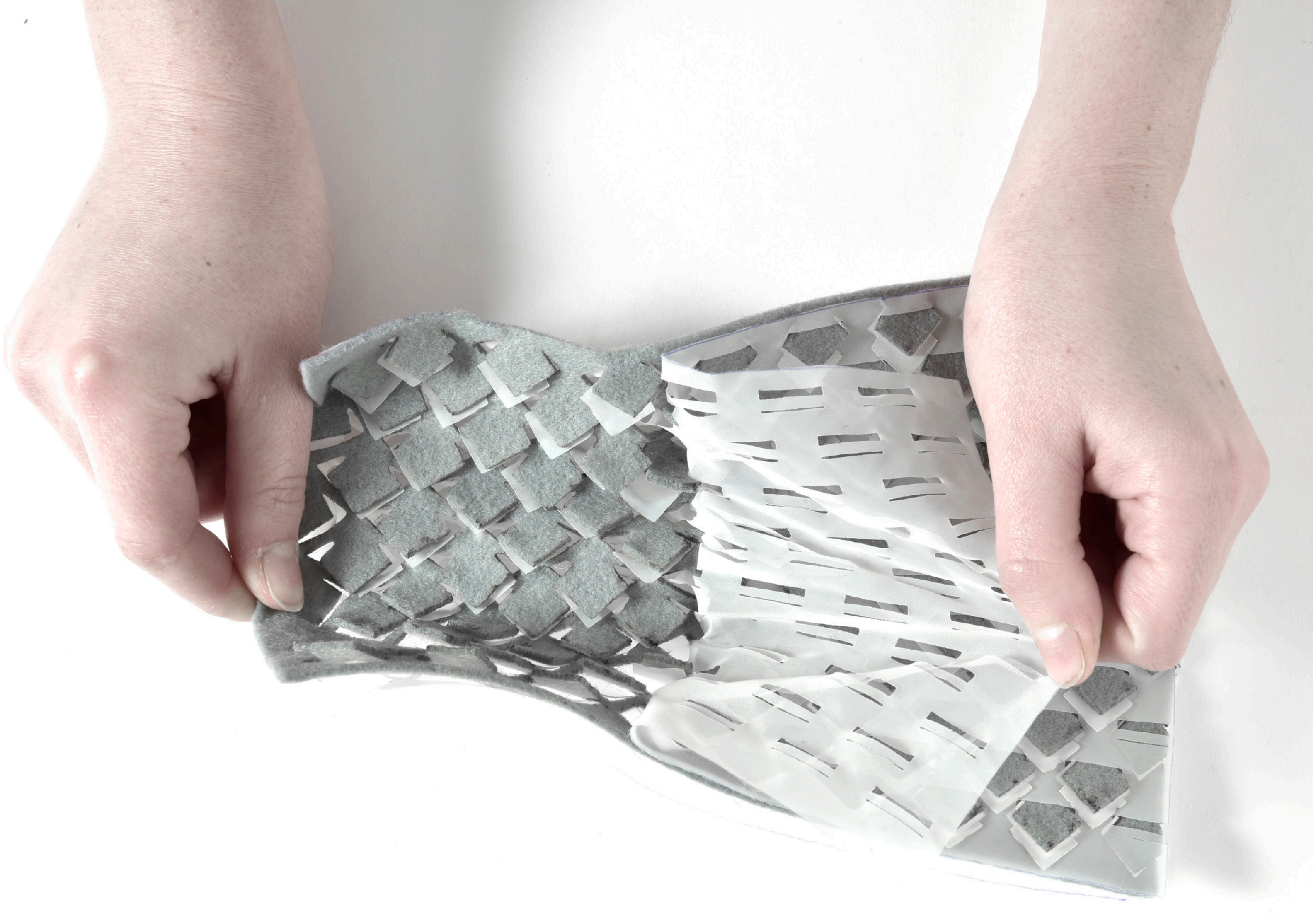

Textile Design for Disassembly

A creative textile design methodology for designing detachable connections for material combinations

Laetitia Forst

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by

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Abstract

Textile waste is a growing issue and with increasing consumption rates, solutions must be explored to close the loop. Currently, only 1-2% of this waste stream is recycled to new textiles (Ellen MacArthur Foundation, 2017a). To enable a shift towards a more circular textile economy, current barriers to effective recovery and recycling of materials must be lifted. Existing and emerging technologies are currently better adapted to mono-material inputs as blends hinder recycling processes (Cupit, 1996; Östlund et al., 2015). However, the creativity of textile design thrives on combinations of resources for aesthetic or functional effects. The problem of blends therefore partially originates from creative textile design, and this study uses this same approach to explore potential solutions. This research suggests the adaptation of Design for Disassembly (DfD) to Textile Design for Disassembly (TDfD) as a strategy to create textile combinations which can be taken apart into their recyclable components at end of life as well as contribute to the longevity of textile products. DfD originates from engineering and industrial product design. This study therefore provides an original textile design perspective on the strategy and its application to practice, it is supported by an expanded understanding of problematic blends themselves. The current engineering approach to the understanding of textile recyclability as defined by Gulich (2006) is adapted to a creative textile design context to enable the effective redesign of detachable material combinations and articulate a methodological framework for TDfD.

Acknowledgments

My greatest thanks go to my supervisors, Dr. Kate Goldsworthy and Prof. Rebecca Earley, for immeasurable support throughout this project and in my professional progression in this field. Thank you also for having so tightly involved me within the Mistra Future Fashion project and their broader research network. Having been welcome as part of the Centre for Circular Design team has provided me with the best conditions one could imagine, and I would like to thank all the researchers and administrators on the Trash-2-Cash and Mistra Future Fashion projects for creating this stimulating environment.

This project would not have been possible without the financial support it has received from the University of the Arts London scholarship, which has allowed me to fully dedicate myself to the project for three years, and from the Cotton Textile Research Trust, which has supported participation in conferences and training in the first two years of the project.

Special thanks go to Cathryn Hall for all the stimulating conversations and for being such an inspiring collaborator in developing the Circular Design Lab and There and Back Again projects. Although strictly speaking they may have taken time away from the PhD, the collaboration has made the experience of doing research in this field so incredibly rich.

Thank you to all the people who have given their time to contribute their expertise to this work, to the participants in workshops which have helped steer the ideas for this project, and to the researchers who have provided feedback throughout the progress of the work, in particular Kay Politowicz for the thorough read of the last draft. I am particularly grateful to the Richmond Maker Lab for opening their doors to me and making equipment available for all the laser cutting involved in the practice.

Finally, I would like to thank my friends for their support throughout, Tanzi for being a great fashion model, Chloë for talking things through and the OBS for the relief from work. Most particular thanks to Andreas for all the emotional support. I dedicate this to my mother and father.

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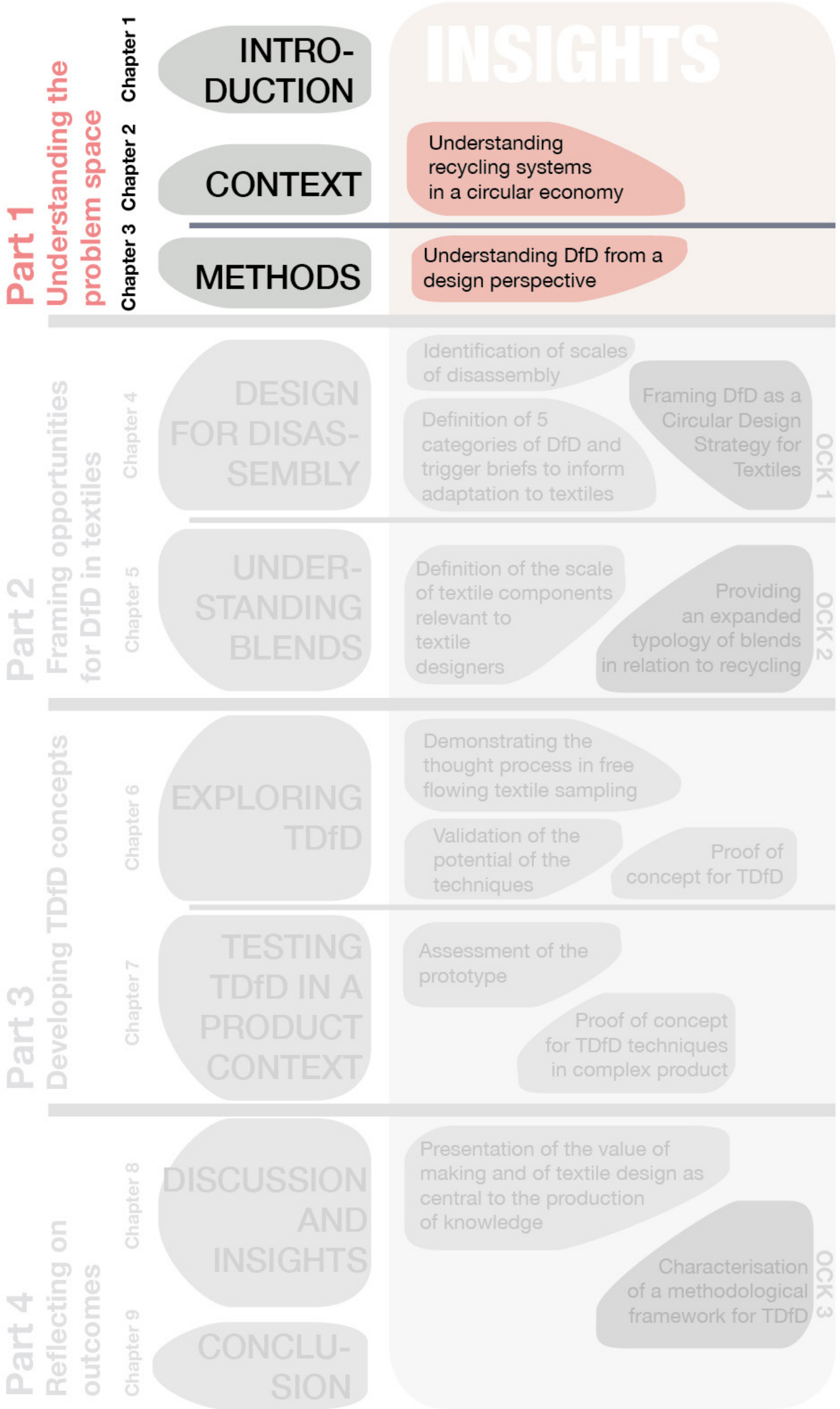
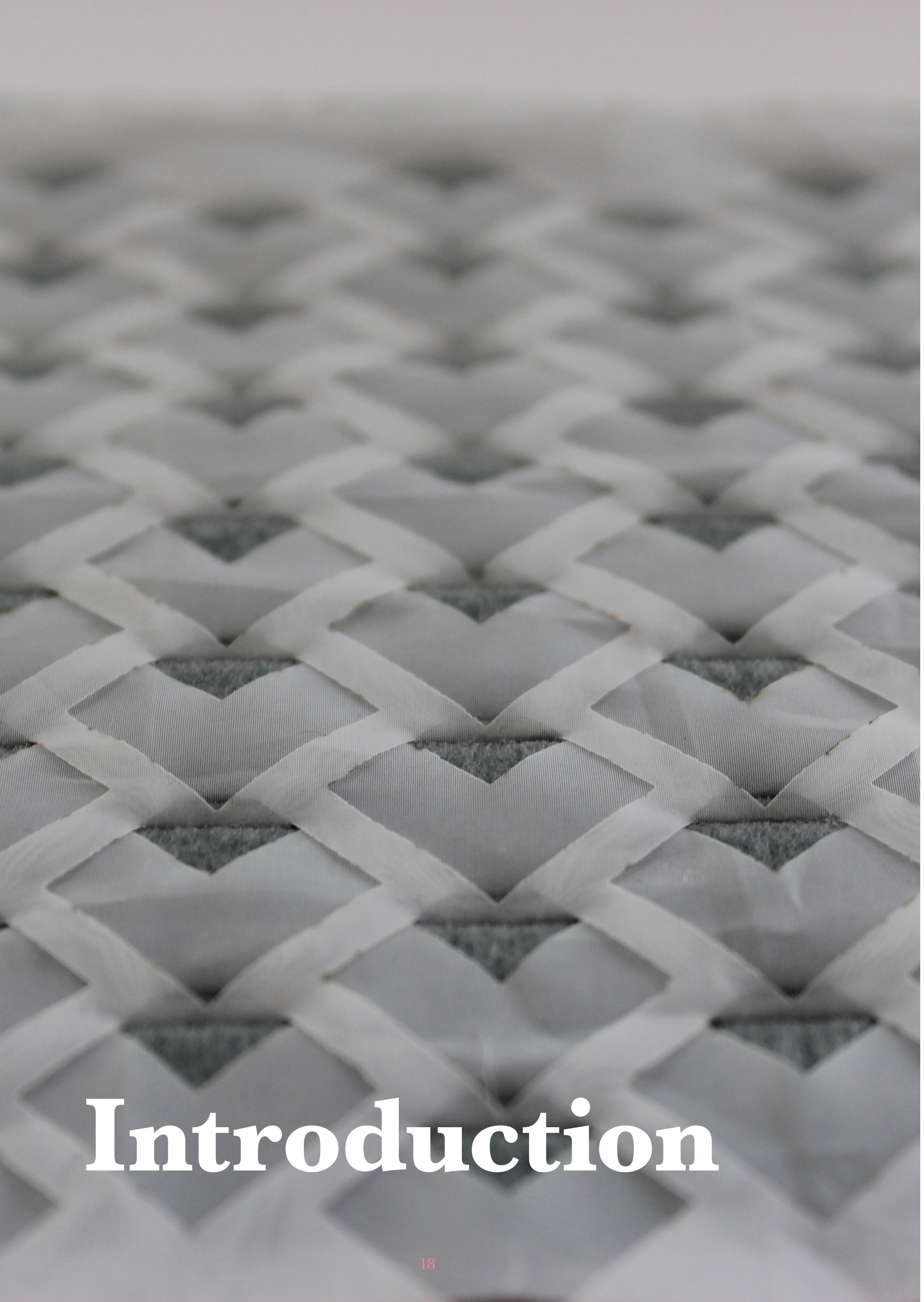


Part 1

The purpose of this first part is to offer an overview of the context of the study. These first three chapters set the context and boundaries for the study and suggest the methods which will be used within this framework.

The specifics of a textile designer's perspective on the problem of blends as well as the rationale for this approach are presented throughout this section. Most importantly, this presents the reasoning and plan for using creative textile design practice as a way of drawing insights for the transferability of this approach to circular design challenges.

Following an overview of the structure and aims of the work, the context review points at the gap in knowledge in terms of addressing blends as a design flaw through textile design. As shown in the diagram on the opposite page, the main insight achieved in the context section is an understanding of the opportunities and challenges embedded within current recycling systems and considering these in the context of a circular economy. This then feeds into the methods section which focusses on understanding DfD from a design perspective and highlighting how design thinking can provide solutions to fill current gaps in research and knowledge.



1. Introduction

This research explores Design for Disassembly (DfD) as a potential alternative to blends which create recyclability barriers and suggests its adaptation to Textile Design for Disassembly (TDfD). This chapter defines the scope of the research project, from the origins of the exploration of the concept of DfD to the contributions to knowledge proposed as a result of this work. It signposts some key aspects which will be elaborated on in later chapters.

1.1. Project Overview

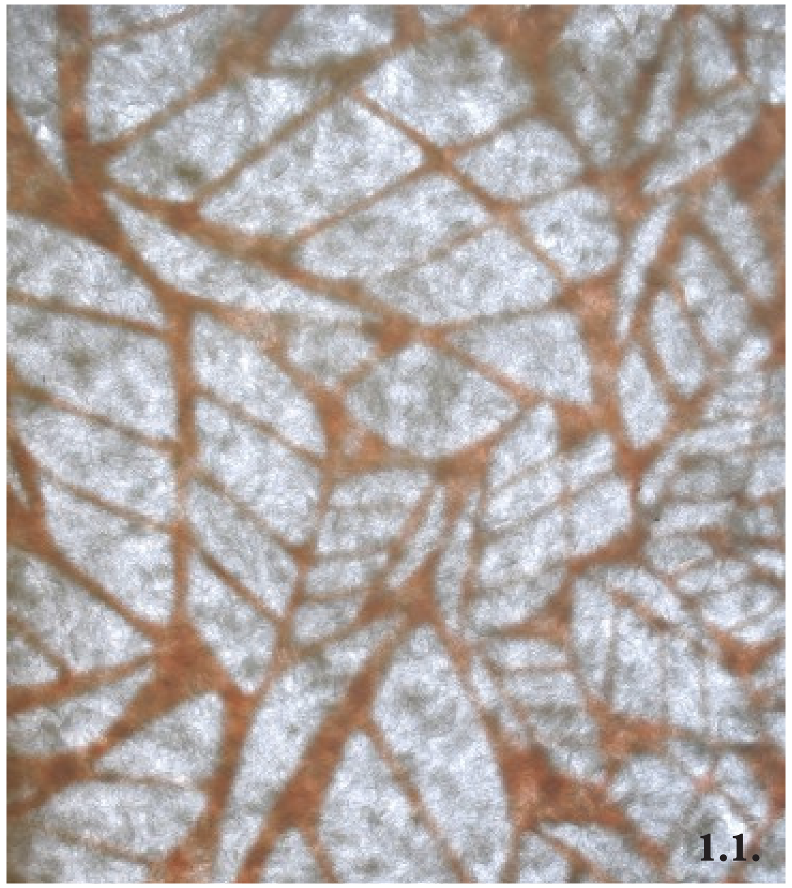
Blended materials currently create barriers to a circular textile economy (Cupit, 1996; Gulich, 2006; Östlund et al., 2015). While blending often occurs as a way to balance cost and functional performance (Hatch, 1993; Sinclair, 2015), the emphasis in this work is on the ways in which blending is used to express creative potential in material combinations for original aesthetic and structure effects.

1.1.1. Introduction to DfD

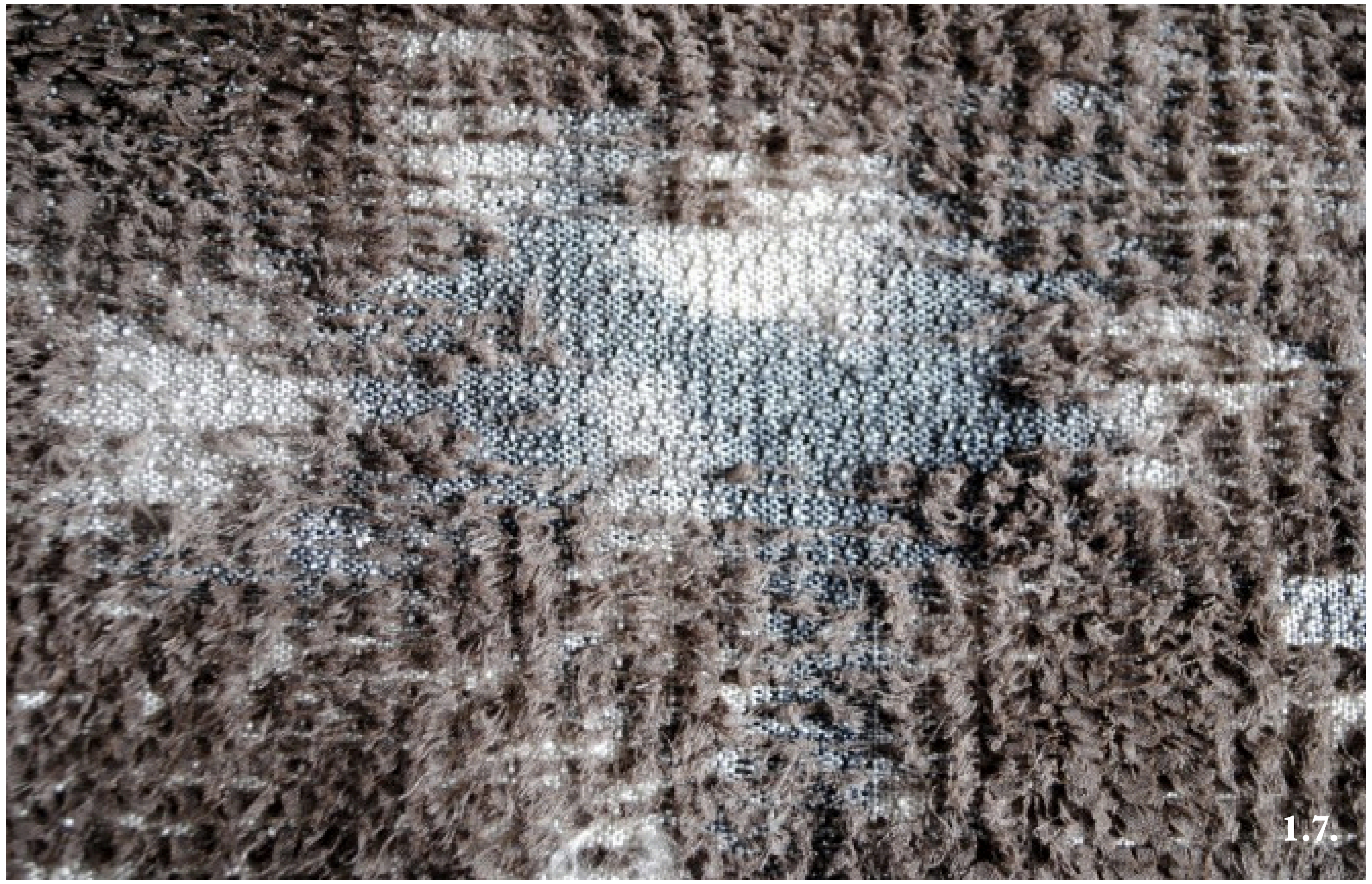
This section offers a brief review of the genesis of this approach in previous work followed by the description of the strategy as it is applied in the research project.

The origins of the DfD approach for textile design: the Muto project

The premise for this research came from the exploration of “Monstrous Hybrids” as the theme for the author’s Masters’ degree collection presented at ENSAD Paris in 2015. This collection explored ways in which cotton and polyester could be temporarily combined in a furnishing textile collection which would draw the best out of their inherent qualities while not preventing them from returning to their separate optimal recycling streams. The term “Monstrous Hybrids” borrowed from Cradle to Cradle (McDonough and Braungart, 2002) was a trigger to the imagination and the collection investigated how these barriers to recycling could be lifted and become “Beautiful Hybrids”. Most of the textiles were mono-materials such as those shown in figures 1.1. to 1.4., using either cotton cloth with natural dyes, or polyester with sublimation printing and laser treatments. These came together through layering which combined patterns and colours with transparency in the different components. The materials were intended for applications in various products in a home furnishing collection, depending on their material type, style, and durability. A few of the samples did however combine polyester and cotton in the same fabric as shown in figure 1.6. and 1.7. These were made using a floating weft technique with a special cotton laser-cut “thread” that would overlap and cover the polyester base, but whose fragility would allow it to degrade and come away from this base gradually throughout the product’s life until only the polyester was left. Overall the collection emphasised the poetic potential of differentiated material aging, celebrating the material’s inherent qualities and bringing their specificities forward through the contrasts between polyester and cotton. A full account of the Muto work and its relation to the research into circular textile design undertaken here can be found in appendix 11.4. (p.420). Taking this initial work into the research project qualified it as Design for Disassembly.



1.1. Papier maché made from cotton calico waste, died with indigo and madder. The flat front surface is backed with a laser cut lattice which creates a filigree pattern when the light shines through
1.2. Polyester sublimation printed mono-material fabric with laser etching pattern
1.3. Textured mono-material cotton fabric. The technique uses knitted cotton tubes to create a bobble effect, dyed with indigo, madder, and reseda.
1.4. Mono-material polyester fabric using laser engraving to create a pattern
1.5. Mono-material polyester fabric. The technique uses an adaptation of ikat techniques by sublimation printing the pattern on the thread before weaving on a dobby loom.



1.6. Test sample to demonstrate the pattern appearing under the layer of cotton scales as the fabric is worn away.
1.7. Temporary combination textile. The top layer made from cotton gauze stiffened with vegetable starch and coloured with vegetable dyes, it is woven onto a base cloth of polyester with a hidden ikat pattern.

From DfD to TDfD

This study explores how DfD can be adapted to relate specifically to the practice of textile design in the form of TDfD. The shift from the existing concept of DfD to the new strategy of TDfD is effected through the analysis of the former and practice to test the potential of the latter. Throughout this thesis, DfD will refer to the existing approach of Design for Disassembly as it is found in examples of product, architectural or modular fashion design, whereas TDfD will refer specifically to the concept that is put forward as the subject of this thesis.

DfD is a circular design strategy (Bakker et al., 2014) that suggests designing products and materials in ways which allow them to be taken apart at the end of their use phase, for the different components to be diverted from waste in the most appropriate way (International Organization for Standardization, 2016; Vezzoli and Manzini, 2008).

TDfD proposes materials which are as desirable as current problematic blends, but which allow for their components to be recovered. This means starting with materials which have been identified as easily and fully recyclable. In some cases, these may already be recycled such as with polyester from polyethylene terephthalate (PET) bottles, but due to current contamination issue with recycled materials, most are virgin. TDfD then combines these different components in ways which will allow them to be recycled without any contamination. In this regeneration cycle, virgin materials that have been included in a TDfD combination could then be recovered and recycled as mono-materials and included in a new TDfD combination following their regeneration. This research does not however go into this system modelling and the scope of the project is confined to the exploration, and characterisation of TDfD as a way of enabling the release of individual recyclable textile components.

DfD is established as a response to extended producer responsibility (EPR) and as a way of optimising the costs and effectiveness of material recovery in the field of electronic and electrical devices where EPR regulation is most prevalent due to the toxic and rare materials involved in the creation of those products (Lindhqvist, 2000; Niinimäki, 2013; Ziout, 2014). This study translates this approach to the field of creative textile design so that resources that go into the production of fabric may be recovered with equal care for optimal regeneration.

1.1.2. A Creative Enquiry into TDfD

The stance taken in a creative textile design project such as the Muto collection is essential to the work carried out in this research. The analysis of DfD first develops a rationale for the strategy to be applied to creative textile design practice. The focus is then directed towards the specific issue of blends which is characterised as an inherently design-led flaw (see 2.2.2. p.44). In response to this design issue, design itself can and must become a way of implementing meaningful change (Papanek, 1985:19).

Material science approaches

In the light of the damaging impact of the industry and potential material scarcity, the drive to close the loop on textile waste has led to multiple systemic and technological endeavours to increase ease of recycling for textiles. The start-up Worn Again (Worn Again et al., 2015) for instance, is a pioneer in the field with their technology which separates and recovers cellulosic and synthetic materials from intimate blends through a chemical process. Other companies such as Re:newcell or EvrNu have used this chemistry approach to recover pulp from high content cellulosic textiles. However, this approach is characterised for the purpose of this study (see chapter 5) as a chemistry or material sciences perspective. While designers may be involved in the process, these techniques reach beyond the approach taken to designing materials and products in the studio. There is a case for involving designers in these chemical and small-scale material processes (Ribul, 2019), but this study is limited to the hands-on action with material combinations that takes place in solo craft-based design practice.

This approach suggests that designers are well positioned to solve issues created by design, and that the decision-making process needs to be re-shaped in order to afford better opportunities for designing for a circular economy. This project therefore focuses on the creative textile design process to develop an approach that can be seamlessly integrated into current practices to challenge the status quo in material combinations.

Engineering approaches

Looking at DfD from a designer's perspective has also reached beyond the engineering approach currently taken to the strategy. Indeed, it originates from an incentive for optimising material recovery through Extended Producer Responsibility (EPR) (Niinimäki, 2013:25). In this study the technical limitations of the recycling system in regard to blends were taken as a creative trigger. With ease of recycling as the overarching aim, DfD was explored for its innovative potential in delivering original aesthetic and functional characteristics to the new materials. In a similar way to that explored in the Muto project, the aesthetic potential of new ways of combining materials was explored. In creating new patterns and textures through TDfD material combinations, the design approach taken here creates materials which can be highly desirable as well as easily recyclable.

