research at Aalto University since 2012. Moreover, the writers have played a key role in these cases. Author 1 has participated in these cases in the specified roles below:

Case 1, DWoC: coordinator, designer
Case 4, Chemarts: coordinator, facilitator, pedagogue
Case 5, New Silk: bridge builder, researcher, designer

Author 2 has participated in these cases in the specific roles below:

Case 2, Crops4Luxury: coordinator, designer, researcher
Case 3, Trash2Cash: coordinator, researcher, participant
Case 5, New Silk: researcher, designer

All the researched cases and the knowledge creation within them build on research through design approach and on constructive design research in which, according to Koskinen et al. (2011, 42), researchers 'imagine new realities and they build them to see whether it is imaginative in design terms'. The knowledge is built through experimenting with materials and through constructing physical and explorative prototypes. The study context in all these five cases is strongly linked to the materials themselves and is always based on material and textile understanding combined with scientific material research.

To enable the transformation of our material world towards sustainability, new and more sustainable materials and production processes need to be designed and developed. This process requires foundational knowledge of new materials and holistic understanding of their potential applications. As our cases represent this important and understudied field, the focus the current study has been narrowed down, therefore societal or political aspects of material research have been excluded.

Our research interest in the current study lies in the collaboration between different disciplines while developing these future materials through design-science collaboration. However, the processes and results are mostly approached from a textile designer's point of view, and the material researchers' or other partners' experiences are not analysed.

Table 1. Cases

Case 1: *Design Driven Value Chains in the World of Cellulose (DWoC) 2013-2018*	Aim: To innovatively use and process

https://cellulosefromfinland.fi	cellulosic materials, textiles as one of the application areas Partners: Textile designers, material scientists and engineers
Case 2: *Crops4Luxury 2018-2019* *https://luke.fi/en/projects/crops4luxury/*	Aim: To grow and use the old European indigo plant, woad, in Finland Partners: Textile designers, chemists, plant scientists, farmers and companies
Case 3: *Trash2Cash (T2C) 2015-2018* *https://www.trash2cashproject.eu*	Aim: To produce new material innovations from textile waste in the context of a Circular Economy Partners: Textile designers, textile engineers, material scientists, economists, industry
Case 4: *Chemarts, ongoing since 2012* *https://chemarts.aalto.fi*	Aim: To inspire students and researchers from different disciplines to explore bio-based materials together Partners: Designers and material scientists with varying backgrounds
Case 5: *New Silk 2017-2020* *https://www.aalto.fi/newsilk*	Aim: To study new ways of producing silk-like materials in the context of synthetic biology Partners: Textile designers, synthetic biology experts, material scientists

The current study combines autoethnography and ethnography approaches. Using the autoethnography approach, the researcher can play an active role in the activities in the project and collect their own experiences and use these as data (Flick, 2014). Autoethnography research describes and analyses personal experiences to help understand cultural phenomena, in our case material cultural phenomena, especially emerging multi- and interdisciplinary material research. In the ethnographic approach, the researcher takes a more objective role and observes, documents and analyses actions within the case (Flick, 2014). In this study, the data consist of fieldnotes, photos, videos and voice recordings. Ethnographic data collection began in 2012 in the *ChemArts* collaboration and has continued since spring 2019. Both writers have analysed the data using open coding, in a reflective setting (Flick, 2014). The understanding of the subject under study has deepened through these reflective writings, and through group discussions and iterative processes. The study is qualitative by nature and the analysis is descriptive. The following section describes the results in tandem with the current understanding of the material world and identifies the key elements in each case.

POTENTIAL PATHWAYS AND OBSERVED DIALOGUES BETWEEN DISCIPLINES

1. TRANSFORMING

The first pathway, *Transforming,* focuses on how natural materials or industry/agriculture side streams are or will be transformed into textiles. As a case study, we used the multidisciplinary material research project *Design Driven Value Chains in the World of Cellulose DWoC.*

Most current textile fibres are transformed from oil or wood sources. Today, 64% of all textile materials are synthetic, produced out of fossil-based materials. Together with existing wood-based (cellulosic) man-made fibres they present 70% of total fibre consumption (Lenzing, 2017). From the sustainability point of view, the main point is to find new raw material sources and to invent more sustainable production processes.