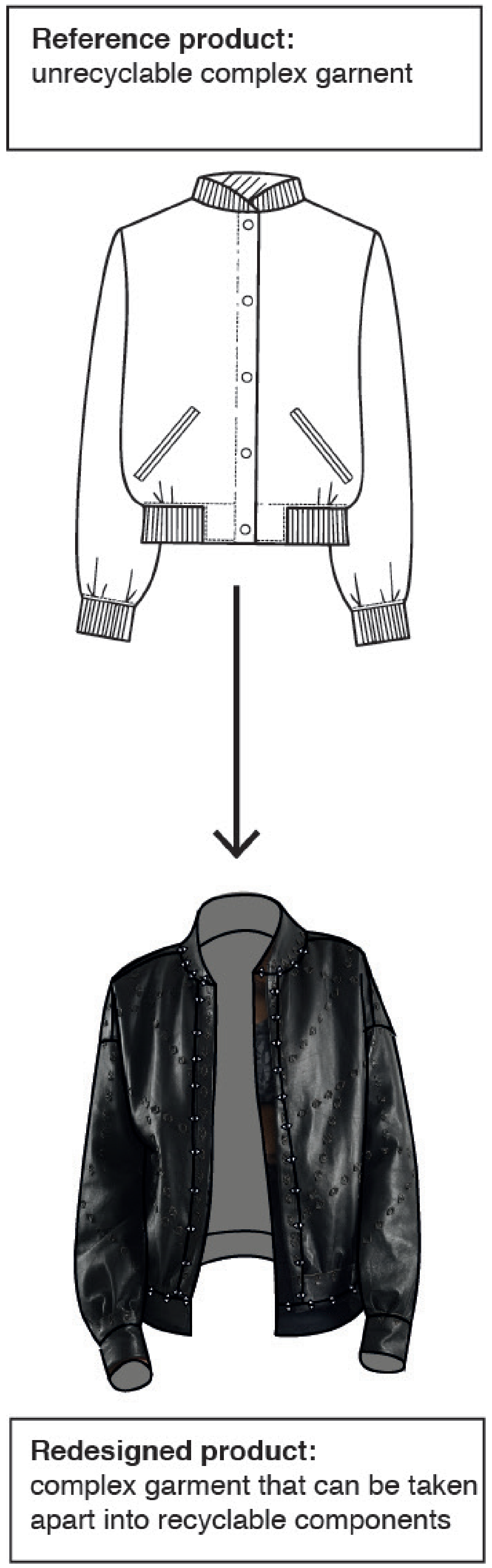
A creative approach

The creative textile design approach is also characterised by the leading role of practice in achieving insights. As will be described in the methods chapter (chapter 3) and in the relevant sections throughout the thesis, practice has taken different forms from the visualisation of complex information to the creation of samples and prototypes. Practice takes a central role and the originality of the insights reached derives from this designer-maker approach.

The work adds a new strategy for textile designers to apply circular design to their work and challenge the status quo which is currently leading to recyclability barriers. To effectively develop these strategies for textiles, the ways in which conventional textile samples and prototypes are made was mimicked with the inclusion of the DfD brief. As will be described in following sections, the making started with a mood board-like process, then went into sampling and refining to prototype. In taking the research through these steps, the aim is to transfer these circular strategies to conventional textile design practice to transform it for a circular economy. These characteristic processes are then translated into the methodological framework which underpins this work (see 3.2. p.68).

Redesigning a complex product

The creative textile design process is essentially applied to solving the issue of blended and complex materials and products which create barriers to effective sorting, recovery and recycling of resources. The example of a specific problematic product is used to demonstrate the validity of this approach in solving the problem set at the outset of



1.8. Simplified representation of the redesign process

the work. Jackets and coats are currently difficult to recycle due to the large number of pieces and different materials that enter their composition (Norris, 2012:47). This garment type is therefore used to demonstrate the redesign process through TDfD.

The radical simplification of the task laid out in this thesis is visualised in figure 1.1 as a way of signposting the end goal for the work as a measure of success. The steps of this redesign process will be expanded on in the concluding chapters to demonstrate how each phase of the practice contributes to achieving this goal (see 8.1.1. p.254). A redesign process as defined by Bhamra et al. (2017) requires a thorough understanding of the original problem product. The jacket therefore acts as an example for complex products and materials that can be studied in detail before proposing solutions.

It is also particularly relevant to use this concrete example at the outset of the work to highlight that this study aims to suggest strategies that can be directly relevant to individual designers. Grounding the process within a specific product directly connects the exploration of solutions to unrecyclable material combinations to the designing and making activities of textile

designers. While the development of jacket prototypes will be detailed in chapter 7 (p.193), this target guides the work throughout the thesis.

1.2. Aims and Objectives of the Study

The aims and objectives were set at the very start of the project to outline the goals of the work. The listing of the sections of work that would need to be produced in order to achieve the overarching aims of the study is reiterated in the conclusion chapter (table 9.1. p.274) to demonstrate how these were completed.

Aim 1: Understand the current “state of the art” and potential for DfD in designing textiles for recyclability.

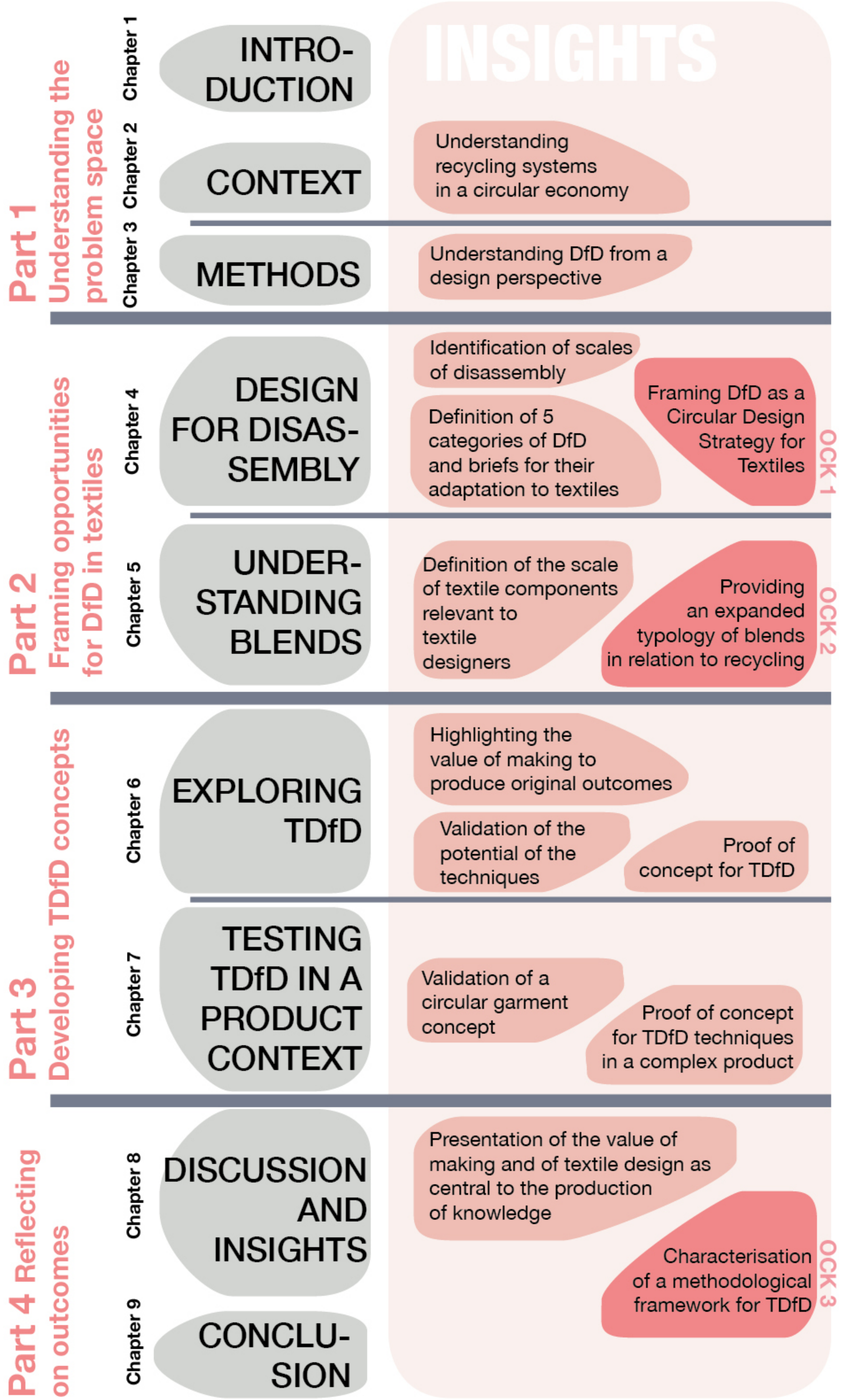
Objectives:
• Create a visual map of the typology of existing blends and their characteristics,
• Understand the barriers to recyclability created by blending fibre types,
• Identify the ways in which DfD can influence product end-of-life and recycling opportunities.

Aim 2: Design textiles with detachable connections and draw insights for the use of TDfD within a circular economy context.

Objectives:
• Carry out textile design practice exploring TDfD,
• Identify the opportunities for textile practice to propose models or TDfD,
• Apply the TDfD concepts to a set product context,
• Draw insights from the challenges of designing for disassembly and the opportunities for the product life cycle.

1.3. Project Outline

The thesis is presented in four parts which group the chapters into the main phases of the research. The structure of the thesis follows a chronological unfolding from the context review into more in depth exploration of key concepts and their interpretation in practice then summing up the findings in final chapters. The production of insights which contribute to the new knowledge put forward in the work follow this format. Figure



1.9. Outline of the thesis and insights.

1.8. offers an overview demonstrating the sequence of chapters and the main themes or insights within each of them, it also forms the basis of the methodological framework which will be constructed throughout the presentation of the work and summarised in chapter 8 (p.268-269).

As visible in figure 1.9., Part 1 of the thesis offers an initial understanding of the problem at hand. The context and methods chapters respectively outline the circular economy context and frame the design perspective through which DfD will be explored. These descriptions feed through the rest of the work.

Part 2 reframes the problem space defined in earlier chapters in terms specific to textile design. Chapter 4 lays out the concept of DfD, in part through case studies, and suggests ways in which the strategy can be taken forward in textile design. As shown in figure 1.9. with the dark pink emphasis, the first of the three contributions to knowledge proposed through the work is achieved in this chapter with an original framing of DfD as a strategy for textiles. Chapter 5 contributes further to connecting DfD to textiles with a definition of the scales of components in existing problematic blends. This leads to the second contribution to knowledge which builds on the work of Gulich (2006) and expands the current understanding of blend complexity in relation to recycling, also highlighted in the diagram.

Part 3 takes the findings from the previous phases into exploratory textile design practice in sampling and prototyping to develop and test TDfD concepts and techniques. Chapter 6 offers proof of concept for TDfD techniques using felting, weaving and laser cutting. This chapter focusses on the importance of hands-on making by describing how the samples were made in a free-flowing process and then used as tools to communicate and reflect on the design process. It later outlines four assembly techniques defined in a retrospective mapping process. These are then put into context in chapter 7 with the use of a combination of techniques as part of the redesign of a jacket as a circular garment concept. The context for the development of this jacket concept as part of the Mistra Future Fashion research programme is laid out and key insights for TDfD are drawn from the analysis of this design process. This collaboration with Professor Becky Earley used the brief from the ongoing Mistra Future Fashion research as the setting for the product context. The key findings from this were then transferred into a second iteration of the jacket, removed from the Mistra Future Fashion context, which is refocused on the combination of materials belonging in different recycling systems. This second prototype is offered as the result of the overarching redesign process. The detail of the nature of the work with the Mistra Future Fashion project is laid out in chapter 7, table 7.1. (p.208) shows how the different aspects of the project were distributed amongst collaborators. As can be seen in figure 1.9. the insights from this section are not highlighted as contributions to knowledge per se, however they are key to the validation of TDfD as a circular design concept and provide the basis for the development of the third contribution.

Part 4 reflects on the work and traces the findings from the exploratory practice to articulate a transferable methodological framework. Chapter 8 formalises the lessons from the research process, outlining the influential role of making and the different forms it takes throughout the work, whether this is in making models and visualisations to analyse the issue or in making samples and prototypes to test new ideas. This is then translated into the methodological framework which offers the transferable recommendations from this work. The conclusions in chapter 9 check the work laid out here against the aims and objectives presented at the outset and reframes the contributions to knowledge in regard to the detail given in this thesis.

The diagram in figure 1.9. serves as an outline for the thesis structure but also for the methodological framework building. It will be repeated at the beginning of each part of the thesis as a reminder of the key insights which will be represented in each section. It will be expanded on in chapter 8 (p.268-269) to demonstrate how the methods contribute to the series of insights and form the overarching framework for the research.

1.4. Contributions to Knowledge

The research articulates Textile Design for Disassembly as an alternative to unrecyclable material combinations where different components can be assembled as part of a material or product and later be taken apart. The challenges of the recyclability of material combinations have previously been addressed mainly through mono-material design (Goldsworthy, 2012), this study therefore addresses the absence of solutions which

embrace material combinations while still enabling recycling. Where no previous description of this approach to circular textile design existed, this work suggests alternatives to mono-materiality through TDfD.

The three contributions to knowledge provided by this thesis are of two distinct types: the first two offer a new perspective on existing work in this field, while the third articulates an original methodological framework based on the analysis of new creative practice. This section briefly summarises the contributions which will be supported by the description of the research process and key insights in later chapters.

DfD as a circular design strategy for textiles

This study proposes an expanded definition of existing DfD concepts which relates to creative textile design, highlighting their potential as circular design strategies. Using case studies as a way of extracting intermediate knowledge (Löwgren, 2013) from existing practice, this work demonstrates the breadth of potential of this strategy in addressing circular design challenges. For example, it shows how it can reach beyond raw material recovery and contribute to product longevity. The new analysis of the concept of DfD across various fields leads to insights for its adaptation to textile design through the articulation of a series of briefs to guide creative textile design practice.

An expanded typology of blends in relation to recycling

The research provides a needed description of the variety of blends which currently hinder recyclability in order to operate a shift towards a type of textile that is easier to recycle. It builds on Gulich's (2006) classification (see figure 5.1. p.121) and adds granularity to the understanding of the most problematic category to enable a shift towards what Gulich defines as "multi-material composite systems with detachable connections" (Gulich, 2006:29), and here is redefined as TDfD, to offer an optimal compromise between ease of recyclability and functionality.

This is relevant to the field of textile design as the scales and type of connections existing in problematic blends require a redesign process to enable better recyclability through TDfD. Understanding the characteristics of these types of blends enables this shift in the way of combining materials. It suggests an alternative to the current mono-material approach to textile design for recycling which embraces the creative power of the combination of different materials, colours and textures in textiles.

A methodological framework for TDfD

This study offers a model for the investigation of circular design strategies through practice. This follows from the identification of design as a main contributor to creating barriers to textile recycling and therefore being a key angle to approach for targeted solutions. This framework is achieved by demonstrating the phases in the design process that lead to the development of solutions to recyclability challenges in textiles.

The research moves through four stages: Scoping, Making, Mapping, and Reflecting to achieve transferable insights to remove current barriers to a transition to a circular economy (see diagram on p.268-269). By retrospectively analysing and understanding the mechanics of drawing insights from the practice, the methodological framework can be abstracted from the specifics of the jacket brief used to guide the work here, and formulated for designers to adopt in future work taking on circular design challenges.

2. Context: Blend Recycling Challenges

This work aims to address the recyclability barriers created by blending incompatible resources through design. This chapter defines the different elements of the brief, from framing the circular economy as the ideological structure for the work, to arguing for the validity of a design perspective on the issue and as an approach for the exploration of solutions.

2.1. Framing the Problem of Blend Recycling

The contemporary framework for this investigation is laid out in this section through a review of the context of a circular economy and how it relates to textile blends. This is followed by indications of how this research aims to address the existing issues in the field.

2.1.1. Describing Blends as a Barrier to Recycling Processes

Blends are symptomatic of an approach to materials design which does not account for end of life. To move away from a linear economy this status quo must be understood and addressed.

The linear economy

Historically the focus of design has first been as a driver for economic growth and a tool to increase consumption (Packard, 1960). With little consideration for the dramatic effect of human activity on the environment, the systems and mind-sets put in place by these practices have lasting effects to this day (Murray, 2002). This approach to manufacturing and using everything that surrounds us as disposable together with the application of programmed obsolescence principles and other such strategies to induce over-consumption, has now been labelled as a linear, or “take-make-waste” model (Ellen MacArthur Foundation, 2011). In this context, resources are taken from the environment, whether it be natural renewable resources such as wood, or non-renewables such as oil, then transformed into the products we use, before being thrown away. Yet there is no “away”. In the light of the direct effects of chemical leaching in landfill and other issues linked to waste management, the need to switch models is evidently urgent. Moreover, the linear model is connected to exponential growth which collides with the reality of a finite planet with finite resources.

Beyond the technical issues embodied in harmful practices in various industries, these failures are also the symptoms of outdated mind-sets. Alongside improvements in technologies and systems which will enable a transition to regenerative businesses, there is a need to radically rethink the way we design the world around us.

In the textile industry, this broken system is exemplified by a dramatic increase in garment consumption which has almost doubled in the past 10 years, with a decrease in the number of wears per garment, leading to a rise in landfill and incineration of these products at end of life (Ellen MacArthur Foundation, 2017a). Less than 1% of these textiles are recycled as fibres. There are many barriers to the recovery and regeneration of textiles which in theory could be recycled. They can be connected to the challenges in sorting the materials effectively (Maldini et al., 2017; van Duijn, 2018), the current lag in recycling technologies, both chemical and mechanical (Hall, 2018; Mathews, 2015), or the lack of markets for the resale of these resources (Royal Society of Arts and Innovate UK, 2016; van Duijn, 2019).

These challenges all point to the fact that textiles are still designed for a linear economy, and systems are failing to adapt to this. One of the questions posed by this work is: how can we design materials that are adapted to existing and emerging systems so as to connect them in a circular framework? As put by Sophie Thomas:

> “We urgently need designers to visit end-of-life facilities so they can see for themselves how we are blindly designing waste into the system by creating products that are increasingly complex and harder to deconstruct and recycle.” (Royal Society of Arts and Innovate UK, 2016)

This call for a direct understanding of the systems within which material and products move is interpreted from a designer perspective which unpicks the problem through direct confrontation to the materiality of blends. Furthermore, the development of solutions is embedded within the practice it aims to change and material experimentation drives the redesign process. This work will demonstrate how textile practice can be adapted for the creation of textiles that are appropriate for circular systems and will provide a methodological framework (see chapter 8) for the transferability of this approach.

Blends in a linear economy

In this study, blends are described as the combination of two or more different fibres in the same yarn or cloth (Hardingham, 1978). The emphasis is particularly placed on the notion that the various fibres combined cannot effectively be recycled in the same process without impacting the quality of the outputs.

There are many reasons for combining fibres, but these are generally connected to the need to improve the performance of the materials (Sinclair, 2015). The combination of fibres with complementary characteristics is either aimed at improving the quality of the end product, or at improving the efficiency of processing. Another strong driver for the creation of blends is the need to reduce costs by, for example, combining a high value fibre with a low value one to balance the price of the final product (Hatch, 1993; Sinclair, 2015). The different reasons for combining materials lead to different types of blends, whether this is in fast-drying poly/cotton sheets, or a price-balanced wool/acrylic jumper. Different material types and applications involve different fabric structures as well as an immense variety of fibre combinations. These can range across various assembly techniques available in knit, weave, or other textile manipulations, adding another layer to the complexity of blends.

To provide an effective alternative to these material combinations which create barriers to recyclability, the characteristics which make them desirable must be understood and replicated or surpassed in any solution which is offered to ease recyclability. A more detailed account of the criteria by which samples were assessed for relative success is put forward in section 3.2.3. (p.79). Alongside this, a full description of the making of samples and prototypes are provided in chapter 6 and 7 respectively.

2.1.2. The Circular Economy as a Reference Structure

The ultimate aim of this research is to facilitate a transition from a linear to a circular textile economy. The framework for this approach relies on the concepts of circular economy and Cradle to Cradle, but as will be demonstrated in this section, the work takes a critical approach to these models and expands beyond their primary interpretation. The requirements for this transition are laid out in this section, stating the rules to follow and the specific approach to the circular economy framework which is taken here.

The rules of a circular economy: non-contamination

The circular economy has emerged within the context of sustainable development as a model which combines multiple approaches for a vision of a future in which economic growth is decoupled from resource consumption and pollution. Since the mid-seventies, the circular economy concept has been put forward as a potential solution to the wasteful and environmentally harmful model in place. The foundation of this framework is a vision for a restorative system that would return as many resources to the biological or industrial sphere as it takes out.

The framework for the circular economy cannot be attributed to any one single date or author. It is, however, endorsed in the works of various academics and businesses (Ellen MacArthur Foundation, 2017b). Walter Stahel described this model as a loop, or lake economy where the development of services and durable goods over disposable products plays an important role (Stahel, 2006). Furthermore, Stahel's approach to the circular economy theory presents dematerialisation and the shift from products to services as an essential driver to reduce the impact of systems. This view corroborates Kazazian's call to leave an era of materialism and ownership and aim towards lighter systems (Kazazian, 2003).

Within the framework of the circular economy, the Cradle to Cradle model presented by Michael Braungart and William McDonough offers a vision for design (Ellen MacArthur Foundation, 2017). The concept advocates for restorative design which goes beyond minimising the negative impacts of products and services and instead emphasises the potential positive

impacts. In his TED talk the architect William McDonough (McDonough, 2005) highlights the lack of appeal of a merely "sustainable" approach to the planet, calling for a relationship which encompasses joy and creativity both in making and in experiencing environments. This aspect of designing for the circular economy is also put in words by Tim Brown (Ellen MacArthur Foundation and IDEO, 2017) as a "sense of meaning" in being able to design in a way that not only does not damage the environment but can be carried out perpetually in a regenerative way. These approaches are well tailored to a creative take on the constraints of designing for sustainability and underpin this research. The creative approach to the issue of blends aims to provide solutions which go beyond the primary problem solving to outline an inspiring process leading to desirable outcomes.

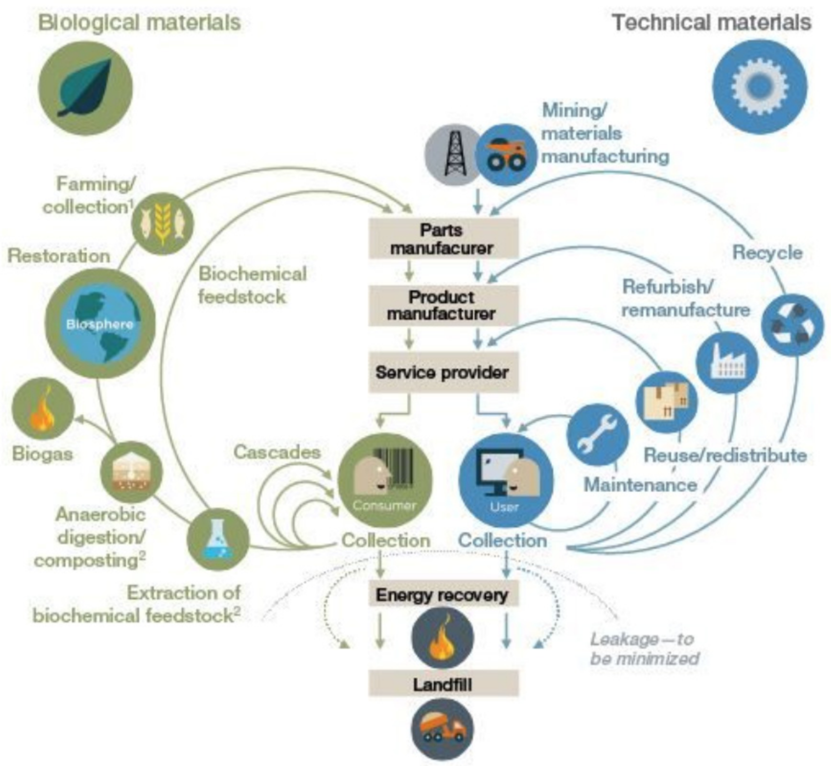
The main contribution of the authors of Cradle to Cradle is to define all resources as nutrients which can perpetually feed biological cycles of decay and growth, or resource regeneration in manufacturing cycles. Thus, the essential principle for designing for a circular economy is to allow for equivalent value recycling or regeneration at the end of the product's life. One of the main requirements to achieve this closed loop use of resources is to maintain materials either in the biological and ultimately biodegradable or compostable cycle, or in a technical cycle, free of contamination and adapted for the industrial recovery and reuse of components in subsequent life cycles.

A critical perspective on the circular economy model

This research acknowledges the limitations and pitfalls that accompany a circular economy framework. This section addresses two main types of criticism towards this approach, namely, the drive for economic growth, and the impracticality of an immediate and full transition to a circular economy as originally defined in the literature.

The circular economy suggests a model in which economic growth is decoupled from resource extraction and depletion, it therefore inherently takes a business as usual approach to growth. This aspect of the model can be held partially responsible for its success in recent years, making itself attractive to businesses who see in it an opportunity to combine profits with sustainability targets (Ellen MacArthur Foundation, 2011; Webster, 2017). Criticism concerns the support of growth-

2.1. The Great Recovery Project mapping of circular systems (Royal Society of Arts and Innovate UK, 2016).



2.2. Cradle to Cradle Butterfly diagram (Ellen MacArthur Foundation, 2011).

based economies, which need to be challenged at core to effect any meaningful progress towards sustainable and resilient futures (Cochet et al., 2015; Meadows, 1974). While the circular model has been associated to capitalist growth models it can also be used in other ideological frameworks. The non-contamination imperative is a starting point here and has driven the prototyping to use approaches such as modularity or other techniques which can, for instance, be connected to de-centralised manufacturing. These characteristics suggest ways in which product lifetimes can be extended and shared between different users, moving away from a traditional business model. The circular economy context as used in this study, rather than imposing a strict model, acts as a trigger for sustainable practice which enables a plurality of material journeys leading to regeneration.

Other critiques have highlighted the unrealistic expectation of achieving a fully circular economy (Korhonen et al., 2018; Zink and Geyer, 2017). This is primarily connected to the loss of quality in most materials in successive recycling cycles, undermining the potential for perpetual resource circulation. Such a point is further reinforced when acknowledging the immense complexity of supply chains and material flows, discrediting the possibility of tracing materials back into closed industrial loops.

The butterfly diagram shown in figure 2.2. is proposed by the Cradle to Cradle model and constitutes an example of this Cartesian approach to the circular economy. While the model is helpful to describe the need to avoid contamination between resources, as indeed it has inspired this entire project, it over-simplifies the complexity of material circulation. Presenting the journey of natural and technical resources as symmetrical loops omits the specificities of each resource and associated system. Recent material approaches to circular economies suggest acknowledging the associated timeframes for different resources (Bridgens and Lilley, 2017; Goldsworthy et al., 2018). Following from this, the research suggests using the butterfly diagram as a radical blueprint which is explored with the diversity of material timeframes in mind. Moreover, the simple return of resources to their most primary form is acknowledged as a shortcoming of the original Cradle to Cradle model. The Great Recovery project (Royal Society of Arts and Innovate UK, 2016) offers a more nuanced model, demonstrated in the diagram in figure 2.3., which considers the possibility of multiple recovery loops that extend the value embedded within products and materials in each cycle, before allowing for the full recovery of the raw materials.

The framework for the exploration of DfD as a circular economy strategy therefore combines the focus on non-contamination of the Cradle to Cradle approach with an allowance for multiple life cycles and differentiated material lifetimes.

To finish on the review of the circular economy framework, the present work acknowledges the utopian element this framework suggests. The critiques of the model are taken onboard and the material exploration of TDfD seeks to expand the plurality of approaches which can allow for the adoption of key components of circular strategies to push towards more regenerative practices. The ambitious model spearheads practical system changes, setting the milestones for a holistic transformation in which textile design practice plays a key role. A best-case scenario is therefore used as the basis of the exploration to probe the potential of DfD as a variable that can be addressed for meaningful change in the future.

2.2. Blended Textiles as a Design Problem

In a circular economy model, waste is nothing but resources in the wrong place, yet materials are currently designed in ways which prevent recovery. This way of inadvertently designing waste must be addressed and this research suggests that it can be tackled through design itself. This section details the contemporary context for design's responsibility in current unsustainable practices, then demonstrates the potential that this angle can offer in developing solutions which move beyond limitations to creativity.

2.2.1. Designer Responsibility in Waste Creation

From the early realisation of the impacts of a consumerist society, designers have been seen as responsible for many of the issues we are facing today (Packard, 1960). Understanding waste as a design issue leads to exploring design-led solutions, which can eradicate the barriers to effective recycling from the outset. Therefore design can be considered as well equipped to enable a transition from a linear to a circular system.

Waste as a textile design problem

According to Graedel and Allenby (1995), 80 to 90% of the environmental impact of a product is defined at the design stage. This is indeed when most of its characteristics are determined, such as the type of material it is made of, the manufacturing processes it will undergo, and how it will be disposed of and potentially recycled. The decision to create a blend of materials that cannot be recycled together is a part of the designer's role in the overall environmental impact of materials and products. It is therefore crucial to provide alternatives to this approach to textiles so that designers may create in ways that consider the end of life from the outset.

Beyond considerations for the technical properties of a material or textile, blends may occur from a desire to achieve aesthetic or handle effects by contrasting colours or textures as part of the same fabric. Indeed, while most technical literature on material combinations focuses on the complementarity of technical properties in the different elements, Hardingham (1978) for example, considers blends which bring together different colours of yarn of the same fibre type such as in checked patterns in tartan fabric. Dormer (1997) describes quality creative textile design practices as relying on a tacit skill to combine materials with contrasting textures and shines within the same cloth so as to create surprising and pleasing effects. In common forms of textile design, the blending of different yarns or the application of a coating on the surface of fabric often results from a need or desire to achieve a specific pattern or finish in the most cost and time effective way. Such an ability to create combinations is an essential part of the textile designer's work and will be further expanded on in following sections.

A creative textile designer's perspective is taken here to explore solutions to blends. It stems from the personal practice of the author such as described through the Muto project (see 1.1.1. p.19). Igoe offers an analysis of the identity of textile designers with a focus on the material as an "agent of tactile and visual experience, specifically decorative qualities" (Igoe, 2010:5). She goes on to acknowledge materials positions as part of a broader context of use and habits, in which functional properties may come into play (Igoe, 2010:8). In this specific approach to textile design the role of tacit knowledge is key in exploring the qualities of materials. The tools and processes used follow an intuitive approach to pattern, texture and function. It is this material exploration driven approach which guides the development of solutions to unrecyclable blends.

This thesis suggests a way of challenging the mind-set in textile design which leads to the creation of unrecyclable blends. It provides insights to change the status quo in this way of producing materials. In the fast-paced textile and fashion industry, the additional effort asked of designers to take on-board new concepts which may be foreign to them and which do not fit into the existing design and production process can be a reason for the failure to adopt such strategies (Vuletich, 2015). By using methods in the development of solutions to match the processes which currently create issues, the research aims to offer strategies which can seamlessly be integrated into creative textile design.

2.2.2. Blending as a Result of Creativity

The issues connected to blends in textiles are an inherent component of textile design practices. If considering waste as a design issue as established above, then textile design needs to be more specifically scrutinised over the ways in which it creates barriers to material circularity.

Blending for more resilient material systems

Despite the fact that blends are a barrier to a full transition to a circular economy, it seems unrealistic to expect material combinations to be eradicated entirely. Blends can offer many qualities and improve not only the technical but also the environmental performances of materials (Thackara, 2006). Moreover, the textile industry already relies heavily on a small range of fibre types with cotton and polyester as the overwhelmingly predominant resources (Ellen MacArthur Foundation, 2017a). In the light of possible resource scarcity and price fluctuation, a shift away from this monoculture take on resources therefore needs to be encouraged. Blends can offer more variety in this matter. Stahel supports this claim from a circular economy and systems perspective by suggesting that “nature, the market economy, democracy and innovation are successful examples of highly diversified, decentralised and chaotic systems which are inefficient in the short term but durable and resilient in the long run” (Stahel, 2006:196). As resource availability becomes a challenge in a fast-changing world, using material combinations to spread the strain over different types of fibres could by a valid strategy for resilience.

Textile blends and creativity: bisociation

Beyond the output-focused approach to blends, this study takes on the designer’s perspective and questions the making of a blend as a creative act. As described by Arthur Koestler, “the creative act consists in combining previously unrelated structures so that you get more out of the emergent whole than you put in” (Koestler, 1989:392). This bisociative process, as coined by Koestler, is indeed present in textile design creativity through the playful and creative combination and juxtaposition of materials, colours and textures. As Dormer phrases it, textile designers are “especially drawn to the interplay of contradictory materials” (Dormer, 1997:69). This is an essential element in the creative process. As put by Dewey “to think means, in any case, to bridge a gap in experience, to bind together facts or deeds otherwise isolated” (Dewey, 2010:80). Moxey expands on this by highlighting that the combination of varied elements is a vector for the creative output generated by deep tacit knowledge of the current zeitgeist. As he frames it “successful designers are aware that the combinatory play of combining basic elements of yarn, colour, shape, form, style, theme, and motif is not enough. Creative output is generated, in line with a series of aesthetic conventions that are shaped by a climate of fluctuating market conditions and constant advances in technological innovation”(Moxey, 1999:4). Rather than stating that it is not enough, this thesis argues that the process of blending is an integral part of this tacit understanding of the world in which the materials will evolve. It acknowledges the act of combination as embedded within the creative process and values it as leading to the design of meaningful products and materials.

As described by Hirshberg, and further developed by Moxey and Studd (2000) regarding the creative process in textiles specifically, “unprecedented thinking” (Hirshberg, 1999:75) involves the connection between apparently disconnected or conflicting elements. Hirshberg goes on to describe the particular feeling experienced by the designer when ideas emerge in this process. This “sense of lift” (Hirshberg, 1999:75) is one of the joys of designing and an essential component of this approach. This study therefore looks at ways of maintaining this degree of creativity without involving the permanent combination of incompatible materials.

The approach to textile design throughout this project uses the constraints of recyclability as a creative impulse. Indeed, it is when the conventional ways of designing materials seem closed off, due to the environmental damage that they cause, that problem solving approaches can be intermingled with aesthetic creativity to produce original outcomes. Craft writer Peter Dormer, uses metaphors of dance or jazz to highlight how the "the unity provided by these rules encourages rather than closes down innovation"(Dormer, 1997:171). Indeed, the rules of the circular economy embodied through the two separate cycles for resource reuse provide the frame within which core innovation may take place. TDfD can therefore be used to combine high levels of creativity and compliance with recycling constraints.

The rules of textile recyclability, as set by the processes and technology which allow for best value conservation, are used as the starting point for creative textile design. These technologies, and the materials that fit them, are the framework for the development of innovative textiles using TDfD strategies.

Allowing for blends in a circular economy: beyond a mono-material solution

One of the existing ways in which the solution to blends preventing recycling has been explored, has been to develop alternatives to blended materials using only one resource or a combination of resources which can be recycled together. This approach is referred to as mono-material. These mono-material approaches are tackling recyclability issues through the creation of textiles that can fit in to existing recycling systems and be recovered either through a technical cycle, or a biological cycle.

In a technical cycle, polyester has been used for its versatile qualities which make it an ideal candidate for mono-material design which still displays an array of aesthetic and functional qualities. Moreover, polyester recycling streams are well developed, whether this be concerning the thermal route or the chemical deconstruction of the polymers. Kate Goldsworthy's work on textile finishing with mono-material polyester is a pioneering example of this proactive approach to circularity for materials, using laser processing as a tool for creative material transformation which does not hinder recyclability (Goldsworthy, 2012). Extensive experimentation with polyester laser finishing provides guidelines for keeping the material within the criteria for recycling set by the Teijin Ecocycle technology (Teijin, 2006), namely that no more than 5% of the material's composition should be other than polyester. Despite such a

strict limitation, the technology and design skills provide a wide variety of aesthetic finishes and functional effects for different uses.

In the biological cycle, many design projects have experimented with the potential of biodegradable and compostable materials. These approaches may also explore new production modes such as with Suzanne Lee's Biocouture cellulosic leather which is grown from bacteria and can be fully composted at the end of life (Tibbits, 2017). Other stances on the use of compostable materials originate from using organic waste as a starting point. The Fruit Leather project (https://fruitleather.nl/) is such an example in which food waste is made into a material while conserving the biodegradable properties of the resource. Many other explorations of alternative material resources have led to the development of biodegradable or compostable materials which can therefore be regenerated in natural cycles following Cradle to Cradle principles. These approaches are expanding under the urge to explore alternatives to fossil fuel based materials and question the potential of bio-materials or bio-benign (materials that can be returned to natural environments without unbalancing eco-systems) materials to replace our current over-use of plastics (Materiom, 2018).

In both instances, maintaining recyclability criteria follows from an understanding of the original material or resource and a respect for its qualities. In a similar way, overcoming technical limitations through design solutions that do not involve contamination by another material is currently explored in conventional materials.

This study aims at looking at a yet underexplored alternative to these approaches. Indeed, while mono-materiality offers a relatively direct path to material recovery and recycling, it also tends to limit the scope of materials that are used throughout the industry (Fletcher, 2008; Niinimäki, 2013), and seems to contradict the belief that sustainable design should also celebrate diversity (Benyus, 2002; McDonough and Braungart, 2002). Moreover, based on the advantageous characteristics of blends described in this section, ruling out these aspects entirely to achieve full recyclability seems a harsh limitation to the potential of design. The approach to TDfD developed in this work could therefore provide strategies for harnessing, in the best possible way, the aesthetic and technical performances of a wide range of fibres as part of complementary blends. While many functional or aesthetic aspects can be replicated using mono-material textile design, the creativity found in combination is still an element that is very specific to blends. What this research aims to achieve, is to replicate the benefits of material combination while allowing for individual recovery of these mono-material or recyclable elements at the end-of-life.

2.2.3. A Creative Exploration of Solutions through Design

The creative challenge to maintain the benefits of a bisociative process, moving beyond mono-materiality while not preventing recyclability is therefore inherently a design matter. In this circular economy context, the role of designers is expanded to a broader understanding of the systems in which the materials and products which result from this creative process evolve.

A new role for designers: designing for the full lifecycle, starting from the end

The work laid out here takes a proactive approach to blends. It means that all the stages of a material's extraction, processing, manufacture, use, disposal, and recovery are considered from the outset to pinpoint the potential environmental issues and address them in the creation of new materials. One of the tools available to assess the impacts at these different stages is Life Cycle Assessment (LCA). LCA tools provide quantifiable information as to how the stages of the life cycle of a product or material affect the environment over a list of impacts covering climate change to freshwater eutrophication. This tool monitors if and how redesigning a product improves its environmental impact, avoiding transferring pollution from one indicator to another. Changes need to be implemented at all levels, from the models that influence consumption rates, to the types of materials that are used, to the systems in place for the recovery and recycling of textiles. In terms of developing a design brief and guidelines, this means understanding the various phases of a material's lifecycle and taking these all into account.

Of particular interest to this study is the emergence of a circular system, in which the end of life is nothing other than the beginning of a new cycle. Indeed, as the extraction of raw materials, especially from non-renewable resources such as fossil fuels, is seen as more and more of an issue, the need to circulate materials through repetitive use cycles becomes apparent. The designer therefore needs to understand all the phases of

this life cycle. Where previously a designer's understanding would span from the sourcing of threads or fabrics, potentially of chemical dyes and printing pastes, to the shop floor, it now needs to reach out beyond these limits (Ribul and Motte, 2018). This study takes on such considerations from the very first ideation stages and in the understanding of the issue itself and makes them a key component of the methodological model.

Creatively redesigning blends through TDfD

This work explores the ways in which complex products and materials can be circulated throughout these repeated lifecycles using TDfD as the main strategy. TDfD is proposed as a way of circumventing the issues that blends pose to recyclability and as an alternative to mono-materiality which is currently the main strategy to address this challenge. This supports the creativity that comes with material combinations as described in terms of bisociation.

As described above the creative potential in taking on this challenge is central to the research. In this sense the role of the designer is explored to gain a better understanding of their role in achieving a more circular economy for textiles. The redesign process aims to target current environmental issues posed by blends throughout their lifecycle. The designer's perspective is then used to understand these problems and explore solutions which are best suited to challenge the mindsets which created them.

2.3. The Textile Design for Recycling Brief

To enable designers to design waste out of the system, the specifics of this system first need to be known. The understanding of the recycling framework laid out in this section signposts the goals for a design-led solution to the problem of blends. This part of the redesign approach identifies the issues which can best be addressed through a creative textile design approach and articulate the brief for the exploration of solutions.

2.3.1. Understanding Existing and Emerging Recycling Systems

Textile recycling is a complex process and involves many different stakeholders at different stages. A series of interviews were used to overcome this complexity, scope the field and gain information relevant to the design challenge set out here.

Recycling streams

Textile recycling systems are complex and interconnected, making it hard to trace a single clear route to a new use cycle for any material. Moreover, the term recycling itself is used in different ways across the literature. Recycling generally refers to the reprocessing of pre-consumer or post-consumer textile waste into new textile or non-textile products (Cupit, 1996; Livingston, 2003; Mathews, 2015). However, the Resyntex project, for instance, suggests an open loop recycling system in which textile waste is converted to biomass and other commodity chemical precursors ultimately feeding the chemical industry (Nikolakopoulos et al., 2017). Similarly, Sandin and Peters' review of recycling streams includes the recycling of packaging waste into textile fibres. In some instances, the term recycling is even used concerning the recovery of energy from waste incineration (Sandin and Peters, 2018).

This study is not embedded within a specific or located recycling system but instead aims at drawing insights which can be transferred to different site-specific contexts. The Cradle to Cradle model is therefore used as a framework to define the meaning of recycling used here. This is embodied in the notion of recovery for reuse in an equivalent or better value use cycle. This therefore includes recovery and reuse of materials at different scales; from pieces of cloth down to the monomer scale, which is opposed to the down-cycling approach most common today. With down-cycling practices, the use of recycled materials tends to reduce the quality of the output due to the shortening of fibre lengths during mechanical shredding of the garments, or the breaking down of the polymers through washing and exposure to light in the use phase (Ellen MacArthur Foundation, 2017a; Östlund et al., 2015).

In current recycling systems, garments and household fabrics are first sorted for reuse, which is the way in which the most value is preserved. If the garment is not suitable for reuse it may be recycled in different ways; cut up for use as wipes, or incinerated for energy recovery. This study focuses specifically on textile-to-textile recycling with high value outputs, therefore also excluding the shoddy trade or more open-loop approaches such as conversion of biomass to fuel.

In designing for recycling, the materials must return to the most appropriate stream at the end-of-life. Identifying the recycling paths for the fibre types likely to be part of blended materials shows the first steps in the redesign process.

Textile sorting

All recycling processes are preceded by a sorting stage. With textiles, most sorting occurs manually, separating re-wearable items from the different grades of textiles for recycling. This is either done according to the sorter's skills, or the information on the care labels. Christien Meindertsma's 'Fibre Market' exhibit at the London Design Museum in 2016 made clear how unreliable this method is. Indeed, out of the 1000 garments under scrutiny, a large number displayed inaccurate information on their labels. The garments in Meindertsma's piece were analysed using the FiberSort, a near infrared spectroscopic device developed by Valvan (van Duijn, 2018), which automatically identifies the fibre content in textiles following a set of models. This technology is extremely promising for overcoming the unreliability of care labels as well as drastically speeding up the sorting process through automation. NIR technology can also detect the difference between broad categories of structures, such as knit and weave, allowing for even more specific recycling techniques (Ackerman, 2017; Wedin, 2017). Such technology provides considerable optimisation of the sorting process; however, it has limits when considering blends or complex material combinations. Based on an optic reading, it can only analyse one side or zone of the textile, making the detection of materials in complex garments or structures impossible and thus contaminating the sorted categories with incorrect readings.

Mechanical recycling

As of now, one of the most available fibre-to-fibre recycling paths for non-re-wearable garments is mechanical recycling. The process involves the shredding and re-spinning of textiles. The shredding process shortens the fibre length and diminishes the quality of the output, which is then often re-blended with virgin fibres to counteract this effect. New processes are currently being developed to achieve higher quality outputs (Hilaturas Ferre S.A., 2018), eliminate the need for virgin fibres (ReBlend, 2018) or accommodate blended inputs (Hall, 2018). However, this process is best suited to post-industrial waste for which the content can be guaranteed, and if possible, as a mono-material (Nichelson, 2017).

Mechanical recycling presents several limits when applied to blended materials. One of them is the preservation of colour, which means that on top of needing to sort by fibre type, colours must also be considered as an element of the output (Nichelson, 2017). Moreover, the process is hindered by the input of cellulosic and synthetic blends, as different fibre strengths within the same textile make the shredding process less efficient and can even damage the machines (Östlund et al., 2017).

Chemical recycling

Chemical recycling mimics nature by breaking down polymer chains in synthetic textiles to extract the unwanted elements, such as colour or contamination, and spinning high-quality yarn. Until recently, these processes were only applicable to mono-materials, whether in the biological or the technical cycle. Well-established viscose processes adapted to use waste cotton textiles rather than wood as an input, are an example of chemical recycling for cellulosic fibres (Palme, 2017). Chemical recycling can be used both in what would originally be considered a biological cycle such as with cellulose being transformed into fibres through a viscose process, and in the realm of synthetic fibres. Until recently this process was only applicable to polyester and some types of polyamide, with a very limited allowance for contamination.

Since 2015, H&M, Kering and the start-up Worn Again have been developing a chemical recycling process which can separate polyester and cotton in blends and mono-materials, and recover them independently for recycling as equivalent-virgin polyester and cellulose pulp (Worn Again et al., 2015). This promising technology can take up to 20% of contaminating materials, beyond which the profitability of the process decreases. A valorisation stream for this left over waste from the recovery process is currently being researched. This technology is also being developed to process other fibre types such as animal protein fibres or other synthetics. The success of such a recycling stream will enable the regeneration of many materials which are today condemned to landfill or incineration. It may also be considered as a possible end-of-life scenario for materials being designed today which will reach the end of their use phase when this technology has matured. However, it must be remembered that these technologies are not yet available at commercial scale (Mathews, 2015) and that completely dissolving materials will necessarily use more energy than returning to larger elements of the materials (Beton et al., 2014) and must be considered as the last stage in a material's lifecycle.

In his talk at the Beyond Green conference in 2016 (https://vimeo.com/189638719), Issac Nichelson, a representative for the mechanical recycler Recover, advocates the compatibility and complementarity of mechanical and chemical recycling streams. This points to the importance of considering all available recycling routes on top of the criteria set by the technical and biological cycles when developing materials for recyclability. Taking them into account at the outset of a TDfD process can allow for the individual materials to be recovered for the most appropriate stream. In a circular system, different recovery and recycling technologies do not necessarily function in isolation. They are part of material cascades (Sandin and Peters, 2018), allocating the best options in terms of resource and energy consumption to different levels of recycling in different stages of the material's lifecycle.

The development of chemical recycling for blended materials runs side-by-side with the exploration of TDfD suggested here, offering an alternative solution for blends in the circular economy. The proactive approach described earlier (p.48) is opposed to the reactive approach of chemical blend recycling, in the way that it moves upstream of the end-of-pipe approach to put the source of the problem under scrutiny. Eliminating the difficulty of recycling from the beginning of a material's lifecycle is seen as a path for more regenerative (McDonough and Braungart, 2013) design and for providing insights in the textile design process which can foster innovation.

Complex systems

As later described in the methods section (see 3.2.1. p.69), the literature to gain these insights from different areas of the textiles recycling supply chain was complemented by a series of interviews. While they cannot lead to sweeping generalisations since the waste inputs, types of technologies used, and end-markets will vary from one facility to another and from one country to another, the resulting insights are nevertheless well rooted in the experience of managing fibre to fibre recycling. Hearing first-hand accounts from the different parts of the process from sorting, mechanical recycling, and chemical recycling, was completed by a more holistic and systemic view of this complex supply chain.

The learnings from this review in terms of the design of blends for recycling show the necessity to embrace the complexity of the system and design for the different parts of it simultaneously. In the framework of the experimental textile design research carried out here, the challenges and opportunities encountered by the individuals at each stage of the process are translated into recommendations for the design process. Beyond the contrasts of each approach, similar themes occur across the board and can lead to a design brief and creative impulse. As articulated by Gwen Cunningham, for meaningful progress to be achieved in this field, the complexity of the challenge needs to be acknowledged. While positive change should be celebrated, the failures of enterprises should also be discussed to move forward from them (Hall and Forst, 2019).

2.3.2. The Non-Contamination Brief for Design for Recyclability

The circular economy dictates a series of rules to achieve the regenerative system set out by the framework. The main rule is that biological and technical resources should not be combined in permanent ways. In this study, this is translated as a non-contamination brief. As laid out in this section, the brief is set by an understanding of recycling systems and is directly translated as a creative trigger for textile design practice.

Identified barriers to recycling

The issues pinpointed by the experts varied depending on their place in the supply chain (see 3.2.1. p.69 for a list of the experts interviewed). Some types of blends, such as those with even proportions of polyester and cotton, are seen as a challenge for mechanical recyclers. For sorters, the main issue perceived is small proportions of contaminating fibres within any type of blended fabric. Being positioned at different places in the recycled textiles supply chain and distributed around the material's life cycle was also a determining factor in the way issues with blends in recycling were perceived. For an NIR automatic sorter, fabric structures that prevent certain yarns from being read by the machine's lens were seen as a true problem compromising the efficiency of post-consumer waste management. On the other hand, for mechanical recyclers, the consistency of inputs is the main focus, therefore leading this part of

the industry to use predominantly pre-consumer waste. In mechanical recycling, the challenges of post-consumer waste and the variations of this type of input are rarely considered. In general, the access to feedstock such as consistent post-industrial textile waste for fibre to fibre mechanical recycling; or to technology in the case of experimental start-up companies such as ReBlend, were a crucial factor in the approach taken towards the recycling system. Indeed, the case of ReBlend shows how using machines which are calibrated for consistent virgin quality input for a more fragile and irregular 100% post-consumer input was a challenge both in technical terms and in changing the mindset of the technicians responsible for these machines (De Wit, 2017). This coincides with the literature (Östlund et al., 2017) and points to a case for design exploration to provide proof of concept for recycled fibres which can be powerful tools in bringing meaningful change to the industry as was the case for ReBlend when succeeding in the production of a 100% recycled yarn from post-consumer waste. Understanding these types of experiences as recounted by the experts has been influential in the positioning of this research and in validating intuitions for the practice.

The FibreSort project team have released a report, presenting the potential of their sorting technology, which ranks the most common types of fabric recognised by the NIR technology according to their availability and prices for end-markets (Interreg and Fibersort, 2018). The report reflects the challenges in providing input for recycling systems which can guarantee high-quality end-products. Indeed, blended materials such as poly/cotton or other miscellaneous blends have very low monetary values when compared to mono-materials such as 100% cotton which already has applications and adapted technology for recycled products (Chang et al., 1999). However, mono-material polyester also ranks low in terms of price in this classification. This may reflect that current commercially available recycling technologies are not yet optimal.

Combining knowledge of the state of the art in such literature with first-hand accounts from recycling experts bridges the gap between the quantitative data available and design intuition (Horváth, 2007; Kimbell, 2011). This approach to gathering data is detailed in chapter 3.

Redesign challenges for blend recycling

In a redesign approach (Bhamra et al., 2017) defining the initial problematic object to redesign is an essential part of the process. The literature review, supported by interviews, has led to an understanding of the context which singles out two types of materials that currently act as main barriers to recycling and which are used as benchmarks for the practice all through this work.

Elastane, as used in stretchy materials, is often blamed for impeding recyclability. While the Mistra Future Fashion research programme has pioneered recycling techniques that apply to nylon/elastane blends (Östlund et al., 2017), this is yet to be upscaled, especially given the increase of these blends' share of the market. Stretch is seen as a quality, often dictated by design as well as by functional requirements, which is directly linked to non-recyclable blends.

Similarly, an overarching challenge is any structure, finish or treatment which will prevent all the elements of a material from being visible simultaneously. It is particularly relevant as it impedes the very first stage of sorting and therefore has repercussions over the whole supply chain. This type of blend could take the form of a patched item or of a laminated or coated material. These hinder the potential for automated sorting and the benefits that could come from such a technology. Once the materials are sorted for recycling, some of these characteristics are barriers to recycling processes themselves, such as coatings which have similar consequences to elastane (Beton et al., 2014). The fact that sorting was not carried out properly may also lead to contamination of the output. These considerations are therefore translated directly into the design brief for textiles for disassembly to explore alternatives to these issues. It is intrinsic to the activity of design that noticing these issues should spark ideas for potential solutions. As described by Suri, designers are attentive observers and notice how existing problems can be inspiration for meaningful design (Suri, 2005).

While acknowledging the immense complexity of the field of recycling, this review offers a focus on elements that can be addressed within the remit of the project and with the skills available to creative textile designers. Wider systemic issues are therefore allocated a best-case scenario status so that they can be considered as non-variables for the redesign process to address the issue of short-sighted creation of combinations in textiles. Solutions explored in the present work are aimed at the smoother implementation of a circular system at large. Within this framework, it is

also assumed that all efforts necessary will be put into achieving the most optimal products and recycling systems possible, regardless of policy or monetary constraints. The work also ignores the complexity and unpredictability of consumer behaviour. Within this safe framework, the most innovative proposals for solutions may emerge, freed from the constraints of these challenges. By addressing the issue of blends, the work designs ahead of current barriers and removes one aspect of the system which is currently leading to an unsustainable textile system.

2.3.3. TDfD as a Design for Recyclability Strategy

TDfD is suggested as a strategy for the recovery of recyclable materials and their allocation to the most appropriate recycling stream. Rather than addressing barriers in recycling technology, the study suggests that material combinations should be designed with the requirements of current and emerging systems in mind from the outset.

TDfD as a proactive approach to blends

TDfD is used to design new materials which will fit within the requirements of existing and emerging recycling systems and still allow for variety and creativity in the outcomes and design process. DfD is currently defined as the design of materials and objects in ways which allow them to be taken apart for their different components to be diverted from waste streams (Fletcher, 2008; International Organization for Standardization, 2016; Vezzoli and Manzini, 2008). It is a strategy available to designers to enhance the ease of recycling for a product at its end of life (Chiodo and Jones, 2012).

This strategy as applied to industrial design has, in recent years, come to the forefront of the circular economy debate as a way of designing for recycling. The H&M Foundation have, in the past two years, awarded their Global Change Awards to start-ups pioneering DfD; Resortecs (www.resortecs.com) and Circular Fashion (www.circular.fashion). This points towards the emergence of a realisation that the status quo in materials and product production is at odds with optimal recycling systems and that proactive approaches need to be taken on to solve these issues.

DfD is suggested as such a proactive approach to designing for recyclability. Instead of addressing the problem of waste when items reach end of life and suggesting ways in which technology can optimise recovery despite existing barriers to recycling embedded within them, this research removes these barriers from the very first stages of the design process for new products and materials. The exploration of TDfD therefore shows how instead of combining resources in the conventional ways which prevent the recovery and recycling of the parts of the blend, the strategy could be used to make textile combinations that can then be taken apart. Starting with raw materials it suggests ways of assembling resources that do not generate waste but are designed for end-of-life recycling from the outset.

Redesigning blends

As defined by Bhamra (Walker et al., 2017), redesign offers a pro-active approach to minimising or eliminating impacts over a product's lifecycle. This implies a thorough understanding of the existing problematic product, and a re-evaluation of the related functions and processes at each stage of the lifecycle. This is the approach taken towards textile blends here. The understanding of assembly systems in textiles is used to generate alternatives through TDfD. The redesign process concentrates on the difficulty to extract high value resources for recycling, or to return the blend to recyclable mono-materials. The use of TDfD strategies is therefore suggested as a component of these redesigned blends.

Design for recycling is explored through the specific lens of design for disassembly as it has been identified as a strategy used in products but not yet in creative textile design. While the project is narrowed down to pinpoint a specific gap in in the field of design for recycling, the various other stances that have been taken in this area are kept in mind as the research process unfolds. The researcher's background and skills in creative textile design are the backbone of the project, but they are nourished by insights from more systemic or technical approaches.

2.4. Context Summary: Blend Recyclability as a Design Challenge

This chapter argues that the textile designer is a key agent in current unsustainable and linear approaches to material creation and in the

combination of resources which prevent recycling, and that this places them in at a vantage point to explore solutions. Not only are these complex challenges best explored through the exploratory process of textile design, but solutions coming from this perspective will also be better adopted in the time and energy pressed environment of the textile design studio if they are articulated in the language already spoken there.

TDfD is therefore put forward as a proactive way of designing recycling barriers out of the system while still maintaining the benefits of creative bisociation. This approach moves beyond the current limitations of mono-materiality.

The circular economy model is taken on board as a framework to guide the design process in taking a full system approach to designing materials and products with their end of life in mind. In this respect, the review of existing and emerging recycling systems identifies the most relevant challenges for a redesign of unrecyclable blends through TDfD: elastic and laminated textiles. These will be taken into the practice in the following sections of this work.

Overall the design perspective in this work is central. It guides all the steps in the redesign process from understanding the issue to prototyping solutions and it will be a key aspect of the methodological framework developed throughout the thesis. The next chapter therefore offers a more detailed review of the way in which this stance is embodied in the research methods.

3. Methods: A Practice-Led Framework for Enquiry, Exploration and Reflection

Having established the perspective taken on the issue of blends for recycling and argued the need for designer approaches to the issue, this chapter details the way in which research methods have been adapted and assembled into a new framework to draw insights relevant to Textile Design for Disassembly.

3.1. Using Textile Design Practice as a Tool for Enquiry

The complexity of recycling systems has been described in the previous chapter. As presented there, alternative approaches to traditional information gathering, such as expert conversations, have been used to overcome this complexity. This section describes in more detail the rationale for this bricolage approach to methods: the textile design approach to the problem shapes the way in which information is gathered and processed throughout the research. The chronological sequencing of methods is presented in the second part of this section.

3.1.1. Understanding Complex Problems

While many environmental issues have been approached through design thinking methods (Brown and Katz, 2009; Manzini, 2015), the role of textiles is often left aside. The work laid out here therefore draws on the emerging theory encompassing textile design research, or textile thinking (Igoe, 2010; Kane et al., 2015) and applies it to the environmental and circular design challenge of blend recyclability.

Textile design to explore wicked problems

Rittel argues (1972, quoted in Buchanan, 1992:16) that the problems addressed by designers are most often what he describes as wicked problems. These are issues that encompass broad systemic frameworks and do not offer a clear pathway to a potential solution. The issues with blend recyclability are typical of a wicked problem in the way that the question itself can take on different forms and subsequently be addressed in a variety of ways. Rittel goes on to identify that, for every possible explanation of a problem, the answer will depend on the designer's personal perspective. This reflects accurately the complexity of the issue with blends as described in the previous chapter.

Ill-defined issues are central to design thinking. As proposed by Cross, the designer's skills are therefore channelled in order to first analyse the context and create a "problem frame" (Cross, 2011:22) which gives them room to explore solutions and sets the boundaries and rules for this work. Moxey also defines this initial phase of gathering information to lay out what he calls the "problem space" in textile design practice (Moxey, 2000:53). Following from this, the first stages of this work were aimed at understanding the issues concerning blends and recycling to define the problem frame or space.