One example of a renewable raw material is cellulose, one of the most abundant materials found in nature. Cellulose is mainly produced by plants, but also by bacteria and algae. It is a structural component of plant cell walls, which is considered sustainable, renewable and multifunctional (Kataja & Kääriäinen, 2018). Due to its abundance, biodegradability, recyclability and chemical tunability, new methods of using cellulose for textile fibre production have become an active research topic in recent years (e.g. Kääriäinen and Tervinen, 2017). Viscose (or rayon) was invented already over a hundred years ago, and other cellulose based man-made fibres such as modal, cupro and lyocell have followed. However, new kinds of sustainable production processes are needed, to enable the replacement of some oil-based textile materials, partly also cotton.

The case study for the first pathway, *Transforming,* is the multidisciplinary materials research project *Design Driven Value Chains in the World of Cellulose DWoC (2013-2018*). This was funded by Business Finland (former Tekes, the Finnish Funding Agency for

Innovation). The project focused on finding new, innovative uses for cellulosic materials, and textiles were one of the application areas; for example, functional nanocellulose filaments. The *DWoC* project combined design thinking and design-driven prototyping with a strong competence in technology development. The partners in the project were: the Technical Research Centre of Finland VTT, Aalto University, the Tampere University of Technology and the University of Vaasa. The project team consisted of designers with backgrounds in textile design, industrial design or architecture; material researchers; engineers; and business researchers. The role of design was to screen the suitable end-use opportunities, identify the most potential application areas, to enhance and speed up technology development through an iterative prototyping cycle, and to explore how design can be used as a communication tool for scientific material research.

Table 2. presents the main elements of this pathway: the approach, material sources, enablers of this pathway, objectives for this phenomenon, and the type of dialogue needed between disciplines.

Table 2: TRANSFORMING

Approach	Transforming natural materials or industry/agriculture side streams into textiles
Materials	Wood, plants, algae, - anything containing cellulose, or protein-based materials such as feathers etc.
Enablers	New or renewed, sustainable and resource-efficient fibre production technologies
Objectives	To use only renewable raw materials To develop sustainable production processes using non-toxic chemicals
Dialogue	Multidisciplinary collaboration between design and material research, to enhance other disciplines

The dialogue in this case has been multidisciplinary by nature. As Grix (2010, 97) points out, 'different disciplines speak a different language' and therefore crossing over disciplinary borders is challenging. In multidisciplinary collaboration, each discipline mainly stays in their 'silo', and the dialogue takes place in between them. This could also describe mean knowledge sharing or knowledge exchange.

Accordingly, the outcomes of the collaboration mainly contribute to each discipline separately. In *DWoC,* the design research mainly used the methods of constructive design research (Koskinen et al., 2011), meaning constructing knowledge through prototyping. Here, the knowledge is formed through intertwining making/experimenting and theorizing, which can also define experimental design research (Redström, 2017). In the studied case, the main design research contribution goes back to the design discipline and creates knowledge that can be applied in product design. In addition to iterative experiments and prototyping, design skills were used for communication, to build an attractive 'design story' for *DWoC*, and to promote the cellulosic materials to an audience outside the research communities.

The *DWoC* project used traditional textile design skills for material experimentation and prototyping, especially for 3D structures, surface design, colour design, and design for haptic material properties, material hybrids and flexible structures. Working in a multidisciplinary material research project has expanded textile designers' material knowledge and understanding of how traditional skills can be successfully used in a non-traditional context.

2. REINVENTING

The second pathway, *Reinventing*, explores traditional textile materials and production processes, and how these could be used in a new way. The case study here is the *Crops4Luxury* research project.