As argued by Igoe (2013), textile designers are particularly comfortable with high levels of uncertainty which are an inherent part of the practice. This positions textile design as an interesting candidate to take on a wicked problem such as blend recycling. Using practice to solve such a huge and complex problem steers the research through the embodied knowledge inherent to textile design. Rather than formulating the issue and the steps to a solution in a prescriptive way, following the flow of creative practice lets the concepts emerge in the safe environment of the studio. Where more rational approaches might encounter limitations, creative textile design practice thrives in the fuzzy front end of a wicked-problem-solving process. Acknowledging that there is no single right answer to a wicked problem, only a gradient along a scale of innovative designs (Malpass, 2017), TDfD does not suggest a perfect solution to blend recycling. Rather, the practice shapes the understanding of the problem as is carves out new ways of solving it, drawing transferable insights along the way. This flexibility and the uncertainty inherent to wicked problems means that the brief may shift in response to the exploration of a new approach to the issue.

Translating design thinking to textile design

Following from a tradition of design thinking (Cross, 2011; Dorst, 2010; Rowe, 1987) the definition of the problem is an essential component of the design process. This approach to problem solving, is however removed from the experience of textiles as described by Igoe:

> "When I first began to read into design research literature I experienced real difficulty in relating to the idea of a design problem, to which, as a designer, I should develop a solution. These terms had never been used within my design education or in professional work contexts. I reflected that either the discourse was overlooking my experience as a textile designer or that textile design was rejecting the invitation to take part in it. Design problems for textile designs are not just ill defined but unknown, at best entirely tacit." (Igoe, 2013:95)

This experience of the definition of problems from a design thinking perspective reflects the divide, uncovered in this study, between current approaches to material recyclability and the need for a textile design interpretation of the problem.

Design thinking has been translated from the applied considerations of product design (Cross, 2011), to the abstract domain of organisation design (Kimbell, 2011). This framework is also represented in the double diamond diagram (Design Council UK, 2005; Royal Society of Arts and Innovate UK, 2016). The core guideline for this approach is the focus on the problem prior to the development of solution propositions. As will be represented in section 3.2. (p.68), the research was thus initiated with a scoping and framing of the issue from a textile design perspective.

The work presented in this thesis aims to adapt the structure of design thinking and problem-solving to the field of textiles to best explore solutions to blends. This interpretation of exploratory phases leading into solution prototyping is represented in the methodological framework developed throughout this thesis and introduced in Figure 3.1 (p.67).

This study aims at offering a "translation" as understood by Baule and Caratti (2016). In their introduction to the 2016 Design Research Society symposium, they describe the designer's capacity to perform "transformative design activities" to generate new concepts and define the tools to do so (Baule and Caratti, 2016:201). This approach is harnessed in order to generate an understanding of blends that may help in developing solutions for the circular economy. Following Oxman's injunction to cross disciplinary boundaries and produce knowledge from the interlacing of perspectives across science, engineering, design and art (Oxman, 2016), the work moves across engineering and design perspectives to explore the issue of blend recycling.

Another characteristic put forwards by design thinking approaches (Brown and Katz, 2009; Cross, 2007; Rowe, 1987) is the central role of prototyping. This prototyping of solutions connects the work to a thinking-through-making approach which is described in the work of Marr and Hoyes and of Philpott as applied to textiles (Marr and Hoyes, 2016; Philpott, 2013). This will be particularly put forward as a key component of the methods presented here.

The approach taken in this exploration of TDfD borrows all these components of a design thinking process and adapts them to the specifics of a creative textile process. This leads to the development of a new framework for this type of research.

3.1.2. A Bricolage of Methods

In the absence of a pre-existing methodology for TDfD, this work draws on multiple perspective across disciplines and ties them together to form the framework that underpins this research. This bricolage approach "folds multiple layers of knowledge and discourse together creating novel points of interaction between the researcher and the researched, producing enriched interpretations of the subject of study" (Philpott, 2013:39). As demonstrated in Figure 3.1 (p.67), the research moved from phases of literature review into making and analysing the outcomes of sampling or prototyping phases. This fluidity between approaches emulates the creative process of designing textiles and is an essential element of the development of insights for TDfD.

Bricolage in textile design research

Bricolage approaches in textile design research have emerged from the agile attitude of makers who react to the materials and adapt processes accordingly. In the same way, the methods used here do not follow a predetermined route from the outset but rather embrace the shifting and

morphing of targets as the challenge comes into focus. As put forward by Rao (2012), designers tend to stray away from established rules and methods and rely on intuitive decision making throughout their creative process. This tendency has also been identified as a characteristic of practice design research in doctoral studies. Yee and Bremner demonstrate how in this area, "the usual academic norm of using an established method or methodology is often discarded in favour of a 'pick and mix' approach to select and apply the most appropriate method" (Yee and Bremner, 2011:1). The agile approach to collecting, interpreting and analysing data is representative of dealing with wicked and complex issues and enables the responsive development of solutions in this area.

Vuletich (2014) connects the French origin of the word "bricolage" to the idea of tinkering. As put forward by Parisi, Rognoli and Sonneveld (2017) tinkering is closely related to a tactile perception of materiality and intuitive responses through design practice. Vuletich goes on to frame this idea of bricolage specifically in terms of textile design for sustainability: the crafts-based angle of the discipline resonates with the exploration of solutions based on tacit understandings of materials and processes rooted in tinkering.

In line with these perspectives on bricolage in design research, the methodology was developed responsively and iteratively through practice, mapping and reflection in and on action in order to achieve transferable insights. The methodological framework which was retrospectively extracted from the sequence of actions and reflection phases is divided into 4 phases: Scope, Make, Map, and Reflect. As will be further articulated in the discussion and insights (see chapter 8), these stages collectively lead to insights for circular textile design practice.

Chronology of Methods

The diagram in Figure 3.1. shows the sequencing of research processes across the three years of the research from the initiation of the project until the first draft was completed for writing up status at which point no more new research or reflection was carried out.

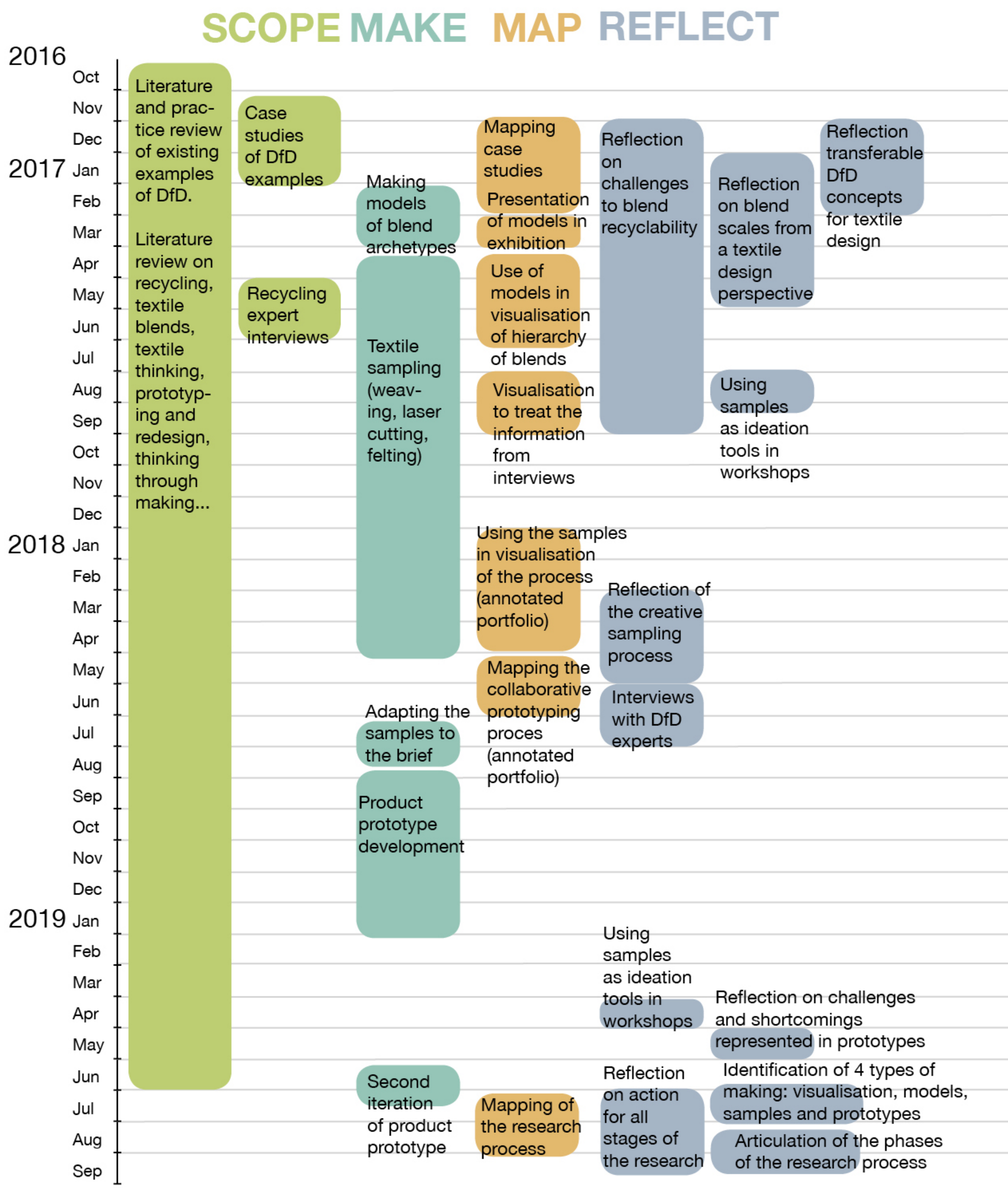
As visible in the diagram, the literature review ran throughout the project, supporting all actions taken in practice and reflection with references to other research and work in the field. The review covered a multitude of themes from the current state of the textile recycling industry, to textile thinking methods. In some instances where the complexity of the field was a hindrance to framing the problem space, the desk-based review was complemented with alternative approaches to gathering data such as expert interviews or case studies. All these actions together constitute the scoping phase of the work.

The make phase, shown in teal in figure 3.1, encompasses work that was carried out at different times, whether this was making models of blends as a way of understanding the issue in early stages, exploring disassembly potential in textile sampling, or transferring these ideas into garment prototypes. As will be reiterated in the discussion chapter (see 8.2.1. p.258), making in all these forms is essential to the production of insights in this work.

Throughout the work, visualisation, shown in brown in figure 3.1., was used to crystallise information contained in either case studies, interviews, models of blends, or in the process of making samples and prototypes. These visual representations of information were a way of communicating the research to others as much as a way of drawing new concepts from originally disconnected elements.

The information represented in these mappings is then reflected upon to draw insights in the phase shown in purple here. This phase often goes hand in hand with the mapping such as with the annotated portfolio exercises which offer a reflective approach to work recently carried out and represented in images or samples. The reflective phases can also involve conversation such as with the second round of expert interviews carried out in June and July 2018, or the workshops bringing the emerging concepts into a group discussion and redesign exercise in August 2017 and May 2019.

The recurrence of actions from each phase throughout the timeframe of the work demonstrates the repetition of the sequence of methods with almost each body of work including a scoping, making, mapping and reflective element. This structure is the main framework offered as a transferable methodology and which is described in further detail through this thesis and expanded on in chapter 8 (p.268-269).



3.1. Chronology diagram of methods representing what month the individual actions of the research took place and how they fit in the four phases of the methodology

3.2. Four stages of the methodology

The four phases shown in figure 3.1. form the overarching structure of the work. As can be seen in the chronology diagram, actions from the different stages were performed at different times in the project, yet for each body of work the sequence of actions moved through the scoping, making, mapping and reflecting phases as a way of first understanding the problem space, translating it to practice and analysing the results. This section delves into the detail of methods used within each of these phases, focussing on the specific perspective of a textile designer inside this framework.

3.2.1. Scope

The complexity of the issue and the scarcity of literature on the topic written from a designer perspective has led to seek and collect information in dynamic ways. The use of interviews, case studies and subsequent visualisations result from this focus on "designerly" ways of understanding (Cross, 2007) which complement a conventional literature review.

Case Studies

The review of the field of DfD showed that while it had been extensively described in the context of engineering for industrial design (Chiodo and Jones, 2012; Ziout, 2014), and some recommendations for strategies to use in product design had been laid out (Vezzoli, 2014), no studies of DfD from a textile design perspective could be identified. In the light of the scarcity of design-focused literature on the topic of DfD, a more dynamic approach to gathering information in this area was used. In compiling a selection of cases which show different approaches to the strategy, a broader understanding of how this concept can be abstracted and transferred to creative textile design practice was achieved.

Gaver and Bowers argue for the use of images of products as a way of extracting theory from a body of design work. In analysing and annotating a portfolio of their own studio's designs, they generate insights concerning the overarching themes which lead their practice (Gaver and Bowers, 2012:42). Sauerwein et al. (2018) have adapted the annotated portfolio method to encompass work by other designers and serve the purpose of a field review. They argue for the use of a combination of designer interviews with the portfolios they describe in design research. While the method is used and adapted in various phases of this thesis, the focus in chapter 4 is on the use of images representing a variety of design objects as a way of drawing themes and generalisations.

This approach is adapted to draw insights from the use of a series of design case studies to extract meaning from the examples of assembly and disassembly found in a selection of contemporary designs from fields ranging from material sciences to architecture. These DfD cases are analysed using available literature on the topic, mainly from technical approaches, to highlight the ways in which the objects prove the applicability of this strategy to various areas and situations.

Interviews

As a complementary approach to the literature review and the case study analysis, another alternative method to a traditional desk-based literature review was used through engaging with experts in a series of interviews. Recycling systems are a complex web of processes, facilities, and stakeholders. The interviews were used to enable an understanding of blends that was appropriate for a design approach. First-hand experience is a driver to a deeper understanding (Parisi et al., 2017; Royal Society of Arts and Innovate UK, 2016) and this experiential knowledge can lead to more accurate design outcomes in a creative process (Karana et al., 2015). Short of experiencing the challenges of the system in person, the series of interviews gave insights on the ways in which blends create barriers to effective recycling and what types of blends were most problematic.

Seven experts in various areas of textile recycling were approached:

- Mel Knudsen, Worn Again: chemical recycling for blends R&D
- Issac Nichelson, Recover: mechanical blend recycling R&D
- Helene Smits, Stating the Obvious: mechanical blend recycling and systems overview
- Anita De Wit, Reblend: post-consumer mechanical recycled yarn
- Helena Wedin, RISe: sorting for fibre regeneration
- Lucie Ackerman, Valvan: NIR sorting technology
- Traci Kinden, Circle Economy: sorting and recycling systems overview

Based on the established notion that circular design must consider all the stages of a product's life cycle from the very beginning (RISe, 2015), these experts were selected to offer perspectives from different parts of a material's recycling journey. Indeed, these experts cover grounds from the specific technical challenges of mechanical recycling for cotton-rich post-industrial waste, to the prospective potential of chemical dissolution to separate and recycle cotton and polyester blends. The range of approaches covering different material types and different parts of the system, from the technical aspects of sorting technology to a holistic perspective, gave a sense of the position that this research may take in the field and of the opportunities available for a creative textile design approach.

These experts were contacted following a snowball method (Otto-Banaszak et al., 2011) in which each interviewee was asked to suggest two names of people who could have a complementary approach to their own. This was also interlaced with opportunities to make contacts at conferences and workshops and using the Centre for Circular Design network. One of the shortcomings of the snowball method is that it can exclude valuable experts who are not connected to any of the initial interviewees. The limits of this method, as well as the small size of the sample, are acknowledged. The interviews were complementary to the literature review, the information gathered therefore supported the understanding of the field established in traditional desk-based research. The series of interviews thus was not built to provide stand-alone insights, instead, it allows for a new angle on the field which highlights design opportunities to solve some of the main issues with blend recycling. As shown in Figure 3.1. (p.67) this work was carried out simultaneously to the literature review on the topic.

The interviews were carried out according to a "semi-structured interview" approach (Ayres and Hall, 2008). This provided a deeper understanding of the issues that individual stakeholders in this field identified in terms of recycling barriers for blends.

As defined by Holstein and Gubrium (1995) the active interview process generates focussed information from a conversation between the interviewee and the interviewer. The main concern during these conversations was then to detect challenges for blends that can be addressed in the redesign process of this project. The statements collected in the interviews offer a subjective view of the first-hand experience of dealing with end of life materials. While they cannot be used on their own, they complement the literature review in orienting the design decision making process. Cross describes how input from experts in the early stages of defining a design problem is helpful in gathering valuable input in very short amounts of time (Cross, 2011:83-84). The interviews served a similar purpose here, in giving a breadth of targeted information in the initial phases of research. These interviews highlighted elastic and laminated textiles as recurrent issues for recycling systems as has been outlined in chapter 2 (see 2.3.2. p.56). This understanding was then transferred to the subsequent making phases.

3.2.2. Make

The value of practice as an essential component of academic research is currently still being argued (Research Excellence Framework, 2017). Nevertheless, examples of practice-research, in which making is a subject of the thesis, abound (Goldsworthy, 2012; Marr and Hoyes, 2016; Philpott, 2011; Vuletich, 2015). Making takes different forms here, whether it is the making of models to understand blend structures (see chapter 5), making textile samples (see chapter 6) or fashion prototypes (see chapter 7).

Textile craft practice and tacit knowledge

The approach to textile design taken here uses a craft-based focus on materials, techniques and experimentation processes. It relates to craft in the sense that it is intrinsically linked to the process by which it is produced, using the combination between materials and these processes to elicit visual and tactile experiences that are associated to functional objects (Adamson, 2007).

Karana suggests that "material engagement in craft is a means to logically think, learn and understand through sensing and immediate experience of materials" (Karana et al., 2015:38). The combination of a tacit understanding of materiality with logic is typical of the textile craft process and has been articulated as a key agent in the value of creative research (Niedderer and Townsend, 2014). This fine balance between a state of flow and the clarity needed to overcome technical challenges is a key part of textile design practice. As described by Csikszentmihalyi (1990) "flow" is a form of mind-set which can induce breakthroughs in multiple types of creative practices. It involves a balance, between the level of skill of the practitioner and the challenge at hand, that maintains a level of tension conducive to innovation. Indeed, design work is particularly prone to this mind-set, it revels in overcoming the challenges that get in the way of the set goals. Satisfaction comes from proving the ingenuity of the practitioner in circumventing obstacles and, in the process, opening new routes in the practice.

The making therefore flows from the tacit understanding of materials and techniques until the difficulty challenges the designer. There, as described by Dewey "we metaphorically climb a tree; we try to find a standpoint from which we may survey additional facts and, getting a more commanding view of the situation" (Dewey, 2010:11). Here, this reflection is achieved by retrospectively considering the results of the making process, whether model, sample or prototype, and use it as the basis for the mapping of either the relationship between the different elements or the process which led to achieve them. The reflection on the points highlighted in the visualisation can then inform further decision making.

This approach to textile design lets the materials lead the creative process. It is also described as involving an element of "un-learning" (Marr and Hoyes, 2016:5), or of naivety (Igoe, 2010:4). Tacit knowledge, which is inherent to textile craft practice, has a central role in this study as it is at this level that the TDfD solutions aim to be implemented, offering intuitive ways of making textile combinations that can be taken apart. The study therefore uses retrospective mapping and reflection on action (Schön, 1983) regarding the free-flowing practice to draw an understanding of the process which can lead to more seamless integration of TDfD.

Solo and collaborative practice

In the context of a craft-led and tacit-knowledge heavy approach, textile design is often described as a solo practice (Igoe, 2013; Studd, 2002). However, the unfinished characteristics of the product of this discipline – textile samples, lead to an openness towards other types of design. Textiles are most often embedded within another designer's work when they are handled by users (Igoe, 2013). This need for collaboration was represented in the various phases of the practice, going from solitary experimentation, to expert input, to tight collaboration. While the sampling phases were carried out as independent solo practice with external advisors giving a wealth of inputs, but not directly influencing the design, the making of the first product prototype applying TDfD techniques was a close collaboration process between designers.

The Service Jacket concept was initiated by the author's supervisor. As shown in Figure 3.1. (p.67) this work started in June 2018 after the initial round of sampling was completed and marked the beginning of the collaboration on the Mistra Future Fashion project. This section of the work involved three designers which each contributed expertise concerning a specific stage of the evolving garment's transformation (see figure 7.18. p.209). This tight collaboration challenged the perception of the ways in which TDfD could be integrated to a product, in this case shifting away from and end-of-life recycling approach towards a more user-centred one.

In the next phase of prototyping, in May and June 2019 (see Figure 3.1.), the author returned to solo practice in a second iteration on the jacket brief. In reducing the collaborative aspect of the work, other considerations in terms of the garment's aesthetics, function and role in a circular system were considered, compromising on some of the approaches developed in the collaborative process. However, the lessons from each stage transferred into the next.

The collaborative stage of the research was particularly challenging to the accepted status-quo in textile design practice. Working in close collaboration on different stages of a circular garment system meant considering, not only the end of life for the garment being designed by one designer, but by all three simultaneously. Accounting for the whole life cycle of any product is indeed crucial to circular design strategies (Royal Society of Arts and Innovate UK, 2016). The details of the various phases of prototyping of the jacket are laid out in chapter 7.

Understanding the role of the designer in implementing TDfD across these different types of collaboration and solo practice demonstrates the importance of this textile design approach in developing circular fashion concepts. One of the aims of this study is thus to put forward a methodological framework which demonstrates the importance of making and allows for this approach to TDfD to be taken onboard with the textile designer as a key stakeholder.

3.2.3. Map

Designers are often labelled as visual thinkers (Brand, 2017; Earley and Hornbuckle, 2017) and for the information that will change the way they design to be made available to a majority, it is therefore necessary to translate it to more visual forms. This section details how information gathered in the scoping phase as well as the results of making were used to produce visualisations which highlight the information relevant to TDfD.

Mapping DfD case studies

To establish the areas of DfD which were already addressed in design practice and theory, the series of case studies mentioned earlier (3.2.1. p.68) were mapped out in a grid. The aim here was to define categories that could later serve as boundaries for the author's design practice. These categories showed where potential gaps in knowledge exist in the field and show opportunities for problem-solving.

This exercise initially responded to the scoping phase of the project, to achieve an extensive understanding of the field of investigation. However, it was also instrumental in the research as a tool for ideation. The design process is usually preceded by a data gathering phase, or mood board as defined by Studd (2002). This is used to generate ideas for the creation of new concepts. Thus the review of the field initiated concept development for the implementation of DfD strategies within textile design practice by suggesting types of assembly or ways of using the strategy to influence the user experience. In many ways, the mapping carried out at different stages of the research acts as a form of bridge which clarifies the issue at hand to feed it into a design brief and inform the experimentation with textile techniques. Here the mapping has identified five DfD categories that can be transferred to textile design practice and fuel subsequent making phases as is laid out in chapter 4.

Mapping blend models

The problem of blends is an example of a wicked problem which is ill-defined at the outset and which needs to be clarified before it can be addressed with a problem-solving approach. While most designers who

interact with textiles by making them or by making products from them have an understanding of what a blend is, no representation of a range of these different types of blends has been identified in this review. The current literature focuses on the characteristics of individual fibre rather than offering typologies of blends which can inform textile design practice (Hardingham, 1978; Hatch, 1993; Parcineau and Collet-Barquero, 2015; Sinclair, 2015). Understanding and articulating what blends are and, more precisely, how they can be defined in the context of recyclability is therefore a key phase in understanding the problem.

A series of enlarged and codified models of blends were produced in the making phase to inform a mapping that suggests an understanding that is more directly drawn from and relevant to the designer's experience (Hardingham, 1978; Hatch, 1993). As described by Arnheim, "drawings, paintings and other similar devices serve not simply to translate finished thoughts into visible models, but also are an aid in the process of working out the solutions of problems" (Arnheim, 1969:129). Indeed, this phase of representing the issue in a hands-on approach allowed for a deeper understanding which led to identify potential redesigning opportunities. Using the crafted models of blend archetypes in a mapping exercise provided insights for the subsequent practice.

As described by Manovich (2011), visualisation usually uses reductions of information such as graphical primitives to represent pieces of data, in conjunction with spatial variables, to draw meaning through patterns and relations. However, Manovich also describes the use of direct visualisation, or media visualisation, in which all or part of the objects are used in a spatialised representation as a way of demonstrating patterns. The approach taken here stands at the intersection of these two methods as the models are not a direct representation of blends but rather a codified simplification of blend archetypes. They are however not fully reduced information as they offer a description of the character of an individual blend. Following the second point in Manovich's description of visualisation, these models are arranged in space according to their relations to one another. This type of display in which a network is related to a root element is described as a "hierarchy" (Card et al., 1999:20). The visual representation of blends developed here takes the concept of a hierarchy further by giving it three root elements, rather than one, to which the network is related in layers of complexity.

The visualisation process shown here coincides with Tufte's description of the potential of high-density representation to package the information for a specific viewer to take on board (Tufte, 1990:50). Mapping blends in relation to their recyclability in this way makes the information available to inform the design process for textiles for disassembly in a way that was not possible before. The details of this mapping activity are laid out in chapter 5.

Mapping TDfD samples

This mapping approach is also adapted to the sampling phase of the research to better understand the potential of TDfD. The sampling follows an intuitive free-flowing approach, as described earlier (see 3.2.2. p.71), and is related to a craft-based activity in the way that it resists the verbal articulation of the details of the process (Adamson, 2007). Indeed, as described by Harrison (1978), as soon as the maker starts describing their activity, they are no longer making, but speaking instead. Across the field of design research different approaches have been used to overcome this, such as filming the hands of the maker as they operate (Atkinson, 2019) or by describing the process as it unfolds (Philpott, 2011).

The making activity was analysed retrospectively using the samples and prototypes as indicators of the different stages of the process. This was achieved using a variation on the annotated portfolio method (Gaver and Bowers, 2012; Sauerwein et al., 2018), in which images representing the work are used to extract themes.

While this project mainly corresponds to the definition of a problem-solving doctoral thesis as argued by Scrivener (2000), he also tells us that in these instances, any description of the meandering phases of problem finding and framing are rationalised post-hoc and left out of the writing. This is not the case here as the reflection-in-action (Schön, 1983) is an essential component of the research. It questions the very mechanism of the design process involved in the creation of blends.

This exploratory journey through making textiles for disassembly is therefore retrospectively represented in the mapping of the samples. These act as markers of the different stages and thinking processes involved. The tacit knowledge which allows the creation of these samples is embodied in the results of the making and can be uncovered by

analysing the outcomes. This follows the visualisation methods explored in understanding blends, here it allows a better understanding of the evolution of the techniques through the iterative process. The causes of the emergence of a specific technique or of the discarding of another are highlighted to serve as guidelines for future practice by tracing the journey both chronologically and through the association to inspirational case studies. This process has articulated four different assembly techniques for TDfD as will be detailed in chapter 6.

Mapping prototyping processes

The iterative experimental approach to making a TDfD product, with the relative failures and lessons learned from it, were documented in a combination of after-action review (Morrison and Meliza, 1999) and an annotated portfolio method (Gaver and Bowers, 2012).

Gaver and Bowers use photographs of design objects in conjunction with keyword annotations to draw insights concerning a portfolio of work. In this instance, rather than finished artefacts, the research materials, sketchbooks, and intermediate mock-up prototypes are used as the portfolio. The method suggests that rather than objects speaking for themselves, they are analysed to draw insights from the intermediate knowledge embedded within them (Löwgren, 2013) and are compared to other components of the corpus. This is combined with an after-action review process, derived from its military origins, to retrospectively state the different stages of the actions taken, and describe what went wrong and how this could be improved in the future.

The chronological unfolding of tinkering with concepts, testing garment shapes and materials throughout the prototyping work, were documented through a series of photographs and reflected on to understand how the ideation process evolved through the making. This led to a series of insights concerning the applicability of a circular fashion system to industry, projecting the challenges of making a prototype in the studio into the complex supply chains of a global system.

This approach was used both for the collaborative elements of the practice and for the solo making phases. The understanding of the thought process involved in TDfD leads to an model that can be transferred to other designers' practices. It can lead to a better understanding of the implications of using TDfD in a different type of product prototype by showing the challenges and breakthroughs of the design journey. Furthermore, the reflection on the opportunities and shortcomings of the first jacket prototype led to a second iteration which demonstrates the improvements based on the review. Here again the challenges and opportunities observed in the process of making, and in the finished prototypes, were laid out following the annotated portfolio and after-action review methods to better understand how future iterations could be improved and to lead to the creation of guidelines. This presentation of the prototyping work and the way it draws from the other phases of the research is laid out in chapter 8 (see figure 8.1. p.254) it complements the overarching methodological framework with a focus on the making of circular products.

Beyond the communicative power of the visualisations, the translation activity also involved a thought process which was instrumental in taking the understanding of the issue forwards and in developing new concepts. The learnings from these mappings were then taken into a reflection phase which provides insights that are either iteratively fed back into new making stages or inform the overarching methodology.

3.2.4. Reflect

The reflection process goes hand in hand with mapping, as insights often occur from the connected visualisation of otherwise distinct pieces of information. However, this phase is described separately as it is here that crucial insights were achieved at each stage of the research. This section describes the main points that have led to the development of key insights.

Reflecting on DfD categories

A combined reflection on the perceived challenges to recyclability highlighted in the first round of expert interviews, and on the notion of different scales in blends addressed in the mapping of case studies as well as blend models, led to articulate categories for DfD. These categories contribute to the field by framing disassembly from a new perspective which puts making, and textile design in a broader sense, at the centre of the concept. These categories and how they emerged will be presented in detail in chapter 4 (see 4.2. p.98). The five categories of DfD

have infused the following phases of the work. As with other concepts reviewed in the reflection phase, value comes from the way in which the pause to consider the outcome of the making or mapping feeds into the progression of the research and the development of TDfD methods and concepts.

Assessing samples

Following the free flowing making of samples, a phase of reflection was necessary to assess and understand the value of the results of the practice. The making was intentionally left unhindered by ongoing evaluation and reflection to foster a sense of flow in the activity. The reflection thus takes a retrospective perspective on the samples. In line with the exploratory approach of the practice and the prevalence of the designer's role in developing circular strategies for textiles, the methods for the assessment of the work were also led by a creative textile design perspective. The understanding of success relies on the designer's tacit knowledge and their ability to "recognize and describe deviations from a norm much more clearly than we can describe the norm itself" (Schön, 1983:53).

Beyond the performative function of a material, designers appreciate the experiential qualities of textiles (Karana et al., 2015). The reflection on the outcomes of the sampling therefore leads to an understanding of how a sample is valued for the new pattern and texture effects it may suggest. These are the qualities that are particularly valued as a demonstration of the potential of TDfD to enhance the creative combinations in blends rather than hinder them. The mapping of the decision process throughout the sampling activity helped to highlight which characteristics were deemed more successful and worthy of being experimented further with.

In the framework of this study, the development of shapes and material combinations is the result of the designers' own taste. The aim of the exploration of TDfD is for textile designers to be able to express their own design personality using this strategy to prevent creative material combinations from limiting recyclability. Free aesthetic expression is therefore central to the production of a successful sample.

Tonkinwise suggests that style has been neglected in contemporary design thinking. He goes on to argue that "style is more like the ground of a practice, that which coordinates actions and makes them meaningfully part of a practice" (Tonkinwise, 2011:538). Here the designer's subjectivity and aesthetic judgement have been central to giving a sense of a collection to the sampling. The successful samples were those which could trigger the development of products that highlight their aesthetic and experiential qualities. Reflecting on the material qualities with such a focus on the expansive potential of each cluster or individual sample highlights the value of free flowing making preceding any classification or labelling. Retrospectively considering this body of work then led to the articulation of a repertoire of transferable techniques which will be detailed in chapter 6 (see 6.3.2.p.182).

Samples as tools

The reflection on the outcomes of the material experimentation phase was taken further by using the samples as a vehicle to understand how TDfD can be applied in various contexts. The effectiveness of the samples was thus tested as boundary objects in communicating with other experts and designers over the implications of TDfD. Wilkes et al. (2016), demonstrate how boundary objects can facilitate a common understanding of an issue between stakeholders with very different backgrounds. In the context of this study, boundary objects were used to open the work to other fields of expertise and gain additional insights concerning the potential of TDfD. These two approaches to using the samples as boundary objects are therefore classified as a reflective process in the way they helped achieve direct insights for TDfD. These interviews with experts were used differently from the first round of interviews mentioned as part of the scoping phase: they focused on the interpretation of the samples to explore TDfD concepts in a collective reflection process.

Building on this notion of design objects as translators, Hornbuckle (2010:257) expands this role to the materials expert as an instrumental agent in bridging gaps between different experts, allowing for fluid dialogues that all parties can understand. In this way, the samples enabled further dialogue in a second round of interviews using conversation as a way of eliciting insights (Ayres and Hall, 2008), and checking the validity of the use of TDfD in different contexts. The samples cemented the roles of the different parties in providing examples for what TDfD can be, describing the author as a specific type of material expert and designer. They allowed the interviewed experts to understand precisely what TDfD refers to in the context of this study. With this clarity and precision, the feedback and opinions expressed were made directly relevant to the work and drew meaningful insights from this reflection phase.

The samples were also used in two rounds of workshops in which the participants were invited to perform a re-design activity using TDfD as a key strategy. The presence of the samples was observed to influence the approaches taken by the groups and encourage embedding the TDfD techniques within the materials themselves rather than at a purely product-assembly level. This method of assessment, while not strictly part of the PhD research project and rather a corollary use of the author's expertise in a teaching environment, was however instrumental in demonstrating the potential of samples to generate a deeper understanding of the value of TDfD for designers. Moreover, the abstract nature of the samples using placeholder materials was sufficiently open and non-prescriptive to allow for adaptation within individual design practices. This corresponds to one of the core aims of the research in the way that it shows how the sampling can be used as a starting point for further applications of TDfD.

Learning lessons from prototypes

Beyond the use of TDfD strategies as expressed through various techniques in the sampling, reflection on the work also led to understanding of the effectiveness of the strategy in a product context.

Applying the TDfD strategies to the development of specific product prototypes showed how this influenced their lifecycle. In keeping with the principles of LCA, the product concept enables a comparison with a conventional and equivalent reference product. In the case of the collaborative Service Shirt prototype, an LCA was indeed carried out for the whole concept, proving the environmental benefits of a remanufactured garment over a series of new items.

As described in further detail in chapter 7 (see 7.1.3. p.223), using annotated portfolio methods in the mapping of the design and prototyping process for the Service Jacket provided insights into the potential challenges of taking circular design strategies, including TDfD into the industry. This collective reflection on the process and outcomes was then fed back into a second round of prototyping, the outcome of which is considered the example for TDfD in a product context for this study.

The inclusion of the TDfD strategies demonstrated in the samples as part of a product are also useful in highlighting the innovative potential of this approach. To demonstrate effective innovation, the new product must be able to replace the current conventional one and eliminate the need for it by simultaneously offering improvements in terms of function, or other desirability factors such as aesthetics, and environmental benefits (Tonkinwise, 2014). In this way, applying TDfD techniques in a specific product context pinpoints where significant changes to the use phase can be implemented. The product context enables a reflection on their effectiveness in terms of functionality and aesthetics in a way which cannot be achieved through abstract sampling. This phase of the project is therefore a milestone moment to check the feasibility of TDfD principles within the Service and Split Jacket product contexts.

The prototypes were thought as "deliberate extremes" (Pedersen et al., 2018) purposefully over-ambitious in their challenging of established models. In this sense they use a similar approach to the TDfD sampling as they assume a best-case scenario as their framework. For the strategies to be plausible, one must assume that collection and recycling systems are already functioning in an optimal way and that garment traceability is assured, allowing the end-of-life handler to know all the relevant information for each article of clothing. Such a model has been developed by the Berlin-based start-up Circular Fashion (www.circular.fashion) which supports the proposition of this work. While it is acknowledged that the current state of the industry is very different from this, a best-case scenario allows more freedom in the development of the products.

It is important to highlight that the samples and prototypes demonstrate the potential for resources to be combined in pleasing ways and later taken apart. The effective consignment of these parts to appropriate systems of recovery and recycling falls beyond the scope of this work and this aspect is therefore not a token of the relative success of the work.

The tendency to abstraction is warned against in Dorst's Notes on Design, but is acknowledged as a way of controlling the design process in an attempt to generate design models (Dorst, 2017:51). The prototyping thus endorses a cautious form of abstraction in putting the design process for a circular garment between brackets and taking a step back from real-world industry implications to provide insights that may later be re-injected into a direct design experience.

The project therefore compares to a form of critical design (Malpass, 2017) or future probing in the way that it uses design to explore far-forward concepts and question the future. In this case, this type of design futuring (Fry, 2009), suggest possible roadmaps for more circular textile systems, or at the very least challenges the current unsustainable status-quo in various branches of the industry. Further questioning the causality effect between products and systems, one can argue that the production of such ambitious objects may in turn shape consumer behaviours and resource recovery systems around them in a positive way (Walker et al., 2017). Putting the jacket prototypes at the centre of a reflection on the potential of TDfD therefore makes them such objects. They present a potential future for the regenerative use of resources and TDfD strategies, suggesting a new approach to end-of-life for materials in a circular economy.

3.3. Methods Summary

The methodological standing point taken in this work puts practice at the centre of every step towards the development of insights for TDfD. While the framework introduced here proposes four distinct steps, they each take into account the designer's perspective and keep the act of making as a central component of the research.

This section has demonstrated the value of textile design perspectives and the culture of bricolage research methods which they connect to. The retrospective analysis of these methods and their relation to the insights produced throughout the research have led to articulating a methodological framework in four stages which ties all the actions taken throughout the work together. These four steps: scope, make, map, and reflect suggest a sequence through which complex problem spaces can be understood and translated into practice which can then be analysed through the use of mapping and retrospective reflection. This model is put forward as one of the key contributions to knowledge of this work and will be expanded in chapter 8.

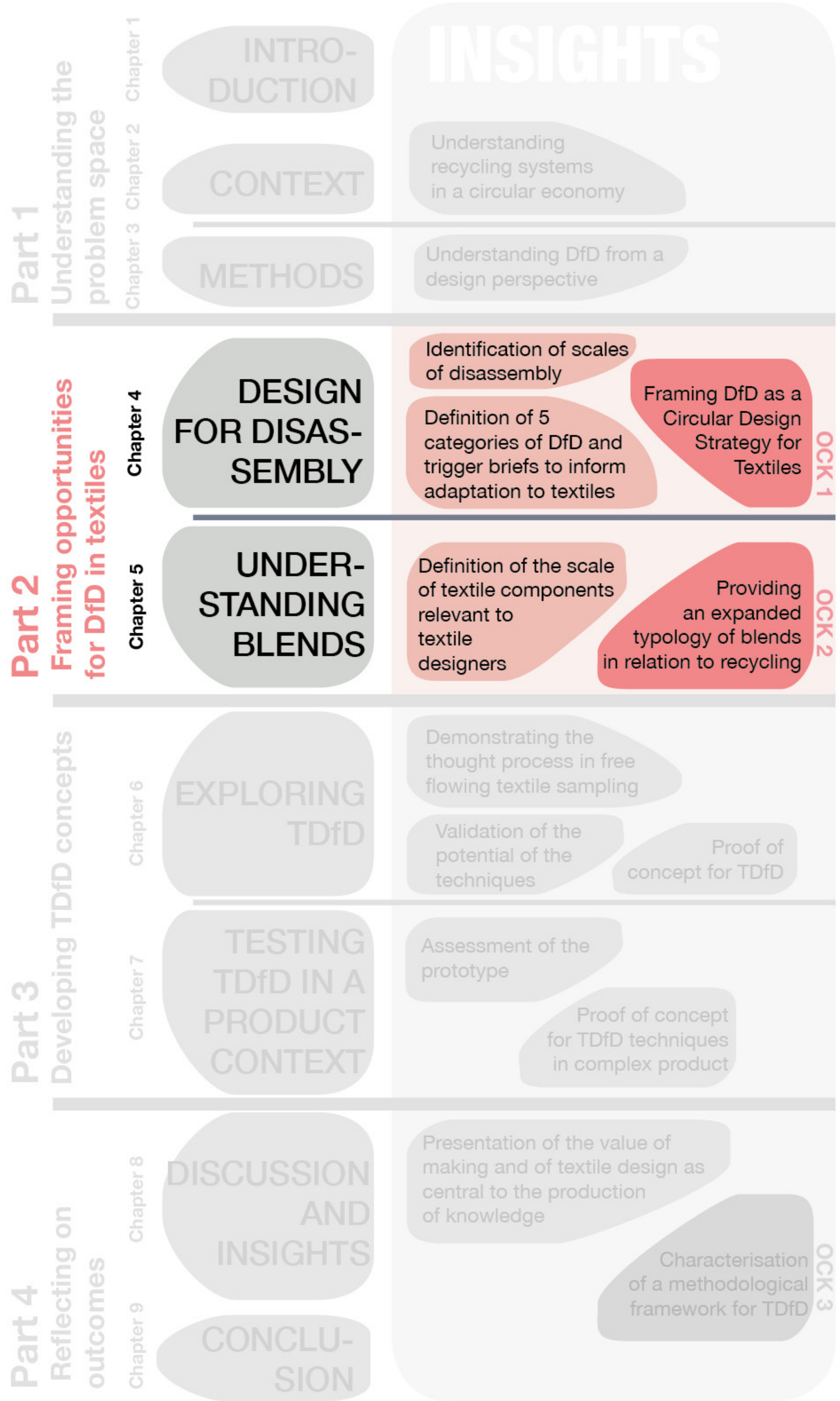
Summary of Part 1

This part of the thesis has demonstrated the relevance of a textile designer's perspective in solving the design issue of blended textiles preventing effective recovery and recycling of their components. As put by Papanek:

> "In an age of mass production when everything must be planned and designed, design has become the most powerful tool with which man shapes tools and environment (and by extension, society and himself). This demands high social and moral responsibility from the designer". (Papanek, 1985:14).

This section has suggested how the research carried out in this project will approach this imperative for designer responsibility in the environmental impact of the products, and in this case textile blends, they design. The circular economy is suggested as a framework for a shift to more regenerative practices and, following from this, the requirements of emerging and existing recycling systems have been laid out as a context for the design of materials which can be effectively recovered for their most appropriate recycling stream.

In order to achieve insights which are directly relevant to creative textile design practice which is described as the reason for the creation of problematic blends, alternative methods have been used to move away from the current engineering-led understanding of the issue. A bricolage of interviews, information visualisation, making and reflection on practice come together as an outline that can offer an alternative to the current status quo. These phases of exploring, understanding and solving the problem of blends for recycling have been translated into a methodological framework following four steps: scope, make, map, and reflect. This will be revisited in the final chapters of this thesis to demonstrate how practice is crucial in achieving insights for circular textile design.

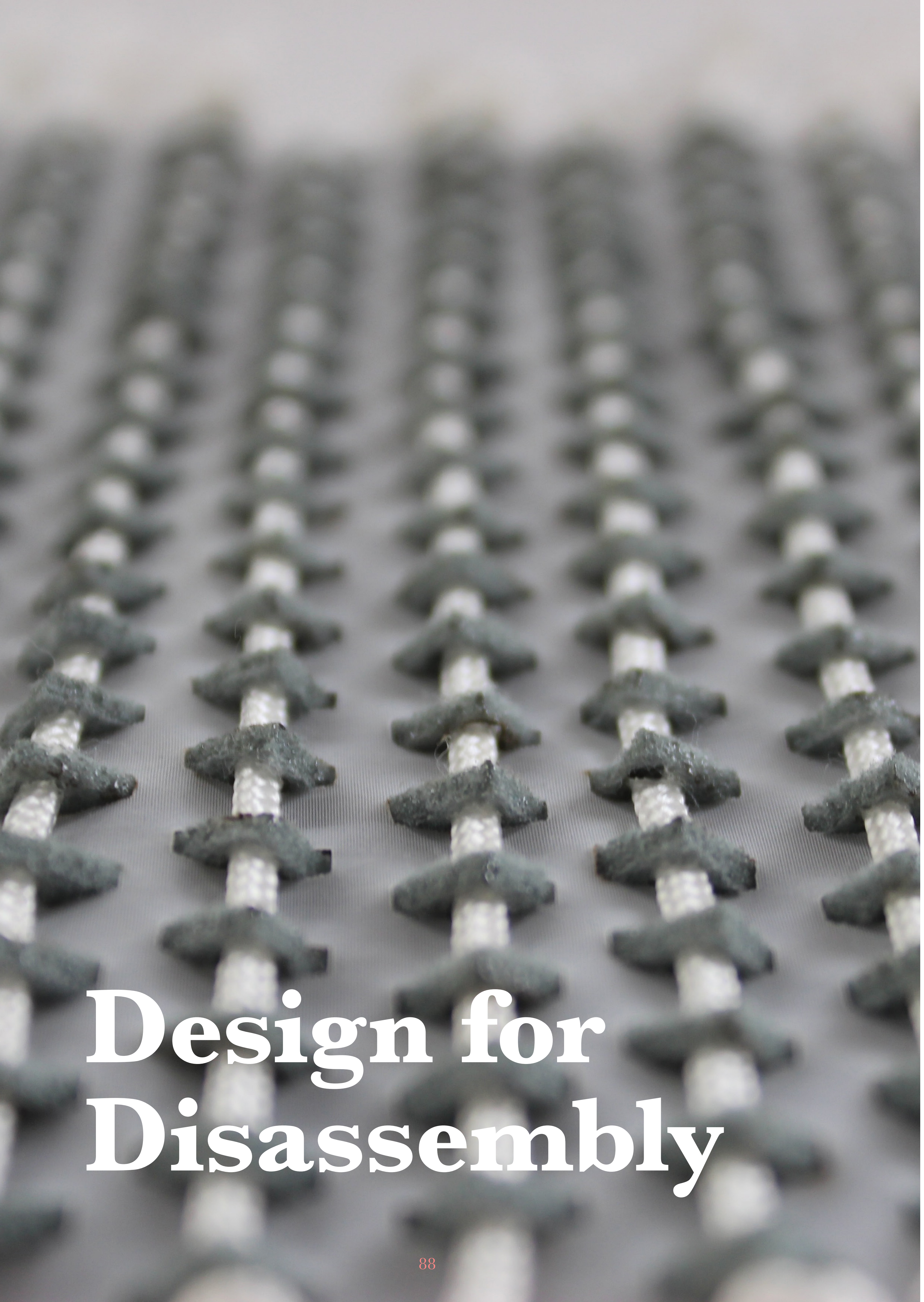


Part 2

Part 2 outlines the main components of the problem space by exploring in detail the characteristics of design for disassembly and then of textile blends. As shown in the diagram here, this section of the thesis presents two of the contributions to knowledge.

Chapter 4 offers a sweeping review of DfD through case studies and their classification. This review provides a new understanding of DfD as a design strategy in the context of a circular economy. The visualisation exercise defines 5 categories which then become creative triggers for textile design practice as will be demonstrated in later chapters.

In chapter 5, to further challenge the status quo in material combinations, a detailed review of the problem at hand, in this case, blended textiles, is carried out through making and mapping. Building on previous correlation between blending and recyclability barriers as presented in Gulich's work, this section pinpoints the aim of the redesign process in offering a shift towards detachable connections. It provides a definition of the scale and types of blends that are addressed in this work. In a broader context, this extended understanding of blend types in relation to recyclability criteria is one of the key contributions of this work to the field.



4. Design for Disassembly

> "Assemble for disassembly? Construct to destruct? It sounds odd, yet with serious concern for environment and ecology, designing things to come apart efficiently is as important as to design them well initially." (Papanek, 1995:58)

This chapter sets out to define DfD as it exists in current design and recyclability approaches in order to present a framework for how the strategy can be used in the subsequent practice of TDfD. The chapter presents DfD through a series of case studies which show different angles of the approach and are then classified into five categories. These categories present the reasons for which disassembly is needed, and further highlight specific design strategies which can be carried into textile design practice.

4.1. A Design Perspective on DfD

Considering the need for material purity established in the review of recycling systems and the challenges this poses to creative textile design, which is reliant on a bisociative process, this research explores the potential of DfD to bridge this gap.

As of now, this circular economy strategy has essentially been explored through the lens of industrial product design. In the field of mechanical engineering design and manufacture, DfD has been explored as an alternative to shredding in recovering plastic and metallic components from a variety of products in the most effective ways (Dowie, 1995:17). These approaches include guidelines for the design of products which take end of life treatments into account from the start (Dowie, 1995; Ziout, 2013:23). The field of architecture has also been explored for the potential of DfD to reduce the quantities of waste going to landfill at end of life (Crowther, 2005; Fletcher, 2000) and guidelines have been offered to rationalise and spread this approach (Crowther, 2005:7).

This study aims to transpose these approaches into textile design processes which plan for end of life recovery from the outset. This section offers a review of the use of disassembly for recycling and shows how there are yet several areas where the application of this approach is underexplored.

4.1.1. Adapting DfD from Product and Engineering to Textile Design

DfD is mainly inherited from the field of electronic products in which the high toxicity and value of components have driven stringent regulation to encourage their recovery. Disassembly, in this case, is a way of reducing the cost associated to recycling materials. This section suggests that design can go beyond this restrictive take on recycling to celebrate the value of textile resources in regenerative systems.

DfD in products for EPR

DfD is used here to allow for multi-material creativity in textiles while not impeding the capacity for material recovery. This is suggested as a possible way of achieving a compromise in which designers may use bisociative creativity while allowing for effective recovery of the elements entering the material combinations at end of life. DfD is defined as the creation of materials or products that can be easily and economically taken apart at the end of their useful life (Bakker et al., 2014; Fletcher, 2008; International Organization for Standardization, 2016; Vezzoli and Manzini, 2008) allowing for re-use in appropriate cycles. DfD has mainly been developed in product design as a response to Extended Producer Responsibility (EPR) regulation (Lindhqvist, 2000). As designers and manufacturers are required to think beyond the end-of-life of products, a systems-thinking approach to design involving DfD will become necessary (Webster, 2013).

This technical approach to DfD in products was mainly developed in Chiodo's work on active disassembly using smart materials (2012) and Ziout's approach to disassembly for sustainable product recovery (2014). Using shape memory materials, this engineering approach to DfD follows EPR guidelines, allowing for efficient recovery of valuable technical components from complex objects. Active disassembly (Chiodo and Jones, 2012) has emerged from this engineering approach to effective disassembly and is offered as a model for cost-effective disassembly of technical products made of many different elements. This allows for sorting into same material categories and maximal value recovery at the end of the product's life. It can be achieved using technologies such as biodegradable layers, thermally reversible adhesives or shape memory materials. While this approach is different from the more intuitive and creative position of this research, it provides many insights into DfD systems and can inspire textile design practice.

Further along the spectrum of approaches to DfD, architect Thomas Dienes also argues for modularity and standardisation, both essential components of DfD as a way of thinking design in systems which allow for more functionality and ease of disassembly and upgrade (Dienes and Mayerh, 2016). While this originally responds to an EPR approach, it takes the concepts of DfD further in providing more functionality during the building's lifespan. This points to an understanding that transcends the simple end-of-life scenario focus and uses DfD as a way of enhancing the use phase performance of the products.

The review of a variety of case studies presented in the following sections offers a range of examples which clarify how DfD can be interpreted beyond a strict response to regulation. While the end of life treatment remains a priority, DfD can influence the other characteristics of an object, garment or system and increase its functionality or appeal as a design object.

Why DfD needs to be adapted to textiles

Owing to the incentive to recover the high value materials contained in electronic products, DfD is relatively established in this field and guidelines have been offered to inform the design process of new products which will facilitate recovery and recycling (Autodesk Sustainability Workshop, 2015; Vezzoli, 2014). In the field of textiles however, no extensive description of this strategy has been identified in this review. There are two main reasons for this. Firstly, textiles being embedded within products, the assessment of their lifecycle and recycling process are complex matters. The complexity of systems described in the previous chapter is seen as a barrier to recyclability in many fields. Regarding textiles, this is only exacerbated. The second barrier to the use of DfD in textiles is related to the scale of the elements and the ways in which they are combined. While connections in electronic goods are often limited to a small number of points such as a series of screws, in textiles the connections between different elements are far more complex and sometimes not even visible to the naked eye. Vezzoli's Design for incompatible materials disassembly list (2014), while providing important guidelines such as the need to prioritise the recovery of elements with higher economic value for example, also suggests the use of snap-fit connections or of hexagonal headed screws which do not apply to textile design. There is therefore a need to develop an understanding of strategies for the recovery of the materials which enter the composition of textile blends.

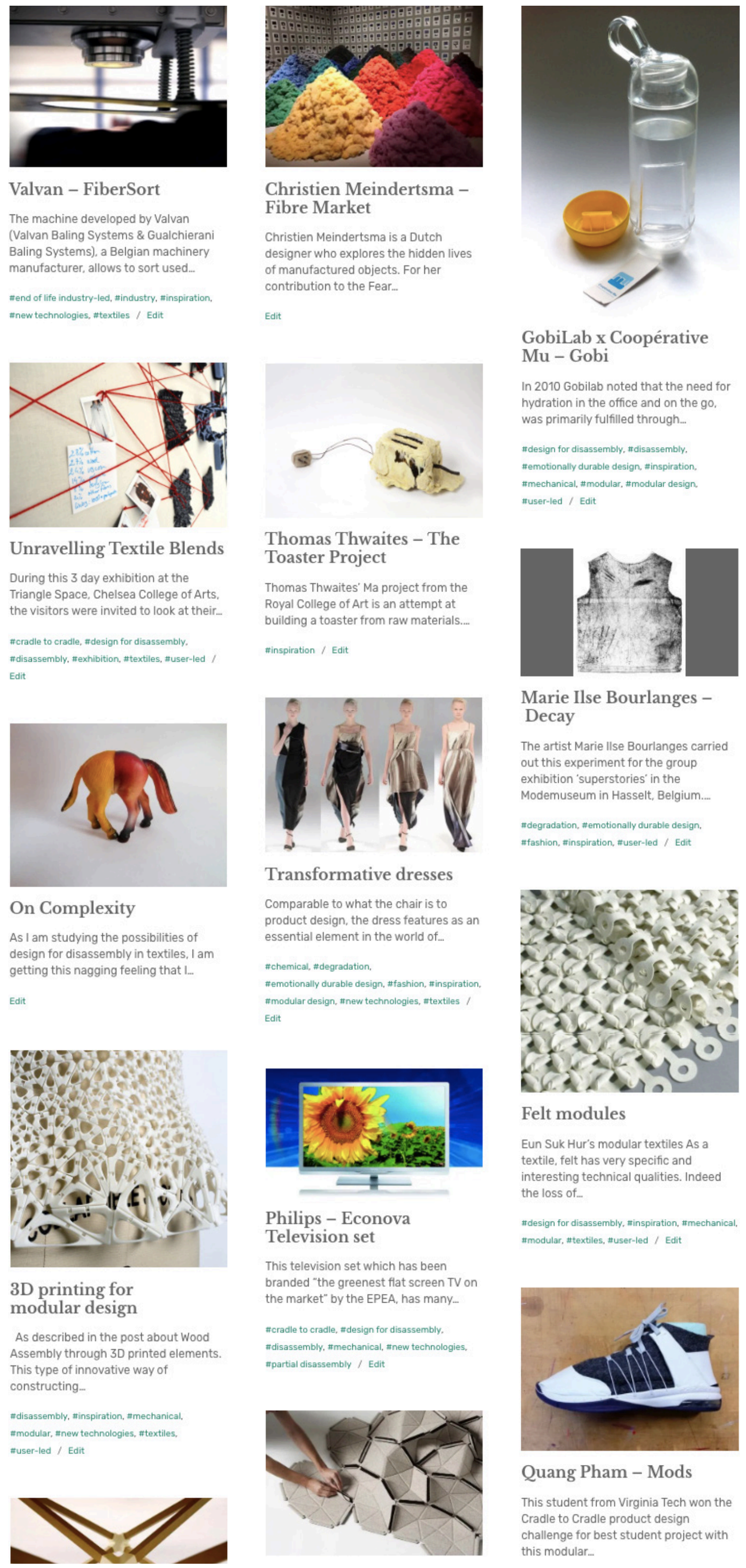
While the need to recover metals and rare earths has become obvious, as reflected in policies such as the Waste Electrical and Electronic Equipment regulations (WEEE), similar frameworks are still needed to enhance the potential for recyclability of textiles. The components that come into the making of a textile blend all have their own levels of embodied carbon and associated environmental impacts, and in the same way that we strive to keep metals in circulation, polyester and viscose should also be valued as resources. Intrinsic material lifespans need to be considered as part of the product or, in this case, of the blend's lifespan. This research therefore aims at overcoming the barriers perceived for DfD in textiles to enable a shift from product design concepts to the field of textiles. Using the core concepts from existing DfD approaches in the field of engineering and industrial product design, the research offers a translation for their application to textiles.

4.1.2. Understanding DfD Across Disciplines

The gap in knowledge that the work laid out here aims to address is the absence of examples for the application of DfD to textiles. This highlights the scarcity of examples in this field, and consequently, to extract concepts from existing practice relating to DfD, other fields of design have been investigated. Following from the designer perspective used in this research (see 3.2.1. p.68) this was achieved through a series of case studies and their classification as laid out here.

Case studies

This series of case studies aims to explore different uses of DfD. Examples were found via sustainable design reviews, online magazines in textile and design innovation, and blogs. The examples shown here are from contemporary design practices. They provide a sense of the zeitgeist of DfD and associated themes such as user-centred design, design for



4.1. Screen shot from the private blog. The website acted as a repository for the cases. These were stored as a representative image alongside a descriptive text. The website format allowed for cross linking between different cases which then informed the creation of common categories.