When constructing a new understanding of sustainability in the context of a bio-based economy, we can turn to history and find 'old' knowledge and explore how textile design and production were carried out before the era of synthetic chemicals. For example, the *Crops4Luxury (2018-2019)* project currently studies the old European indigo plant, woad. The project is funded by Sitra (the Finnish Innovation Fund), from their Circular Economy programme, and led by the Natural Resources Institute of Finland, LUKE. The partners in woad research are Aalto University (design and chemistry), the University of Helsinki, and a few companies. The project includes several work packages, in which other partners (research and commercial) focus on some other special plants.

We can learn from historical textile materials and textile design, which have been forgotten while other fibre and colour sources have become easier to process and cheaper to produce. Materials such as hemp, linen and nettle are traditional textile fibres that could be cultivated in quite a sustainable manner even in Northern countries. Emerging processing technologies using, for example, enzymes can speed up fibre processing, and furthermore lower the environmental impact of the traditional textile processes. However, to be able to produce fibres locally again in Scandinavia,

and to support diversity in agriculture, we cannot aim for only a cheap end price for the material. Therefore, *Crops4Luxury* also studies the aspect of a new sustainable luxury to create new meanings for materials and colours in this context. Table 3 presents the approach, material sources and enablers of this phenomenon, the objectives, and the disciplinary dialogue in our case project.

Table 3: REINVENTING

Approach	Reinventing traditional materials or production methods
Materials	Linen, hemp, nettle etc., Natural dyes and non-toxic chemicals based on natural components
Enablers	Sustainable cultivation methods, renewed fibre treatments and production processes
Objectives	To learn from nature, learning from history To combine tradition with new technologies To revive local production
Dialogue	Textile design research with a touch of chemistry, in collaboration with farmers Using design thinking for meaning-making

Crops4Luxury, brings the historical colour source into the 21st century by modernizing the ways of cultivating woad and processing colour. The collaboration among textile design, chemistry and biotechnology (e.g. the research group of nanostructures and materials) enables the invention of sustainable, modern ways to use plant dyes on textiles, and to avoid the use of harmful chemicals. Even by just basing our work in the historical and traditional knowledge regarding textile design, the dialogue with chemistry enables us to update and modernize this old knowledge. This 'old-new' knowledge sits more on the textile design side, and allows us to interpret that in this case, chemistry and material science lend support to textile design research. This type of collaboration does not challenge textile design research; it uses the strength of deep textile design skills. To renew woad processing and dyeing and to make it suitable for modern production technologies, we need to understand existing industrial textile production.

Crops4Luxury also studies the potential luxury aspect from the stakeholders and consumers' point of view in this very special context. The textile designers use the skills of design thinking and meaning-making (Verganti, 2009) to build a new understanding of value, while combining local sources and production with sustainability and luxury design.

The *Crops4Luxury* textile designers use their basic materials know-how and, for example, their knowledge of dyeing processes. At the same time, they are part of the new technology development, and can have a valuable impact on the development of a more sustainable textile industry. Traditional textile skills can be used to renew material processing through a combination of traditional and modern knowledge.

3. RECYCLING

The third potential pathway, *Recycling*, is related to the emerging circular economy (CE), in which materials are never considered to be waste. Our case study here is the *Trash2Cash* project.

The current dominant linear model in the textile and fashion business causes fast material throughput in the system, ending up with huge amounts of textile waste (Niinimäki, 2018a). For example, in the UK, a study by WRAP (2012) highlighted that 350 000 tons of textile waste go to landfills (worth £140 million), 160 000 tons of textile waste are recycled (down-cycled) and 80 000 tons of textile waste are incinerated every year. As closing the material loop approach is becoming increasingly important due to pressure to move towards the circular economy, we must see waste as a valuable material source and handle it accordingly (Niinimäki, 2018a). Therefore, the approach of recycling textile waste is extremely important in the industrial transition process towards sustainability. As different recycling technologies can recycle only certain materials (see Table 4 and materials category), a huge amount of new knowledge is needed.