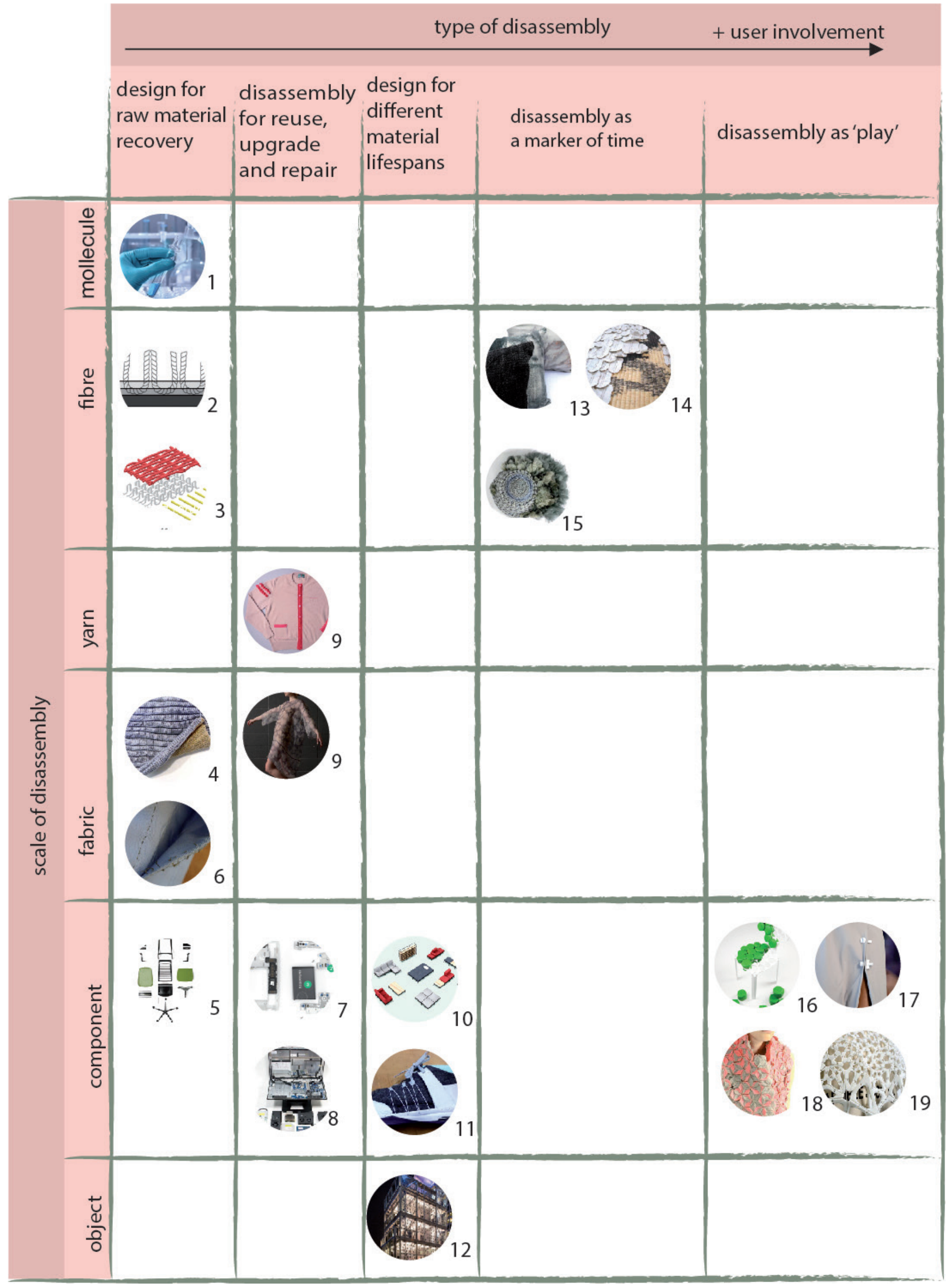
sustainability, or materials-driven design. The examples presented in the following pages are a selection from the review carried out in the initial stages of the research. They offer an overview of the breadth of approaches to the strategy; however this selection is not exhaustive as it was not continued beyond the stage at which the visualisation allowed for the insights and categories presented in this section. Taken up at this later stage of the work, many recent examples could be added to the review.

These examples were examined through a set list of questions as a form of object interview. These were then posted on a private blog as a library of design examples for subsequent classifications. A screenshot from this blog is shown in figure 4.1. This follows from a designer's sketchbook approach, in which visual references and notes are "the basis of a research collection" and inform the creative process (Studd, 2002:14).

While DfD is not widely represented in textiles, it has been demonstrated in fields such as architecture or product design. Shifting this concept to the scale of materials therefore requires a transdisciplinary approach. Depending on applications, the recommendations for DfD principles vary, ranging from specific technical advice, to conceptual considerations. For the pioneers of DfD in electronic devices and other complex products, the list of dos and don'ts covers aspects such as standardisation of components or accessibility of joints (Autodesk Sustainability Workshop, 2015; Vezzoli, 2014). In other fields, where the approach is concerned with more systemic factors, the lifespan of materials and conservation of value are the main focus (Fletcher, 2000; Stahel, 2006). This variety of approaches witnessed in the corpus of case studies was therefore reviewed and classified to feed into the design practice relevant to this research.

Case classification

These case studies were then classified and laid out in a grid as shown in figure 4.2. It combines two criteria through which they are reviewed: the scale of the components which can be disassembled and the type of disassembly. Based on the latter criteria, the columns arrange the examples according to the effects of DfD on the lifecycle and particularly on the use phase, whereas the lines state the scales at which the disassembly occurs. Each case study is represented with the corresponding picture and labelling. This approach draws on the



1. Worn Again chemical recycling
2. EcoMeTex, Interface
3. Climatex, Duacycle Textile Lock
4. 2-4-1, Laetitia Forst, 2015
5. Steelcase, Think Chair
6. Wear2, Microwave Thread
7. Fairphone mobile phone
8. Hewlett Packard, Z1 work-station
9. Craft of Use
10. Strata, Katrine Hesseldahl and Victor Strimfors, 2017
11. Mod shoe, Quang Pham, 2016
12. Cellophane house, Kieran Timberlake, 2008
13. Muto-Ephemeral, Laetitia Forst, 2015
14. Muto-Traces of Passage, Laetitia Forst, 2015
15. Suicidal Pouf, Carole Collet, 2008
16. Bjorn Ischi, Bone Chair, 2011
17. Post Couture dress, detail, 2015
18. EunSuk Hur modular textiles, 2011
19. 3D printed textile

4.2. Classification of DfD case studies. The visualisation shows the areas which are strongly represented by different cases as well as empty cross-sections where no examples were found.

familiarity of the author with the case studies using partial representation (Manovich, 2011), the full spectrum of information is available at one glance. This grid is a working document which produces insights from the visualisation process rather than a final communications support. A tacit understanding of each case's specificities is therefore drawn on in the media representation. Each case is further detailed in the following description of the different categories (see 4.2. p.98). The aim of this visual representation of the different approaches to DfD seen in the case studies was to draw relationships between them and enable a sweeping understanding of the current landscape in this field. This exercise showed the ways that DfD was used in different end-of-life scenarios. This matrix informed the author about the state-of-the-art in DfD and helped to communicate it. By grasping transversal frameworks throughout the various disciplines in which DfD characteristics had been identified, this informed a rationale for using DfD in textiles. The examples show the validity of a DfD strategy in enabling ease of recovery and recycling of the different scales of components. Their representation in this grid takes the understanding of the state of the art further by highlighting in which areas the strategy can be expanded.

This mapping process has provided a series of insights into the field of DfD. Firstly, it points at gaps in the field, showing areas, either related to the scale or the type of DfD, that have not yet been addressed in design practice as no examples for these categories were identified in this review. Second, it has framed the author's work within the field, treating previous work on the same grounds as a case study, and therefore pinpointing the opportunities for the specific type of textile design developed prior to this study. Furthermore, the visualisation has made apparent the five categories which define the different takes on DfD which were observed in the case studies and which are a key component of the understanding of DfD as defined in this research.

The combination of these insights show the challenges that can be addressed through textile design practice. For example, while modular design is well developed in products and starting to gain terrain in textiles, the cross-over between the user-involvement of modularity and designing for recycling systems is yet to be made. This understanding of the relevance of the scale of components in the approach to disassembly is transferred into the exploration of the applicability of the strategy to textiles in which scale is currently a crucial limitation to DfD. Chapter 5 will further question the notion of the scale of textile components in the context of blend recyclability and DfD.

Translating categories into design strategies

This chapter demonstrates how DfD can be represented through five categories which are design-led in their processes and outcomes. Considering DfD from a creative textile design angle rather than a purely solutions-focused one adds a new perspective to the understanding of this strategy. The scarcity of literature has also had a strong influence in using a practice review to determine definitions and categories for different aspects of DfD. The case studies, used to extract intermediate knowledge (Löwgren, 2013) and make it available for the development of TDfD techniques and concepts, show different aims attributed to DfD. These show what the disassembly is for, but also highlight the strategies through which the DfD is effected which can then be transferred to textile design. These five categories for DfD and their associated design strategies expand the notion beyond the current approach to include propositions which are usually classified under modular design or more poetic or experimental categories.

To transfer this understanding of DfD to textiles the five categories are reviewed in order to extract a converging concept which is articulated as a one-word brief. These concepts offer a trigger that can be taken on in further design practice within as well as beyond this project. The collection and association of images and key words relating to the concepts expressed by the cases in the table is associated to the use of mood boards in conventional textile design projects (Cassidy, 2011). This exercise in visual representation of the field is also used as an inspiration and transferred into tools to fuel the creative process. The use of thematic words to trigger a creative process such as these is common as a starting point for a design project (Studd, 2002:14). They usually serve as a way of defining the angle through which a problem must be approached, and hint at a type of solution. The strategies presented here suggest ways in which DfD can be applied for the recovery of materials for recycling, but also point future practice to the insights concerning corollary benefits of DfD uncovered in the case studies.

4.2. Identifying Five Categories and Associated Briefs for DfD in Design

The review and classification of the DfD case studies highlighted five categories which are presented here and ranked from the least to the most user involvement. This section describes these case studies in more detail in order to qualify the categories. More importantly, the categories led to extract one-word briefs which summarise the convergent themes from the different examples of types of disassembly. The listing of case studies presented here show how the intersection of DfD themes can lead to the understanding of abstract briefs which allow for the translation of the product or architectural concepts to textile design practice.

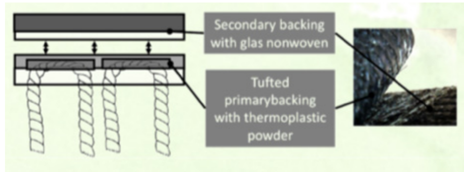
While the cases may seem quite different from one another and show the use of DfD in different fields, their comparison highlights the convergence of the strategy around specific themes or ways of designing for disassembly. As with a mood board, the juxtaposition of the examples provides the tools for the abstraction of the themes which they represent through different characteristics.

4.2.1. Disassembly for Material Recovery: Optimisation

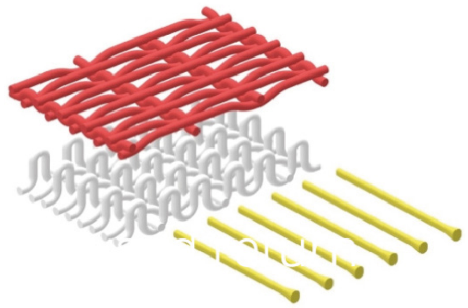
The examples in this category focus on the recovery of materials: the primary concern is to extract a non-contaminated raw material at the end-of-life. The value added by manufacturing processes is lost, but to maintain the value of the materials for new production processes, they must be as pure as possible (Institut für Textiltechnik of RWTH Aachen University et al., 2015). Worn Again's chemical disassembly process (case 1) addresses this need for pure materials in recycling systems. This approach to material purity is also well illustrated through the Interface EcoMeTex (case 2) project. This example addresses how carpets are problematic for material recovery because of the multi-layered backing which impedes recycling processes. A DfD system was therefore developed for the recovery of the elements of the carpet at the end of life without compromising the quality of the product. A similar approach was used in Climatex's Duacycle (case 3), a furnishing textile in which the durable synthetic backing can be separated from the woollen upper-layer by releasing the textile lock thread which is selectively destroyed through high pressure and heat. This type of two-layered material was mimicked in the 2-4-1 sample (case 4) developed as a test prior to the Muto collection (see appendix 11.4. p.420). Simple machine knitting using a bonding thread of soluble PLA can prove the concept of DfD as feasible at a craft-textile scale.

Case 1. Worn Again is developing a chemical disassembly technology to separate blends into mono-material pulps (Worn Again, Kering and H&M, 2015).

Following EPR regulations, the drive to recover valuable components has led to the development of DfD strategies. The Think Chair by Steelcase (case 5) is designed to be disassembled in less than five minutes using no specialised tools. This is the example put forward by the Ellen MacArthur foundation in their description of DfD and is therefore a precise example for this strategy applied to end of life material recovery in a circular economy (Webster, 2013). While this example shows the disassembly of parts of an object, these are all designed as mono-material components, likening it to the disassembly of raw materials shown in the other examples in this category.



Case 2. Example of technical drawing describing one of the DfD processes developed for EcoMeTex (Institut für Textiltechnik of RWTH Aachen University, Gloy and Schröter, 2015).



Case 3. Climatex Duacycle Textile Lock system (Climatex, 2019).

Using active disassembly approaches (Chiodo and Jones, 2012) to the recovery of raw materials, the microwave process developed by Wear2 and Wrap (case 6) takes this smart material approach to the textile level.

Case 4. 2-4-1 sample and disassembly schema, (Forst, 2015).

Case 5. Steelcase, Think Chair (Webster, 2013).

Case 6. Wear2, Microwave Thread (Durham et al., 2014).

The thread is degraded through a microwave treatment which separates the elements. In this case the main garment is separated from corporate badges. This is very similar to the approach developed by the 2018 winners of the H&M foundation Global Change Awards, Resortecs, who are developing a thread which degrades in high temperature for the instant disassembly of complex products such as mattresses or shoes (https://resortecs.com/).

The approach described through these case studies is the most problem-solving and engineering oriented of the five categories shown here. The main DfD approach represented through these examples is aimed at efficiency in recovering materials. It uses an established approach to DfD, which is also connected to the use of smart or reactive materials. The driving motivation behind these cases is for the optimised recovery of the raw materials, often by reducing the need for labour and automating as many stages as possible. “Optimisation” is therefore extracted as the common and transferable characteristic for these cases.

The techniques and concepts represented in this listing of cases offers inspiration as a response to a

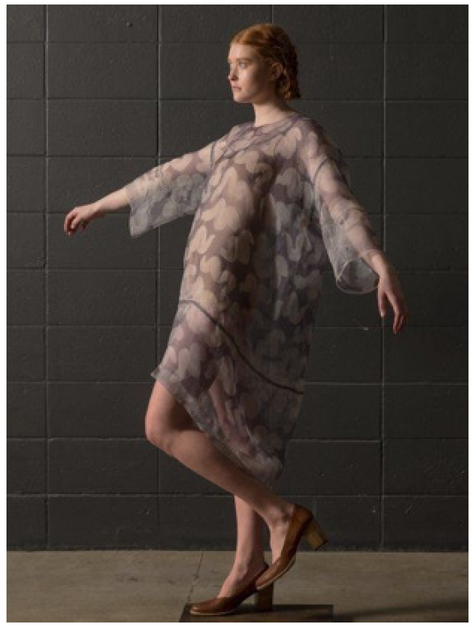
brief such as “how can disassembly be effected with minimal labour and in large numbers simultaneously?”. Using Optimisation as an umbrella strategy to represent this take on DfD lifts it from the specific cases and applies it to further textile design adaptations of the strategy.

Case 7. Fairphone mobile phone (Fairphone, 2019).

4.2.2. Disassembly for Reuse, Upgrade and Repair: Simplification

The following examples can be disassembled for the repair or replacement of parts. This approach is similar to the previous category, however it does not necessarily involve a full destruction of the object and is more selective as to which parts will come apart and in which order. Moreover, the difference with the Optimisation category also lies in the fact that the user is involved in the disassembly as the actor of the reuse, upgrade or repair process. The technical literature relating to DfD stresses the importance of allowing for selective disassembly and how the order of connections should plan for the easy removal of pieces which are likely to need repair rather than encase them deep into the objects’ structure (Dowie, 1995; Vezzoli, 2014:118). In the case of FairPhone (case 7), this approach enables the repair and upgrade of the device, avoiding technical obsolescence and lengthening the

Case 8. Hewlett Packard Z1 work-station (Webster, 2013).



Case 9. McQuillan, Make Use Dress (McQuillan, 2019).

product's lifespan. This type of disassembly can also allow user-led repair in the cases when the user is involved in the assembly and disassembly process. DfD then involves the simplification of the product such as in the HPZ1 workstation (case 8) which can be opened to replace components using no tools.

In line with this approach to making upgrade available to the user, the Make Use open source dress (case 9) incorporates lines along which it can be cut without fraying to shorten sleeves or body-length or widen a neckline with no knowledge of dressmaking.

To incorporate ease of upgrade or reuse of selected components in an object, DfD needs to be coupled with a simplified design. Where in the previous category the disassembly mechanism might be hidden, these examples show how it is important to signal the disassembly potential of the product to the user. These examples highlight ways in which the user or end of life handler can access specific parts of the product, the abstract concept of Simplification is thus the common strategy which draws them together to enable the translation of this approach to DfD to other fields. This highlights that the construction should be understandable to someone not involved in the production process and that it could be partially dismantled with minimal efforts. When considering the complex nature of the electronic products that this approach is inherited from, the need for simplification is crucial.

In textiles this leads to consider the scale at which the elements are connected, combinations of non-compatible resources currently occur at scales which are rarely even noticeable to the naked eye. Translating the notion of Simplification to enable partial disassembly for reuse, upgrade and repair in this field could mean questioning the scale of textile components.

This approach to DfD shows an initial cluster of examples for which disassembly is not exclusively aimed at the recovery of raw materials but rather is a part of a wider strategy of lifecycle extension. Expanding on the engineering origins of the concept, this more systemic approach considers different actors such as the user or end of life handler to inform the circular design strategy.

4.2.3. Disassembly for Different Material Lifespans: Layering

This category specifically focuses on considering the different lifespans involved in different functional elements in a product or inherent to different material types. One of the arguments in favour of designing for disassembly concerns the possibility of designing for disjointed lifespans of elements or materials within the same product. This is particularly relevant in architecture. As put by Crowther:

> "When we discuss a building, we tend to think of it as just that, a single building. Buildings are conceived, designed, constructed, used, and disposed of as complete entities. This notion of the singular building is however flawed, in part, resulting from our reading of the building over a limited time frame. […] Typically the structure of a building may be retained while the internal spaces are changed with components removed and replaced, or services upgraded" (Crowther, 2005:2).

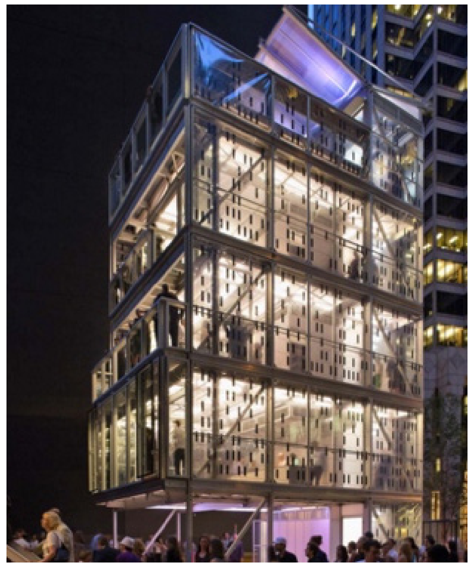
Where the expected lifespan of a building is usually beyond 30 years, the different elements that make up the interior or exterior spaces can be more-or-less subject to wear or to fashion changes. According to Scott Fletcher (2000:24), buildings could therefore be made of layers that allow the structural elements to stay in place while the rest of the building can be "sensitive to future demands, changing with the ebb and flow of use" (Fletcher, 2000:24). This approach to layered lifespans was developed in the Royal College of Arts graduate's work Strata (case 10), a layered furniture system which plans for the dissociation of the structure, foam components and covers, to keep products functional and desirable for as long as possible. This approach draws light to the associated functions of these different layers. The attention to individual functions of materials is visible in the Mod shoe (case 11), created by the winner of the 2016 Best Student Cradle-to-Cradle design challenge. The shoe can be disassembled into its basic functional components; wool felt providing warmth, the rubber sole for shock absorbance, and so on. This layering of function and materials keeps each element from contaminating another, reaching end-of-life as a recyclable material. This approach to embedded function reaches a larger scale in the architectural firm Kieran Timberlake's Cellophane house (case 12). In the case of this temporary construction,

Case 10. Strata furniture by Katrine Hesseldahl and Victor Strimfors (Tucker, 2017).

all the elements can be taken apart and re-built on a different site. They do not disassemble into recyclable components, but rather enable the reuse of the part by isolating its functionality so that different elements can be interchanged. This distance from the recycling-centric approach to DfD is interesting in the way in which it highlights how such strategies can offer benefits beyond the recovery of raw materials. In the case of this architectural example it suggests more adaptability which can extend the building's lifespan in a new site, effectively offering regeneration without needing to return to the raw resource. This is a common approach in construction when DfD leads to the reuse of semi-manufactured components such as beams or other elements (Weetman, 2017).

Case 11. Mod shoe by Quang Pham, (Design Indaba, 2016).

In textiles, as described by Earley and Goldsworthy (2015:3) different materials have different expected durability. While a polyester fibre may have taken millions of years to transform from organic matter to oil and then be processed in heavy industrial systems before being made into a fibre which will take upwards of 200 years to biodegrade, paper, on the other hand, can be made quickly and with a light environmental footprint before it is biodegraded safely (Goldsworthy et al., 2018). This type of DfD, summarised with the



Case 12. Cellophane house by Kieran Timberlake, (Kieran et al., 2011).

concept of Layering, could therefore be adapted for the use of fibres with such varied durability in blends.

As represented in this cluster, when designing for disassembly, the different lifespan of the components or materials which are combined can be considered for appropriate repartition within the object and for the differentiated disassembly and recovery when each element reaches its end of life at a different time. Layering according to their expected lifespan, enables their gradual recovery as they reach end of life. This approach respects the nature of the materials and pairs it with appropriate use phases and functional units.

The examples listed here converge as responses to a brief such as "how can we plan for dissociated material aging and for the recovery of a component at end of life without damaging the elements which are slower to age and still fully functional?". They offer inspiration for the way in which Layering can provide a useful approach to dissociating the different functionality and lifespans of materials within products.

4.2.4. Disassembly as a Marker of Time: Narration

The consideration for dissociated material durability was further developed in the author's MA work, the Muto project (see chapter 1). Through pieces such as 'Ephemeral' (case 13) for furnishing, or 'Traces of Passage' (case 14) for floor covering, a top layer of cotton was designed to wear off through repeated use and reveal a hidden pattern, giving the product a new lease of life. This poetic approach to gradual degradation of textiles was also explored through a biomimetic approach by Carole Collet with her 'Suicidal Pouf' (case 15). This object praises the beauty of programmed cell death found in nature to draw attention to the evolution of a material in an outdoors environment.

This section presents cases that differ from the previous category in the way that different material lifespans are no longer thought of in terms of functionality and need for replacement but rather that this differentiated ageing is used as a poetic design feature in itself. The two examples by the author were developed in 2015 as part of the master's research project into material combinations for circularity. The Muto collection combined cotton and polyester in ways that enable future recycling.

Case 13. Muto-Ephemeral, (Forst, 2015}.

Case 14. Muto-Traces of Passage (Forst, 2015).

Case 15. Suicidal Pouf, Carole Collet, (Collet, 2008).

The intent then was to explore the narrative qualities of dissociated ageing in materials through the temporary combination of fragile cotton on a base of durable polyester. Recyclability at the end of the useful life was considered, but it was not the only disassembly characteristic. Materials were also assembled and left to come apart through time for the poetic appeal that this transformation can offer, creating a deeper connection with the user.

The author's prior experience of the type of disassembly which emerged through the Muto project influenced the classification of the case studies in this project by opening it up towards natural, or slow, disassembly examples that are not usually associated with the problem-solving approach of DfD. This considers the added benefits from slow disassembly in scenarios where users are given the chance to see their surroundings evolve with them and induces better emotional durability (Chapman, 2005) potentially replacing the need for new products.

Following closely from an understanding of differentiated aging in materials and their combinations, this category takes a poetic approach to DfD. The examples here show how the gradual decay of part of the object is recorded to tell the story of the object's evolution.

The examples show how a narrative which is personal to the user can be developed to create an emotional bond by using DfD in combination with the distinct aging qualities of materials. Beyond the benefits in the use phase, this approach also allows for the combined materials to be recycled separately. This Narration strategy represented in these examples gives inspiration that can be applied to further textile design practice.

This strategy is however not used directly in the practice relating to this thesis as it relies on the capacity of the materials involved in the combination to degrade with time. In the experimentation within this project, placeholder materials were used to represent different parts of a combination (see 6.1.1. p.148), making the application of this strategy difficult. This approach can however be taken up in future practice with specific materials displaying evolution within polarised material combinations.

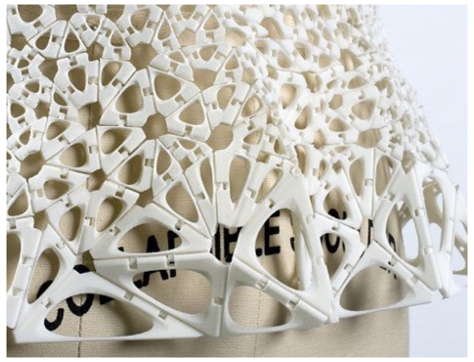
4.2.5. Disassembly as Play: Modularity

Case 16. Bjorn Ischi, Bone Chair, (Starr, 2011).

Lifecycle extension by addressing emotional obsolescence (Chapman, 2005) can also involve the user in a direct way. By giving

Case 17. Post Couture dress, detail, (van Strien, 2015).

Case 18. EunSuk Hur modular textiles, (Hur, 2014).



Case 19. Nervous System, Kinematics Dress (Nervous System, 2014).

the user a say over the appearance of their objects and involving them in a playful way in recombining the products, modularity can help in postponing disposal. This assembly system can be seen at the product scale with Björn Ishi's Bone Chair (case 16) which integrates customisation through the assembly and disassembly of the cushions within the chair structure.

This approach to DfD may seem removed from the small scale of textiles, however emerging technologies are facilitating this modular and user-focused approach to materials. The Post-Couture project (case 17) for example uses laser cutting as a way of involving users in garment construction. This approach to laser cutting as an ease-of-assembly factor allows for redistributed manufacturing (Real et al., 2018) and is an essential agent for innovation in this case. Although this example does not suggest the assembly of multi-material components, it is relevant in demonstrating the potential of simplified and modular assembly systems in suggesting new product-user relationships. The lessons from this type of approach are directly transferred to DfD concepts in this study.

EunSuk Hur's work with modular textiles (case 18) also uses this technique to involve the user as a constant maker and re-maker of the textile pieces. 3D printing (case 19), while still marginal in textiles, takes the modular approaches seen in products to a materials scale. Modularity, as argued by designer Thomas Lomée (2016), can have many benefits such as forcing designers into more collaborative practices where open standards give more flexibility to the process and outcomes of design.

The concept of play which is inherent to the examples in this category leads to a deeper involvement of the user within the product's lifecycle and contributes to extending it. This is essentially enabled through the use of Modularity. This strategy combines several elements from the previous categories such as simplification or narration and suggests the use of grid systems for customisation within certain sets of rules defined by the designer. The examples in this section show how products and materials can be designed for users to engage with their construction as well as effectively recycle the different components at end of life.

As with previous categories, although the examples presented here do not necessarily take recycling into account, Modularity as a circular design strategy in the context of DfD can be channelled for better ease of recycling. The value of these categories lies in the interpretation of DfD that they offer for textile design practice. The case studies suggest an understanding of the strategy which reaches beyond the benefits of raw material recovery.

4.3. Conclusion: Understanding DfD as a Circular Design Strategy for Textiles

This chapter has offered a review of the current state of the art in DfD through a form of enhanced literature review which has combined an interpretation of case studies as a practice review with a more conventional investigation of written material on the topic. This scoping has allowed an understanding of DfD which relates directly to a designer's perspective on the issue of blend recyclability.

Adding granularity to a design-led understanding of DfD

The mapping of the different case studies has added nuance to the concept of DfD beyond its conventional engineering and industrial product design origin. Moreover, the classification according to the scale or size of the components being disassembled showed the distribution of this approach across different areas of design. This has highlighted the opportunities to expand the approach from a textile design perspective. Indeed, examples of disassembly at the fabric and yarn component level were very scarce. This can therefore guide the subsequent exploration of the concept through textile design practice to understand how DfD can offer solutions to blend recyclability.

Following the deliberate focus on a designer's approach to the issue of blend recyclability taken in this work, the visualisation of the existing references in the field have narrowed the scope of this project. While sections of the case study mapping were scarcely represented such as molecular disassembly or disassembly at the scale of products, the classification identified them as beyond the remit of the textile design skills available in the framework of this research. Considering the scale of the components is crucial to the translation of DfD to textile design where the small elements which enter blends have been identified as a barrier to the implementation of DfD strategies to enable better recyclability. Showing the range of scales in different references challenges the conventional approach to textile combination. Understanding the importance of the scale of the components which enter a material combination is one of the crucial points which has supported the exploration of problematic blends described in chapter 5.

The approach taken here does not suggest that DfD can offer a silver bullet solution to the problem of blend recyclability, but rather it offers a new alternative to unsustainable design that can be added to the range of options already available. A design-led understanding of DfD as a circular design strategy shows how this approach can fit within the field of textiles and which stages and scales of the creation of a blend can be influenced in this way.