Trash2Cash T2C (2015–2018) was based on multi- and interdisciplinary collaboration, and was steered by the experimental and iterative design-driven approach. The project was funded by the EU Horizon 2020 programme, and the project consortium consisted of 18 stakeholders from ten countries. The partners came from materials research, design, design research, business research and sectors of industry. The overall objectives of the project were to develop new material innovations from textile waste in the context of the CE, to construct innovative design cases for circularity (Trash2Cash, Tubito et al., 2019, Niinimäki, 2018a), and to integrate design, business and technology into a coherent discipline to establish new creative industries in Europe. Chemical methods were used for textile waste recycling. The chemical recycling process returns the material to the polymer level by dissolving it. After this, the

material is regenerated into high quality fibre (Heikkilä, et al, 2018, Niinimäki, 2018a). The aim is to keep the value of the fibre as high as possible, unlike in more common down-cycling processes. *Trash2Cash* successfully recycled cotton, man-made cellulosic fibres, polyester and cotton-polyester blends.

Table 4: RECYCLING

Approach	**Recycling** textile materials
Materials	Chemical recycling; cotton, cellulose, polyester and their blends Thermal recycling; polyester Mechanical recycling; all materials Both pre- and post-consumer textile waste
Enablers	Effective chemical, thermal and mechanical recycling and regenerating technologies System for reverse logistics; efficient textile waste collection systems System for material sorting
Objectives	To reduce the need for virgin materials To close the material loop
Dialogue	Interdisciplinary research Constructing dialogue through co-designing for cross-fertilization

Trash2Cash co-created the innovation in a real collaborative setting. The design-driven process forced everyone to collaborate. The dialogue created a interdisciplinary and in some level even transdisciplinary process in which each participant learned from the others' 'trade' (Grix, 2010). To some extent, the process even managed to construct a cross-fertilization between disciplines, as well as between different professions/stakeholders. According to Grix (2010), cross-fertilization means that 'scholars learn from one other, share methods of research, and are willing to accept different interpretations of events' (Grix, 2010, 98). Holistic and active collaboration is essential between different stakeholders to create a closed loop and functional systems for textile waste recycling. Accordingly transdisciplinarity, which needs cross-fertilization is needed here. Real knowledge sharing, and even knowledge co-constructing are beneficial when constructing an innovation, and especially when constructing systems for circularity.

Trash2Cash expanded the role of textile designers: they were not only disciplinary specialists, but also facilitators and bridge-builders between different disciplines and between academia and industry. Traditional textile skills and collaboration with the textile industry can be beneficially used in a context in which traditional and non-traditional skills need to be combined.

4. BIOFABRICATION

We see *Biofabrication* as a fourth potential pathway towards sustainable textile materials. Our case study comes from *Chemarts*, an interdisciplinary long-term education and research collaboration project between the Aalto Schools of Arts, Design and Architecture (ARTS) and Chemical Engineering (CHEM).

Biofabrication has recently become a 'hot topic' not only among material researchers, but also within the design community. *Biofabrication* is a term used to describe, for example, methods of growing actual materials using microbes, yeast or fungi. *Biofabrication* is based on the bioeconomy, which uses biomass and biofabrication principles as well as principles from farming, brewing and bio-processing while exploiting the latest scientific knowledge (Collet, 2018).

Chemarts represents experimental collaboration within Aalto University, aiming to inspire students and researchers from different disciplines to explore bio-based materials together. The main focus is on education: summer courses, for example, have been organized since 2012. *Chemarts* pedagogy is based on hands-on working in an interdisciplinary environment, starting from creative material explorations and problem framing (as opposed to problem solving) (Kääriäinen et al., 2017; Niinimäki et al., 2018b). Students are free to use any available bio-based materials, although the main focus is usually on wood-based lingo-cellulosic materials such as micro- or nanocellulose. However, many students are extremely curious and passionate about growing materials, and many of them have experimented with Kombucha (microbe and yeast) or Mycelium (fungus) at home before participating in *Chemarts* courses.

Table 5: BIOFABRICATION

Approach	**Growing** textile-like materials
Materials	Microbe, yeast or fungi, with proper nutrition
Enablers	Bioart, biodesign Synthetic biology Right conditions for growth

Objectives	No waste materials No extra production phases
Dialogue	Explorative and experimental design Includes critical and speculative design elements

The dialogue in *Chemarts* can be described as following the principles of explorative and experimental design. Explorative design is rooted in critical design or even speculative design. Critical design takes actions beyond disciplinary borders (Malpass, 2017) and creates a statement, very often touching on current social, cultural or ethical realities. The *Chemarts* statement can be seen as the experimental use of industrially produced materials such as pulp, nanocellulose or lignin together with alternative materials from nature. Speculative design, according to Malpass (2017, 101) is situated 'between emerging scientific and technological themes and material culture, speculative design operates in an ambivalent space; it typically focuses on the domestication of up-and-coming ideas in the sciences and applied technology'. In *Chemarts*, students from design and chemistry work together in an explorative way. The collaboration takes place in a laboratory setting, but the laboratory space has been especially designed for *Chemarts* activities, enabling collaborative experimentation and designer ways of working hands-on. *Chemarts* collaboration intertwines scientific methods with creative design practices, and therefore really questions the traditional way of doing science in disciplinary silos, as well as the way of many designers working alone with material experimentations.

From the textile designers' point of view, the free material experiments with bio-based materials are very inspiring, and the materials can be designed to be appealing to all the senses. The knowledge of traditional textile production methods (e.g. knotting, braiding, weaving, knitting, dyeing, printing etc.), combined with textile material know-how, is very useful for creative material experimentations and biofabrication processes. Traditional textile skills can be easily transferred to the non-traditional context.

5. DESIGNING NEW MATERIALS

The fifth and final pathway, *Designing new materials*, refers to the rapidly growing field of biotechnology, in which material properties can be developed and designed using various technologies, for example, through genetic engineering. Here, we present our *New Silk* project as a case study.

The *New Silk* project aims to study new ways of producing materials in the future, especially new types of silk-like materials in the context of synthetic biology. The original inspiration for this project was the way in which spiders create materials for their webs, 'spider silk', a material with properties that surpass existing synthetic materials. The material research is fundamental, and the view looks to the distant future: how to design and produce material attributes at the DNA level through genetic engineering. The material developed in *New Silk* is still a dream shared by material researchers and designers, and even utopian application sectors can be imagined. Therefore, this research is not yet even in the fuzzy-front end stage of the innovation process (Lee and Markham, 2013) but in the very early stage of fundamental science.

Table 6: DESIGNING NEW MATERIALS

Approach	**Designing** new materials with biotechnology
Materials	Living cells from various sources, treated with genetic engineering
Enablers	Biotechnology Synthetic biology New production processes
Objectives	To create totally new materials with designed material properties To invent and scale up the production processes in factories
Dialogue	Searching for new interdisciplinary touchpoints Design fiction and utopian design

In *New Silk*, the scientific material research collaboration centres on polymer processing, and the dialogue with design research can be considered mostly multidisciplinary and very experimental. Yet the project aims to create or/and investigate possible touchpoints between design and synthetic biology. Textile design 'visits' the 'silo' of synthetic biology and vice versa. It cannot be defined as meaning design intervention, as the design does not try to affect the other disciplines. Instead, the role of design has been to create and test methods for interactions between these disciplines.

The designers have been inspired by synthetic biology, trying to imagine what these new designed and engineered materials mean for the future (Niinimäki et al., 2018a). The best term to describe this type of design research is design fiction, which is grounded in utopian design. Design fiction is a method that combines science facts and design, and even science fiction (Malpass, 2017, 54). The idea is to step outside your own discipline and tie design and science together using a creative narrative, with an aspect of what could be.

‘Design fiction speculates about new ideas through prototyping and storytelling, where the design device functions like props or conversation pieces that help users imagine. Design fictions are important because they afford us the ability to see the world not only how it is, but also as it could be’ (Malpass, 2017, 54). Here, the context of conducting research is totally separated from commercial reality and the design space is in the imaginary future. Therefore, even if the research is grounded in solid science, it uses a great deal of creativity and the power of imagination and storytelling. This research position also uses the speculative design approach and even utopian thinking. Utopian design provides, as Levitas (2013, sited by Burcikova 2018, 385) highlights, ‘…a critical tool for exposing the limitations of current policy discourses about economic growth and ecological sustainability. It facilitates genuinely holistic thinking about possible futures…’ The utopian approach can be defined to mean ‘social dreaming’ which comes from Thomas More’s pivotal work *Utopia*, published in 1516.