Insights for the translation of DfD strategies to textile design

The analysis, classification, and translation into design briefs of the DfD case studies carried out in this scoping and mapping phase, as defined in the methods overview (see 3.2.1. p.68 and 3.2.3. p.74), contribute to one of the main contributions to knowledge of this study. It has been

established from the literature review that very little attention has been given to DfD from a design perspective, and even less from a creative textile design point of view. Until now, the approach has been led by an engineering, or problem-solving approach. Considering the issues posed by design-led combinations in textiles, it is therefore relevant to offer an alternative to unrecyclable blends from this perspective.

The study puts DfD forward as a potential solution to blend recyclability. It acknowledges the benefits of material combinations in a creative bisociative process, while considering end of life treatment and recycling. Through visualisation and summarisation as design strategies, or creative triggers, the information was translated (Baule and Caratti, 2016) for its appropriation within a creative design process. While the recycling benefits of DfD are laid out in technical literature suggesting the use of smart materials within a product-focussed approach, the creative potential of such a strategy is still underexplored. Moreover, the technical approaches to DfD do not transfer to textile design practice as they involve the use of product-specific components such as screws and snap-fit elements. Through the series of case studies, the different ways in which DfD could be applied across disciplines and how it would impact the various systems the cases belong to, were explored to broaden the scope of techniques and concepts related to DfD that can be transferred to textile design practice.

This section of the work therefore offers an alternative to existing product design checklists (Crowther, 2005; Vezzoli, 2014; Ziout, 2014). The five design strategies for DfD as presented in the case studies are made to be taken on in a creative textile design process as creative triggers. These categories are intended to feed the development of samples which test the applicability of TDfD as will be demonstrated in chapter 6.

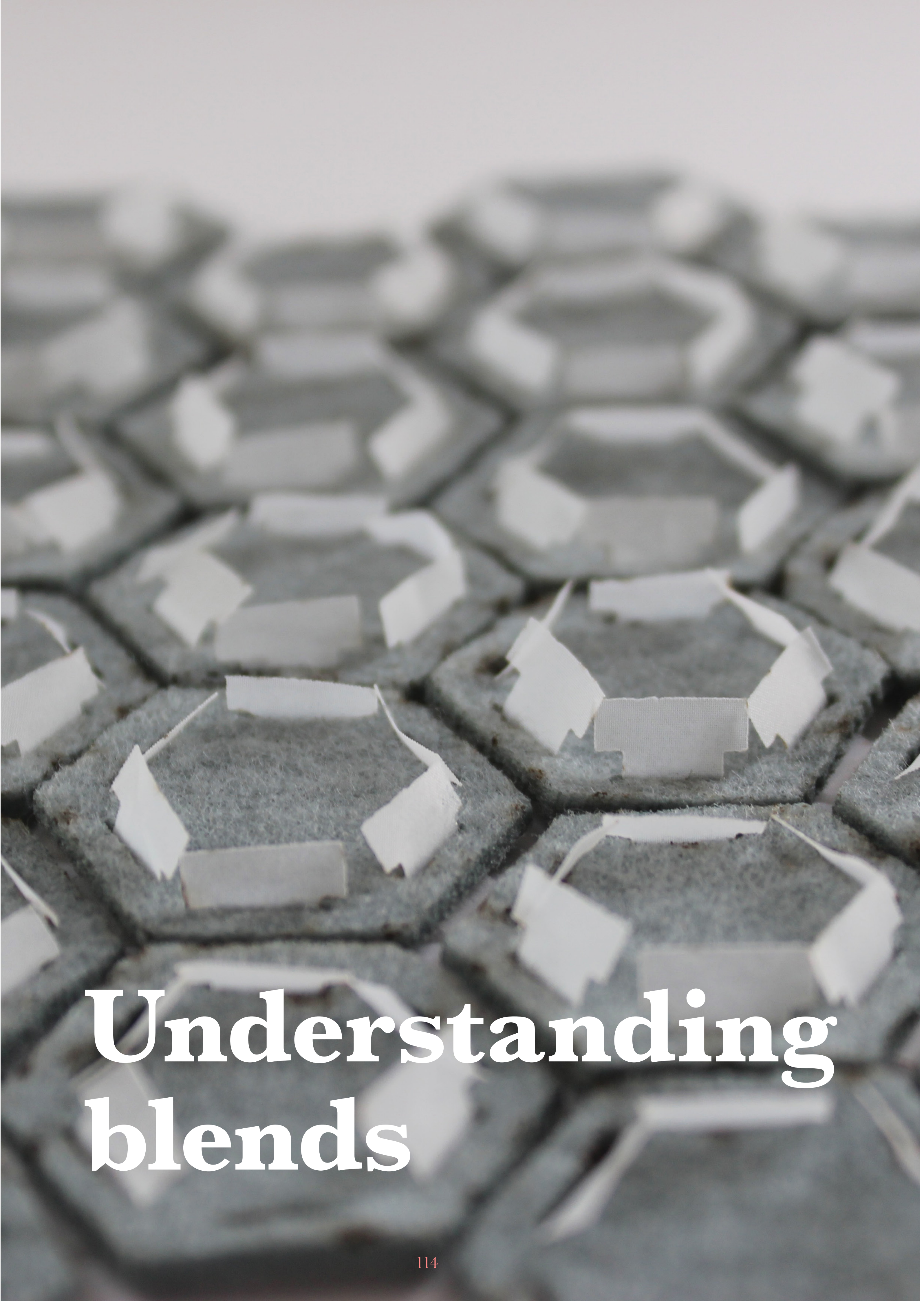
Beyond raw material recovery: corollary benefits of DfD strategies

The categories show the effects of the disassembly rather than focussing on the mechanics of the assembly and disassembly process. They situate the concept and highlight the benefits afforded by DfD. The examples of the different purposes for DfD can then be transferred into textile design practice. The classification supports the notion that disassembly for the sake of disassembly alone cannot be considered as sufficient and meaningful innovation as it will not offer a satisfying replacement to the original problem product. These categories therefore help in assessing the ways in which the disassembly benefits the use phase as well as end of life recycling.

The deeper understanding of how DfD affects the lifecycle of a product beyond its recyclability points at the potential for innovation in applying this approach. While DfD can enable ease of recyclability, for a product designed for end of life to replace its existing counterpart it needs to offer significant improvements (Tonkinwise, 2014:207). In this way the corollary benefits of a DfD approach in terms of functionality or user engagement can provide this attraction to a redesigned object.

This section mainly responds to the first aim of this research “Understand the current state and potential for DfD in designing textiles for recyclability”, the case studies and their use in direct visualisation have been the main method used to create this understanding. This section shows how a design-led understanding of the field based on the analysis of existing concepts and projects can be translated into recommendations for future design. The articulation of the five categories of DfD produced one-word briefs which will guide the practice in the next stages of the research which rely on creative textile design practice and experimentation as described in further chapters.

This chapter has therefore provided an understanding of DfD which goes beyond current conception and is adapted to its appropriation by a new generation of textile designers who are eager to exercise their creativity in ways which do not impede material recycling. In laying out the current state of the art in DfD, it has positioned the work carried out in this project and given the tools to initiate experimentation with the concepts of DfD for textiles.



5. Understanding Blends

In this second phase of part 2 focuses on making, and on the perspective of a creative textile designer to offer an understanding of the characteristics of problematic blends. These approaches are used in combination with the elements already described in relation to recycling systems. Through the translation of existing classifications of materials, and the making and mapping of blend models, the first steps in the guidelines for TDfD are defined as the need to articulate the scale and functions of the components in the new material combinations. This builds on the classification of case studies presented in chapter 4. While the DfD categories were based on an understanding of the aim of the disassembly, in this chapter, the scale of the components which come apart is interpreted in relation to textile blends which are the main issue addressed in this study.

5.1. Defining Blends

Materials combining different fibres, such as a flax warp and a cotton weft, can be traced back as far as 150 B.C.. Blends continued to be used through to the 18th and 19th centuries, mainly as a way of reducing costs through the combination of a cheap yarn with a more luxurious one (Hatch, 1993:229). With the development of synthetic materials, the drive to decrease costs and increase performance led to the combination of natural and synthetic fibres. With a large variety of available fibres, blends are used for many different outcomes concerning performance, aesthetics, or a combination of both. These blends now challenge the effectiveness of recycling in a circular economy.

While no extensive investigation of the proportion of blends in waste textiles has been identified here, some studies carried out to provide targeted understanding of waste streams show results which are relevant to this study. Ward et al. (2013) have reviewed post-consumer waste from the salvation army to find 36.2% of their sample was made of a combination of different materials. Similarly the Dutch Clothing Mountain report (Maldini et al., 2017) found that 37.3% of their 200kg sample was made of a mix of fibres. However this number doesn't account for the 32% of the total for which the labels were missing and which could therefore not be identified either as a blend or a mono material. This type of challenge is common in surveys of textile waste. These are also often geared towards specific outcomes. For instance the Fibersort (Interreg and Fibersort, 2018) analysis of one tonne of waste textiles focused on non-re-wearable garments, which gives different results. Overall it can be agreed that the proportion of blends in textile waste streams, while not an overwhelming majority, is significant enough that it should be addressed as part of the problem. This work focusses specifically on this part of the textile waste issue, and even within this, addresses primarily the creative drive to blend resources.

The description of unrecyclable blends as the issue that this research aims to tackle offers insights which guide further exploration of solutions. This section first offers a definition of these blends which outlines the scope of the research.

5.1.1. Blends in the Context of this Study

To define the context of blends from the design-led perspective taken in this work, this section offers a comparison to other existing approaches such as that of engineering. In a similar way to the review of DfD strategies laid out in the previous chapter, alternative design-led approaches are used to draw insights that feed into the practice and exploration of solutions to unrecyclable blends. This highlights the specifics of the design stance which will be taken forward in the practice.

Blends for problem solvers in an engineering context

Questioning blends from a design perspective is a relatively new and under-explored approach. The review of literature carried out here showed a range of descriptions of blends, whether from an scientific characterisation perspective (Hardingham, 1978; Hatch, 1993) or from an environmental review approach (Beton et al., 2014; Horrocks and Davies, 1996). However, this study did not identify any descriptions which expressed the designer's visual and tactile experience of materials. Furthermore, the gap in understanding blends also exists at the intersection between a design-led understanding of materials and a description of their recyclability challenges. To explore how design may offer an alternative to current problematic blends, the first step has been to understand and translate the engineering perspective to a design-led approach which may offer a complementary perspective.

Sinclair's list of reasons for the creation of blends in textiles matches closely other similar rationales across the literature (Hatch, 1993; Erberle, 2004):

> "1. To compensate for weaker attributes or properties of one type of fibre
> 2. To improve the performance or the resulting yarn or fabric
> 3. To improve or provide a different appearance
> 4. To improve the efficiency of processing, especially for spinning, weaving and knitting
> 5. To reduce costs"
> (Sinclair, 2015:4).

This list, as other rationales found in the corresponding literature, is strongly weighted towards the technical drivers for the combination of resources. The seeming repetition between points one and two, and to some extent point four, indicates the emphasis on the technical aspects of blends.

The main reasons for the combination of different materials are based on technical or functional requirements. Consequently, many descriptions of blended materials concern textiles found in areas such as in civil engineering, medical textiles, the automotive industry, or what is generally referred to as technical textiles (Hardingham, 1978; McQuaid, 2005).

Textile composites are such an example: these are generally composed of a matrix made from yarns or filaments and a binding agent which is usually a polymer. The aim of the combination of these elements is to compensate for weaknesses in each element with the strengths of the other and overall to achieve a low-weight/high-strength balance in the material (Saravanan et al., 2017). This research focusses on soft textile materials which therefore excludes most of these hard composites. Their equivalent in the limits defined by this study are laminated and coated textiles which present similar characteristics to composites. Here the fabric base is covered in a sheet or layer of polymer coating which confers new properties to the combination such as strength or water resistance (Fung, 2002). These two types of material combinations are amongst many examples showing how resources are contaminated by each other in the process of achieving higher performances.

It seems particularly relevant in the framework of this study to understand the design approach to materials such as laminated or coated fabrics as they have been identified as barriers to recycling in the initial context review (see 2.3.2 p.56). The barrier between technical and aesthetic requirements can sometimes be thin, and this understanding of blends suggests a cross over which will enable a new angle through which to tackle the issue.

Given its focus on a design perspective, this research emphasises the importance of point three in Sinclair's list, which relates directly to the aesthetic. This is generally an aspect that is considered to be mostly the designer's responsibility. A note for the value of blending in providing for better quality or handle in textiles is also added to the appearance focussed characterisation suggested by Sinclair. This is where the designer's impact in creating un-recyclable blends mainly lies. However, the different reasons for blending materials are usually combined, and any attempt to challenge these must look at their full range. Blends are currently seen as a necessity to fulfil technical functional requirements (Beton et al., 2014; McQuaid, 2005), this research challenges this status quo, and while not dismissing the importance and usefulness of blended materials, acknowledges them as a form of luxury which may only be afforded by rethinking ways in which they are made so as to lift barriers to end-of-life recyclability.

Blends for textile designers

Bisociative textile design has been identified as a key agent in the creation of blends; the designer's creativity is expressed through the combination of materials for colour or texture effects (Dormer, 1997; Igoe, 2013). This complexity, while still posing problems for the integration of textiles in a circular materials system, is nevertheless a feature which seems important to the field and deserves to be maintained. As Fletcher states, a simplification of the field of textiles towards mono-materiality "could promote inappropriate (and wasteful) use of fibres and encourage the increased dominance of monoculture plantations of fibre crops like cotton, with a significant environmental burden" (Fletcher, 2008:33). What's more, true sustainability "banks on diversity" (Benyus, 2002:7), and a path to resilience should move away from the current reliance on a small range of resources and on mono-culture.

However, the gap between the creative approach to blends and the issues they create for recyclability from a technical point of view is yet to be bridged. For designers to develop potential solutions to recyclability issues, the information concerning blends and recycling must be made readily available and embedded within their practice so as to eliminate recyclability barriers from the very beginning of the process. An understanding of these issues as relating directly to the familiar process of design therefore needs to be developed (Royal Society of Arts and Innovate UK, 2016; Vuletich, 2015).

This study suggests a translation of the current engineering approach to blends through visualisation and making. Designers' skills often rely on a hands-on understanding of materials and shapes, employing prototyping or sketching as a way to evolve ideas (Brand, 2017; Brown and Katz, 2009). Therefore, the quantitative data provided by technical approaches to materials fits badly within these processes. By highlighting the relevant information from a design perspective, the visualisation can have a strong impact on how well the information can be taken on board in the design process. This ease of communication and accessibility of the data is an important part of the design thought process (Earley and Hornbuckle, 2017:13). Indeed, it has been shown that language barriers between sciences and design can hinder progress on both sides. Bridging this divide can therefore enhance the potential of both disciplines to provide solutions to a problem such as blend recyclability. This study therefore aims at offering a translation as understood by Baule and Caratti so that "through the translation paradigm it is possible not only to generate new expressive interpretations, contaminations, simplifications or expansions of meanings, but also define tools and methods capable of dealing with a world that is always more inter/multi/trans-cultural and inter/multi/trans-media."(Baule and Caratti, 2016:201). The analysis of the recyclability of blends is therefore carried out with this transformative design approach in mind, considering how blends are the result of assemblies which are aimed at creating original textures or patterns in a bisociative process.

Blends for recycling

This work draws on an understanding of blends which combines technical considerations with the creative drive that underpins them. It suggests a focus on the way in which this creative approach to blending impacts recyclability. In this framework, a blend is therefore a combination of resources which do not belong in the same waste and recycling stream. These could be based on the distinction between the biological and technical cycles described by Braungart and McDonough (2002) or extend to context specific streams which depend on the equipment and requirements of a given recycler.

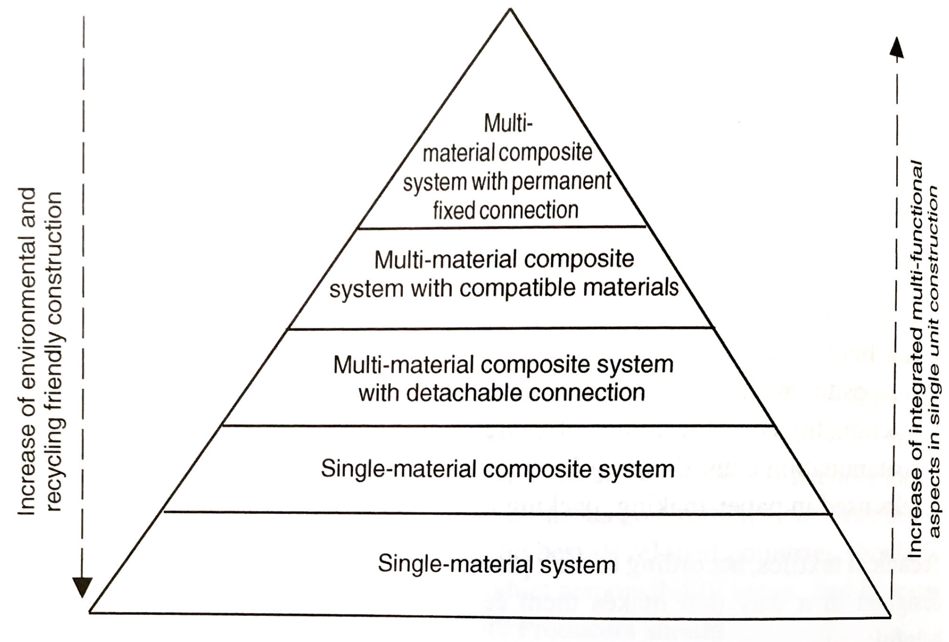
These blends can for example be made of a majority of recyclable fibre but with a contaminant which prevents its recovery such as a cotton base with elastane. They could also be materials made of resources which are individually recyclable, such as polyester and cotton, but are recovered optimally in different systems such as a mechanical or viscose process for the cotton and a synthetic polymer chemical or a melting and re-spinning process for the polyester. If considering these materials for recycling, these types of combinations therefore need to be avoided and replaced with another approach which allows for similar benefits but without the barriers to recycling.

TDfD is explored as a potential solution for blends to be designed for recycling. This requires a new understanding of materials and of their combinations. This section of the study then suggests an understanding of blend types which may lead to alternatives that can fit better within existing and emerging recycling systems.

The approach taken here therefore combines the problem-solving approach of engineering with the aesthetic and tactile focus of a designer's take on materials while aiming for better recyclability.

5.1.2. Translating Gulich's Hierarchy of Textiles for Recycling

As of the start of this research project, the main reference concerning a review of textile for recycling was Berndt Gulich's chapter in Recycling in Textiles titled "Designing Textiles that are Easy to Recycle" (Gulich, 2006). Gulich's work lays out a framework to understand the impact of material complexity on recyclability. This study expands the understanding of designing for ease of recycling based on the classification suggested by Gulich adding a creative textile design approach to the issue. This section studies this classification to translate it to the practice explored in this work.



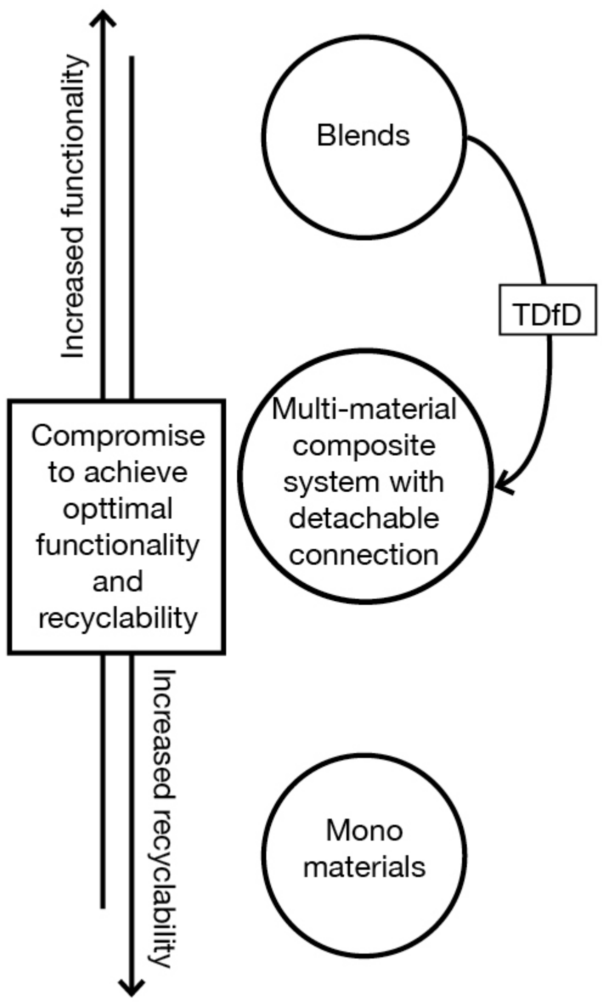
5.1. Gulich's classification of blends according to ease of recycling (Gulich, 2006)

Levels of ease of recycling

In Recycling in Textiles, Gulich (2006) describes the various degrees of ease of recycling in materials. As shown in figure 5.1. this classification separates materials into 5 categories according to the complexity of their composition and how this may affect the potential for recovery of the resources. These range from "multi-material composite systems with permanent connections", the most difficult type of material to recycle, to "single-material systems", the easiest to recycle. One of the most interesting aspects of Gulich's ranking for this study, is that it does not rule out entirely the categories that are harder to recycle. Instead the point of view acknowledges the trade-off between simplification for recyclability and functional performance. In the case of simpler mono-materials, allowing for easier recycling, some of the functional aspects of the combination of different resources are lost. Thus, the need for diversity and complexity is acknowledged, supporting the focus on maintaining the benefits of bisociative blending that permeates this work.

Interpreting Gulich's categories

From the point of view of the textile designer however, this classification seems very abstract, and while it provides broad categories, it does not describe the materials within them. This study therefore aims at



5.2. Roadmap for designing ease of recycling in materials, adapted from Gulich (2006).

complementing Gulich's work by providing an interpretation that draws on textile design based experiences of materials.

Gulich's diagram is interpreted as a roadmap in this study, an outline for a shift from the currently challenging category of "multi material composite systems with permanent fixed connections", which are what this work qualifies as textile blends, as translated in figure 5.2., to categories which are easier to recycle. However, this study does not suggest that this ease of recyclability should be achieved by shifting to the other extreme category of "single material systems", or mono materials. Rather, this research acknowledges the trade-off between functionality and recyclability which is identified by Gulich and offers a compromise in the form of multi-material systems with detachable connections as a target which can be achieved through TDfD.

While Gulich's original representation of recycling-friendly constructions takes the shape of a pyramid diagram with the 'multi-material composite systems with permanent fixed connections' category at the narrow top of the diagram, representing the fewer possibilities for recycling and the need for this category to be reduced in future design, the representation given in this work focuses on the direction to follow for increased recyclability. The translation of Gulich's pyramid shown here does away with the intermediate categories to focus the attention on the parameters of this work. Following Tufte's (2006) approach to information visualisation, the emphasis is put on the information relevant to a textile design approach and other parameters are filtered out for better comprehension.

One of the crucial elements maintained from Gulich's diagram is the acknowledgement of the reverse relationship between functionality and recyclability. Rather than move towards a wider use of easy-to-recycle, low-functionality mono-materials, this diagram and this research suggest that both aspects can meet half-way in the category of multi-material composite systems with detachable connections which would include materials that are designed for disassembly along the lines defined in this work. The notion of functionality expressed by Gulich is understood as including aesthetics and desirable tactile qualities in the outcomes of a creative textile design process.

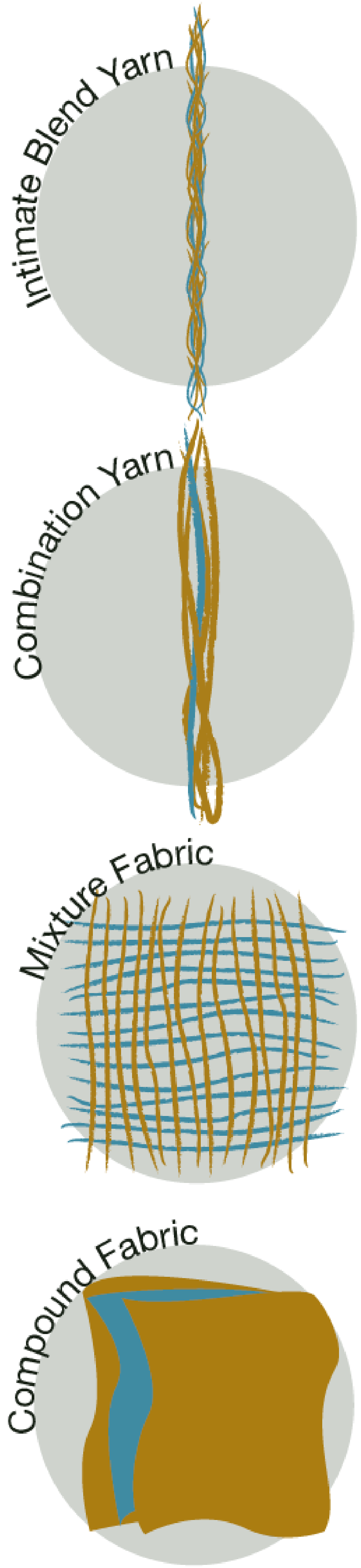
The shift from blends towards multi-materials systems with detachable connections is suggested through a TDfD process in this study. The redesign process is therefore geared towards this transition. The starting category of blends is however still very broad and to enable an effective shift from this problematic approach to material combinations, the specificities of this type of textiles need to be better understood. The research laid out in this chapter therefore suggests adding nuance to this understanding of blends.

5.1.3. A Textile Designer's Definition of Blends

To describe in more detail the specific type of blend which this study aims to redesign, an exploration of the different scales, techniques and types of blends was carried out to inform the TDfD process.

Scales of assembly

One of the principal barriers to a comprehensive visualisation of blends lies in the immense variety of blend types spread over different levels of material construction. In this study, blends are defined as the combination of two or more different fibres in the same yarn or cloth with the fibres



5.3. Types of material combinations (adapted from (Hatch, 1993)

differing in colour or fibre type (Hardingham, 1978). This broad definition is detailed by Hatch (1993:299) and interpreted in figure 5.3. by classifying these blends into four types according to the level of intimacy of the blend.

• The first type is intimate blends, combining different fibres spun together within the same yarn.
• Next comes combination yarn, made of several different strands of mono-materials spun together into one yarn.
• Then mixture materials, combining different yarns within the textile structure, such as in a plain weave in which the warp and the weft are different or in the case of stripes in a jersey knit.
• The last type is compound materials, made of different layers of fabric which are stitched together or combined with adhesive.

Of course, these categories are porous, and a mixture material may be made of a combination of intimate blend yarns and of mono-material yarns for example. However, classifications such as this provide insights to the structures and processes involved in a wide variety of material types, and while they touch briefly on the matter of sustainability, a review of the causality between material combinations and recyclability has not been identified in this work.

This research explores Gulich's classification further and questions the complexity within the main category of multi-material composites. While these materials are described by Gulich as blends with permanent connections, they are not characterised according to the nature or the scale of these connections. When experiencing materials through the activity of textile design, the various levels of textile construction become apparent. In the choice of yarn, of weave or knit, or through the finishes applied to the fabric and even into the premises of the development of a product, the complexity and intimacy of the blends increases at every stage.

This expansion on Gulich's classification of types of blends looks further into the nature of the connections between different materials. It considers the different elements that the designer may be manipulating while creating new textiles and describes this process of blending from a textile designer's perspective. The initial distinction between four levels of blends: intimate blend yarn, combination yarn, mixture fabric, and compound fabric as shown in figure 5.3. is taken forwards in a creative textile design-led understanding of blends which is carried out through making.

Different disassembly approaches: chemical, mechanical, manual

In the same way that the textiles described in Gulich's categories challenge recycling to varying degrees, the scale at which the blending occurs may also imply different paths to the recovery of the raw materials. Hence a better understanding of these differences seems necessary to developing the ways in which the various elements may eventually be recovered.

As described in previous points, the preliminary stages of this project aim to position the textile designer as a key agent in solving blend recyclability issues. The notion of scale takes an important role here, as some levels will be more difficult to access from a design perspective and less prone to being challenged in creative design practice. Understanding where the connections which hinder recyclability occur also leads to envisage how they may be modified to allow for optimal recovery. These different levels suggest different strategies, since a molecular, yarn or fabric scale all involve different sets of skills.

Based on the understanding of blend types in relation to recycling processes and technology described in chapter 2 (see 2.3.1. p.49), three levels of disassembly can be described. The first is a chemical disassembly such as the Worn Again process in which materials are dissolved or depolymerized to some extent to allow for the recovery of the separate parts. Next is mechanical disassembly; the shredding that occurs in mechanical recycling processes, while this does not discriminate between different types of materials in the field of textiles, the same process in conventional plastic recycling separates different types of materials. This translation between the fields could lead to future technological developments. Last comes manual disassembly, which is considered the least cost effective in current systems. This is where the bulky and non-recyclable elements such as zippers have to be cut out by hand. However these three categories connect one to another, indeed a manual process often precedes an mechanical shredding, which in turn would come before any form of chemical dissolution (Sandin and Peters, 2018). It is therefore crucial to understand the scales at which various combinations occur so as to challenge the current time and resource consuming model and design for ease of disassembly at all levels. The review of the current system shows the ways in which blends cause barriers and points to the opportunities for TDfD. Blends must therefore be redesigned to fit within these processes or allow for optimised versions of the existing methods for disassembly for recycling.