New Silk has been an eye-opening experience for the participating textile designers. It is exciting to be able to obtain a glimpse of basic material science, and actual materials at the DNA level. In addition, textile designers have been able to open up the context of textile industry to materials scientists who often work far from the applications. Traditional textile skills might not be useful in this context, but the close collaboration with basic science has inspired us to further explore this non-traditional context for textile designers.

DISCUSSION AND CONCLUSIONS

As Grix (2010, 99) points out, a great deal of the best research takes place between disciplines, more precisely, ‘on the borders between them’. Even if difficulties always arise while collaborating with other disciplines (e.g. Grix, 2010; Niinimäki, 2017), clear benefits can also be seen; for example, finding real innovations which have competitive elements and even speeding up the innovation process (see e.g. Niinimäki, 2018b). While developing sustainable textile material innovations, collaboration is essential, as we have shown here through different collaborative cases. The *Transforming, Reinventing, Recycling, Biofabrication and Designing new materials* approaches have all opened up valuable views for the future and facilitated different kinds of scientific dialogues.

Pavilonyte-Ezerskiene (2018, 134) points out that ‘textiles also invite us to look for new and relevant perspectives of sustainable and harmonious life and mediate how we look towards the future’. Balsamo (2011, 6) further argues that ‘designers work the scene of technological emergence: they hack the present to create the conditions of the future’. This is exactly true in current textile design and textile research involving emerging materials research. In this studied context, multi-, interdisciplinary collaborations have opened up new perspectives for textile design as a profession, and textile designers have tested new roles through different kinds of dialogues.

Some of the researched cases were more futuristic and speculative than others (*New Silk, Chemarts*), some focused on finding new applications and production processes for existing or disappearing materials (*DWoC, Crops4Luxury*), while others were looking at how to close material loops *(Trash2Cash, DWoC)* to fight against the increasing textile waste streams caused by the current consumption culture. Some projects created a meaningful dialogue between materials research and textile businesses to find ways to scale-up and commercialize sustainable material innovations (*Trash2Cash, DWoC, Crops4Luxury*). All these projects have contributed to building new possible futures for different kinds of sustainable textile materials. As Balsamo says, this new collaborative knowledge also builds ‘the conditions of the future (2011, 6)’.

Collet (2018, 97) highlights that real sustainable innovations, even radical ones, are constructed in design-science collaboration. She further points out that designers ‘set the boundaries for a transition from global manufacturing to local horticulturing and open the door to a new kind of design practice’ (Collet, 2018, 98). As she sees it, the dialogue between textile design and other disciplines also changes textile knowledge and design practice. Therefore, textile-related research and professions are continuously changed by existing and emerging technologies, digitalization and requested sustainability, causing an increased need to update the education and skills of textile professionals. The empirical knowledge gained through the cases presented in this paper shows that dialogues between disciplines enhance and transform disciplinary knowledge. Deep understanding of materials, textile technology and production methods combines with creativity and aesthetic skills form the grounding knowledge of textile design; in the cases presented, this has expanded to building bridges and facilitating material innovations between science and commercialization.

Designers can have an immense impact on the sustainable future by collaborating with other disciplines and professions. Open, constructive dialogue between different disciplines could be a strong game changer in our society and may transform dominating practices into more sustainable ones. One crucial part of this transition is our living environment, where materials in general, and in this study textiles in particular, play an important role. Textile designers’ creativity, process knowledge, and understanding of materials, structures and tactility, are beneficial in different kinds of material-related projects targeting a sustainable future. Simultaneously, textile knowledge is constantly changing and evolving in new directions in connection with different scientific disciplines.

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