This understanding of blends aims towards a better allocation of the design skills available in this research so that the redesign process may provide insights for the effective application of TDfD principles to creative textile design. This review of blends is carried out with the end of life challenges which have been identified in the early scoping stage of the research in mind, so that solutions may offer appropriate circular design strategies for textile combinations.

5.2. Mapping Models of Blend Archetypes

In keeping with the practice-led approach of this research, the deeper understanding of blends, of the scales at which their elements are combined, and the techniques used in these combinations, was achieved through making. Twenty-one 3D schematic representations of commonly encountered types of blends were made (see figure 5.4. p.128) and then used as representations of these archetypes in a mapping of the field (see figure 5.15 p.132) in order to pinpoint which type would best be addressed in the context of this research.

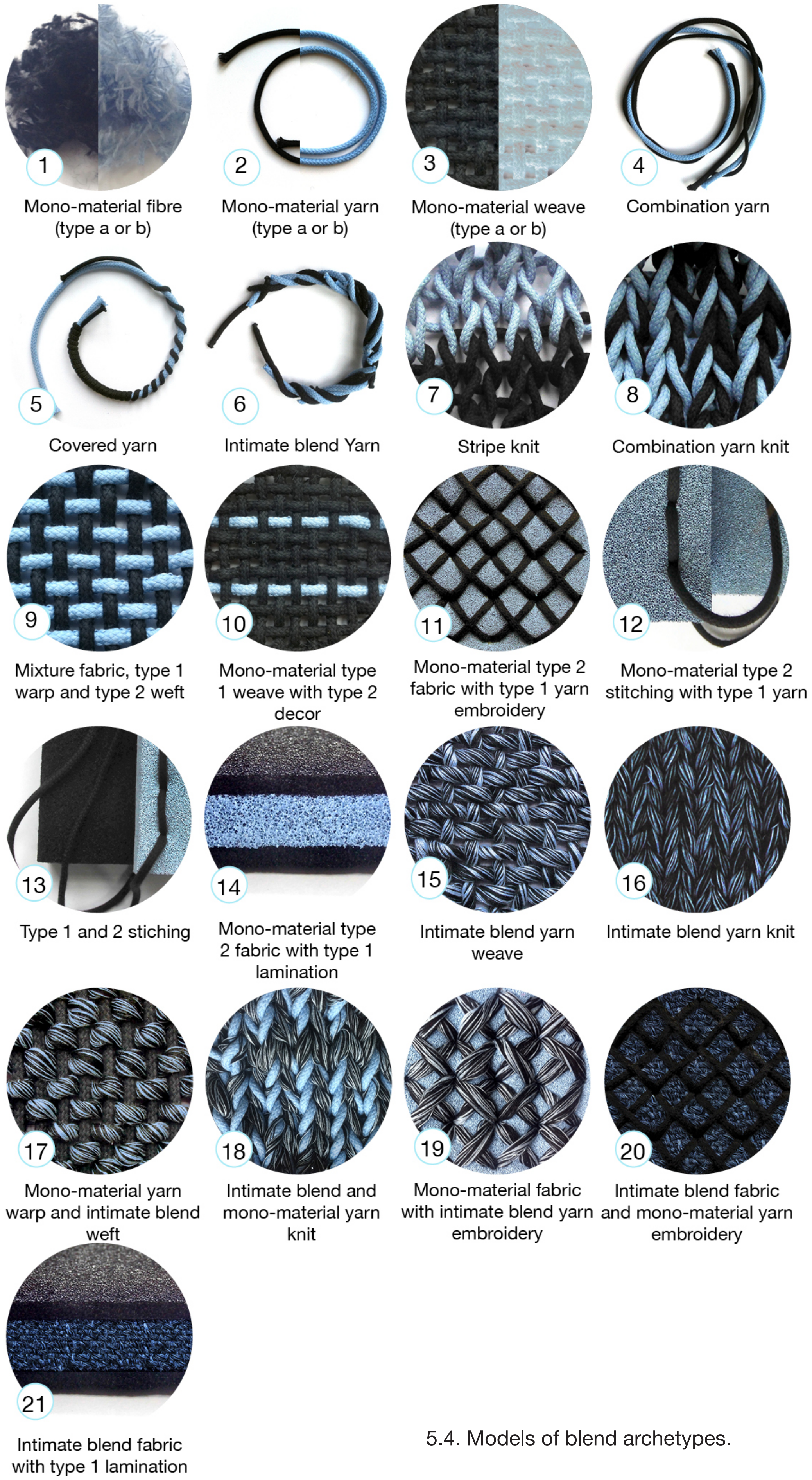
5.2.1. Making Models to Understand Blends

The research presented in this phase of the scoping was initiated as the production of an exhibit to describe the ongoing research. The representations of blends, which were made to communicate the issues in this field to the public, led to a series of insights regarding the mechanisms involved in blending, and went on to be used in a key step to understanding the problem.

Making to understand types of blends

By drastically enlarging the scale of the materials, yarn that would, in the original textiles represented, be but a fraction of a millimetre in diameter is now shown as a seven millimetre diameter cord. This blown-up vision of textile structures represents how materials are linked, highlighting the connections between fibres, yarns, finishes and fabric. The simplified schematic representation of the blends also focuses only on the issues at hand. Colour and structure are entirely aimed at clarifying the understanding of blends. The binary colour code allows for an abstract visualisation, on which different types of resources can be projected. As this study is guided by a questioning of the role of the designer; rather than purely drawing from science-based or quantitative data, the samples are drawn from the tacit knowledge and experience (Polanyi and Sen, 2009) of different archetypes of textile construction as a textile designer.

The act of making is central to this process and represents a key phase of the overarching methodological framework. It helps represent the tacit understanding of blends through the visualisation of the intricacy of their structure. To take the visualisation further into the area of creative textile design, the schematic sketches used to represent different types of blends in figure 5.3. were made into 3D models that replicate the types of connections and levels at which they occur in archetypal blends. Beyond representation, the creation of these models meant that the action triggered reflection regarding the intricacy of the connections. The visibility of the different combinations of elements forced a form of estrangement from the familiarity of textile assembly a designer might be



5.4. Models of blend archetypes.

accustomed to. For instance, this enlarged scale makes the path taken by the thread in a simple cross-stitch pattern very apparent while it would not necessarily be noticed at the normal scale of fabric and thread. This therefore leads to the question of how this path can be reversed, and the stitch undone, if the materials belong in different recycling processes.

Making to understand connections

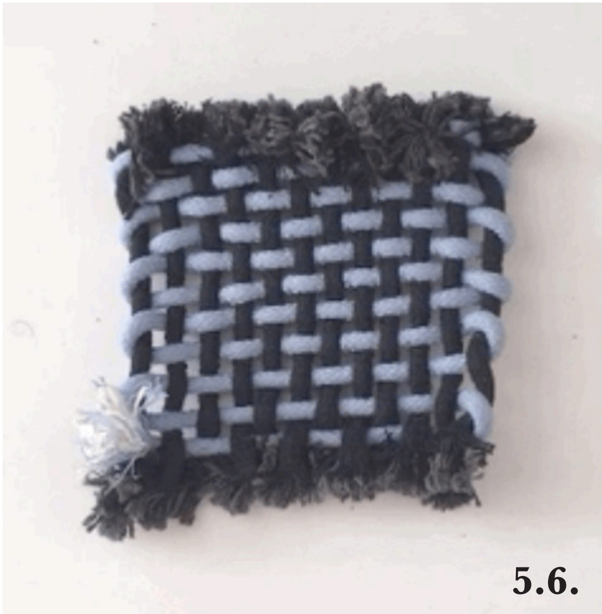
The challenges in the act of making therefore led to reflecting on the potential difficulty of un-making which is the focus of the overarching research. Indeed, the aim of the redesign process here is to offer alternatives to the connections which prevent the recyclable components of materials combinations from being recovered at the end of life. Being confronted with the challenges of tight or multi-layered constructions in blends archetypes thus enables a better understanding of the challenges at hand.

This visualisation therefore serves the purpose of presenting these challenges to a textile design audience with the visual and tactile vocabulary which is built in to the practice. Moving away from the current approaches taken from an engineering point of view and putting the designer's experience at the centre of this understanding of blends, it attempts to untangle the characteristics of combinations which currently prevent recycling. It shows how complex the field is, and suggests a first stage of breaking down the problem following design methods, which can lead to the first iterations of solution suggestions (Cross, 2011). The set of representations shown in figure 5.4. and figures 5.5. to 5.14. do not suggest an exhaustive list of blend types. Rather they show the materialisation of a range of blend archetypes which can provide a more detailed understanding of the complexity of the field in order to target the redesign process.

5.2.2. Mapping Different Levels of Blending

These blend archetype representations were then photographed and used to build a diagram which maps the field of blended textiles and highlights opportunities for DfD. These blends models are typically what Manovich (2011:36) describes as partial representations. Indeed, they show a textile as a recognisable image rather than a graphic point, however these images are simplified to represent only the elements relevant to the study, in this case types of blending.


5.5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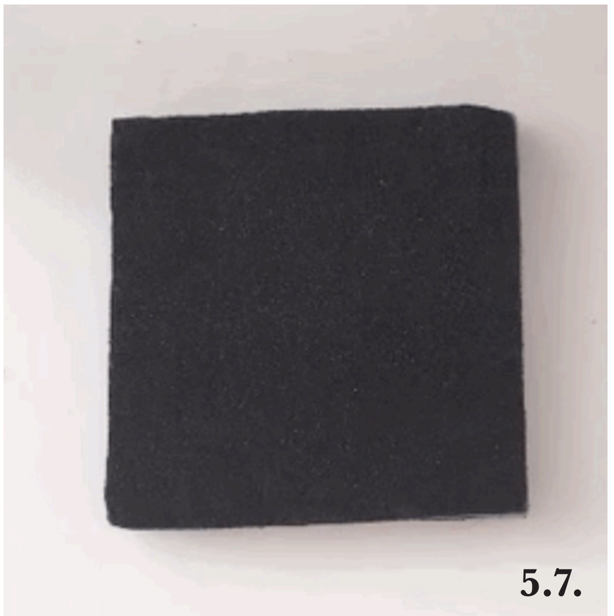

5.7.


5.8.


5.9.


5.10.

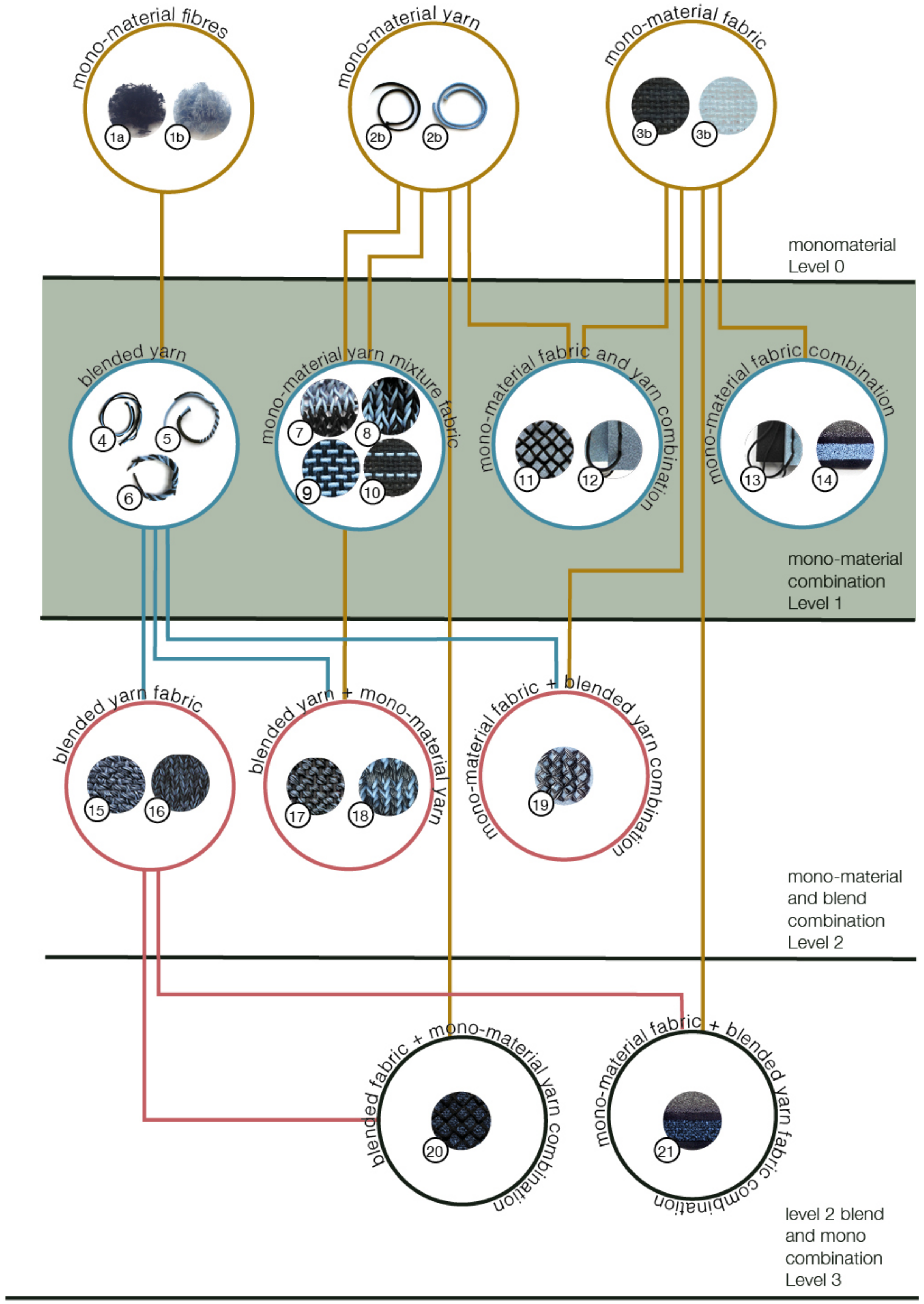

5.11.


5.12.


5.13.


5.14.

5.5. to 5.9. Stills from videos showing the models of blend archetypes, starting with the views that relate to the pictures used in the mapping.
5.10. to 5.14. Stills from the videos with manipulations to show the material qualities of the models. All videos are available to view at https://portfolio.arts.ac.uk/project/45611-models-of-blend-archetypes/



5.15. Hierarchy of blend archetypes

The aim of this phase of the redesign process is to understand how complex materials can be returned to a simple or mono-material form through disassembly to increase their recyclability, the blend models were analysed by considering how many times different materials had been combined, and associating this to the number of theoretical steps that would be needed to return to their most recyclable state.

Creating a hierarchy of blends for recycling

The use of material elements such as yarn in colour a or b, of the mixed yarn used to represent intimate blend yarn or of the foam used to represent mono-material fabric in larger scale assembling techniques such as stitch or lamination makes the distinction between these types of blends clearer as well as it informs a classification which highlights the interconnectedness of these types of blends.

The mapping of this hierarchy shows crossovers between the different levels of intimacy in blends and the different types of connections involved. The creation of samples to visualise these elements articulates a new classification, closer to the requirements of a design-led understanding of recyclability for blends. The three levels highlighted in figure 5.15. show different grades of blending. Level 1 combines mono-materials. Level 2 describes combinations which can be made of a mono-material and a blend made of two mono-materials, or two elements both made of a blend of two mono-materials. Level 3 describes combinations which can be made of a combination of level two blends and any other material. At each level the number of stages of disassembly that would theoretically be necessary to take the mono-materials apart increases.

The relationships between blends described through the classification of the samples highlights the different levels at which the combination of resources may occur, and therefore require different approaches in the exploration of solutions. Indeed, the level of intimacy of the blends may be seen as expressing different characteristics expected in blends. While some blends such as stripes in knits may be pattern-led and focussed on the aesthetic qualities of materials, other more intimate blends such as yarn with a technical core material may have a more function-focussed approach. This understanding of blends aims to clarify the motivations and impacts of designers when combining different resources so that this can effectively be replaced with TDfD strategies.

Most importantly, the different levels in the classification highlight the number of hypothetical stages necessary before returning to a mono-material. Indeed, these can be seen as the path that the materials would need to take to return to a pre-blend state in which the resources have not yet been contaminated and can still be returned to an optimal recycling stream. This suggests a form of retro-engineering, in which the end of life state, in this case a mono or otherwise recyclable material, is taken as the starting point in the design process. This understanding of the process of blending aims to untangle the mindset associated to textile combinations in order to provide a reverse engineered alternative through TDfD.

5.2.3. Identifying the Potential for TDfD at a Targeted Blend Level

This hierarchy of blends has shown the different levels of complexity in existing blend archetypes from a designer's perspective. This fills the current gap in knowledge by offering a more detailed understanding of the issue of blends from this point of view. As presented in the DfD case studies, the notion of the scale of disassembly is essential to this strategy. The skill set drawn on in the craft based creative textile design approach taken in this work relies on a tactile and visual understanding of components, this therefore excludes some types of blends and corresponding disassembly and recycling strategies. The mapping of these blend archetypes has thus allowed to better qualify the remit of this study regarding levels of blending.

Applying designer skills to blends

Visualising the different levels at which non-compatible materials may be combined pinpoints where the skills of a creative textile designer may best be put to use. As mentioned in chapter 3 (see 3.2.2. p.71), the practice of textile design involves manipulating materials in an intuitive way, tinkering with thread and fabric, testing new ideas through prototyping, and assessing the success of these experiments through the aesthetic and haptic qualities of the materials. In these approaches to textile design, the materials that are combined are first understood and valued for their own qualities before being integrated into combinations. This material combination can in turn be seen as reflecting the individual characteristic of the mono-materials involved in ways which allow them to be still be recognised in the final textile combination.

These types of combinations are grouped in the first level of the classification highlighted in grey in figure 5.15. There the different types of combinations suggest that each individual material is still visible or can still be felt in the final outcome. This is as opposed to a yarn in which fibres have been blended at a level that is not visible to the naked eye anymore. This understanding of the field has led to a more precise framing of the types of problematic blends that will undergo a redesign process in this study. The main criteria therefore concern the perception by the designer of the intrinsic qualities of the components in the blend at the moment of assembling them. When considered in relation to the two types of blends which were identified as major challenges by experts in the field of textile recycling: stretchy and laminated fabrics, this means that the qualities offered by the blend of different materials are perceived as adding aesthetic or tactile value to the whole rather than hidden technical properties.

The exploration of DfD strategies in blended textiles therefore focusses on this level of components, suggesting assemblies such as described by Dormer (1997) combining materials with contrasting qualities for surprising effects. This exclusion of technical and small-scale blends as beyond the remit of this work also narrows the types of disassembly paths that will be explored. As stated in section 5.1.1. (p.116) approaches such as a chemical or mechanical disassembly would be connected to the scale of blends which relate least with the designer perspective taken here. This approach to TDfD therefore moves away from the current technical literature on the subject to take on a craft-based approach which aims at uncovering insights which will provide a new mindset for the creation of multi-material combination systems with detachable connections as defined by Gulich (2006).

This design-led understanding of the components which enter a combination is crucial to the following stages of the research. Indeed, it pinpoints the criteria for the building blocks of new TDfD combinations.

Scale of blends and TDfD

This classification showing the path taken from mono-material to blend aims to enable the targeted development of strategies for design for disassembly to achieve the aim of returning from a blend back to a mono-material for ease of recycling. Here again, the notion of scale, or size of the elements in the combination, is central. It questions the size and type of the building blocks in textiles that are designed for disassembly. In combination with the insights regarding DfD from chapter 4, the scale of components may lead to different type of full or partial disassembly which have impacts on user behaviours.

In exploring DfD strategies in the case studies, a majority of the examples were found in fields such as architecture, furniture and product design, thus combining different elements at the scale of woodwork techniques or other assembly devices such as replacements for nails and screws. This revealed a partial absence of such strategies at a scale that can be related to textile techniques, except in the case of the soluble threads as with Climatex's textile lock or the Wear2 microwavable thread. Experimenting with these over-sized representations has therefore bridged the gap between the examples of DfD studied and the implications of textile constructions. The methodological structure is used here, allowing the scoping and making phases to feed into the mapping of blends, which the reflection process draws on to provide insights for the field. This understanding of the scales of blends and the repercussions they would have on a TDfD redesign process thus followed the sequence of methods laid out in chapter 3 (see 3.2. p.68).

As further detailed in the following sections, the exploration of TDfD is carried out by questioning traditional textile construction in samples and garments (see chapter 6 and 7), experimenting with assembly techniques which are derived from product design and manufacturing as observed in the case studies. These later experiments build on the findings from this phase of understanding blends.

Insights for the scale of components in TDfD

The understanding of the issue of blends which is afforded by this review of existing combinations takes a first step towards developing alternatives in a redesign process. Through understanding the existing status quo, the building blocks for the development of a TDfD approach can be laid out.

The mapping in figure 5.15. suggests three types of Level 0 mono material or recyclable components which can be returned to for recovery and recycling. The different types of elements that can be combined in a

blend were thus defined as:

- Fibre
- Yarn
- Fabric

These are used as the starting points in the creation of material combinations for disassembly in the next stages of the work (see chapter 6). These scales are used in conjunction with the description of problematic blends articulated in the context of recyclability. In the same way that existing scales of blends are understood to guide the redesign process, the characteristics of blends which currently act as barriers to efficient recycling; elasticity and coating, are taken as a starting point for the exploration of TDfD.

These two blend types relate directly to the scales defined in this stage as elasticity occurs at the fibre or yarn scale, and coating is usually a finish applied to the fabric scale. Using these elements as the building blocks for the creation of TDfD material combinations, the scales will be adapted to fit the requirements of the design briefs.

This leads to the first stage for TDfD in which the components of the combinations are defined. These are initially selected according to the problematic blend which is the starting point for the redesign process, and can then be revised in the iterative experimentation with TDfD techniques and product contexts. In the framework of this exploratory process, the three scales were experimented with to test a range of assembly and disassembly techniques as will be described in the next chapter.

5.3. Conclusion: An Understanding of Blends for Redesign through TDfD

Building on the review of existing DfD approaches proposed in chapter 4, this section defines the framework through which blends are redesigned in order to achieve better recyclability. This fills a gap in approaches which take a designer's perspective to blends in relation to recyclability. In building on connected fields in this area, the expanded understanding of this issue can lead to better targeted design solutions.

Building on Gulich's classification

This section of the study has added nuance to the existing breakdown of material types suggested by Gulich's (2006) classification, considering the layers of complexity inherent to textile constructions. Where the original representation of blends according to ease of recycling showed broad categories describing "systems", the understanding of blends for this research suggests an approach which relates blends to the haptic experience of handling textile materials. It seems crucial to fill this existing gap in knowledge and add this layer of understanding to the concept of blends. By describing the complexity of the field in more detail, a more accurate solution in terms of recyclability can be tailored to the various types of blends.

Description of blends from a designer's perspective

This study and classification of blends focusses on a textile design approach, using the tools that are specific to this discipline for a more direct applicability of the concepts drawn from the mappings into creative textile design practice. The making is central to the translation of the understanding of blends from a functional and technical perspective inherited from engineering. This enabled a visual and tactile understanding of the issue. While this form of material visualisation pre-forms ideas for the solutions which will be later expanded on, it is also an effective means of communication of the problem to a broader design audience.

This emphasis on the design perspective through the hierarchy of blends has identified the level at which creative textile design skills can be most appropriately used to suggest solutions. Indeed, it identifies the most complex types of blends, which are removed from their mono-material origin by several levels of combination, as beyond this expertise and narrows down this study to the exploration of alternatives to the first level of blending presented in the hierarchy of blends. This level is the one in which the materials are combined with a design, or aesthetic focus. This understanding frames the description of specific blends such as stretchy and laminated fabrics as defined in earlier research stages, within the textile design-led approach defined in this study. This in turn will enable the exploration of solutions to this type of problematic blend.

Using this design approach, the visualisation and questioning of different types of blends with a focus on scale has moved the focus of this work away from intimate blending as it was identified as beyond the scope of this research. Instead the work is deliberately geared towards what is described as material combinations; where the different elements that are combined are still visible in the final material.

Insights for TDfD

This phase of understanding the issue is a crucial part of a redesign approach to a circular design challenge. In placing the designer's perspective at the centre of the sense-making process, new methodological frameworks have been tested and presented here. The use of making is central to the subsequent mapping as a way of representing connections in blends as they appear to a designer in the tacit-knowledge rich act of creating bisociative combinations. This body of work highlights the value of the four steps of the methodological model presented in chapter 3 to draw insights for circular design challenges.

The scales which are proposed as the mono material or recyclable building blocks for new TDfD material combinations are also demonstrated in the visualisation of blend archetypes. This redefines the ways in which they are combined to achieve the effects which are presented in the current problematic blends without compromising recyclability.

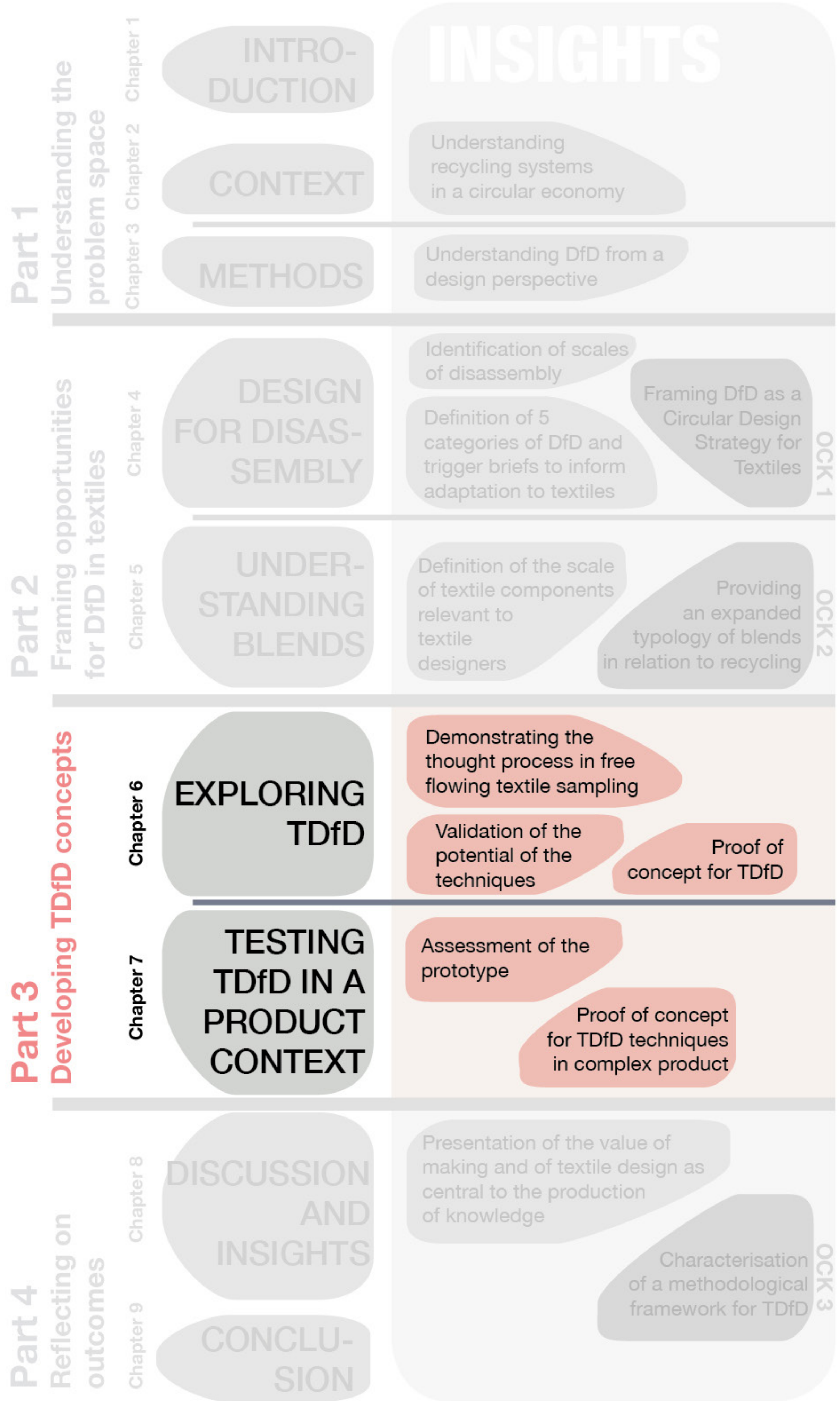
This combination of visualisation with textile design practice as a means of understanding blends has highlighted the first step in the redesign process for blends currently acting as barriers for recycling. Based on the findings laid out in this chapter, the first step when setting out to design material combinations for disassembly in a circular economy is to identify the scale and the function, whether technical or aesthetic, of the elements which compose it. This leads to the first stages of experimentation with TDfD as a potential solution to blends as barriers to effective recycling. The translation and expansion of Gulich's classification of materials for ease of recycling therefore sets the main goal to achieve in subsequent exploratory textile design practice.

Summary of Part 2

Part 2 has contributed to the understanding of both blends and of DfD as a potential circular strategy to solve the problems they cause to effective recycling. Some key contributions to the field have been laid out here and will feed into the next sections of the work.

Firstly, DfD has been articulated as a circular design strategy in a way that allows it to feed into textile design practice and highlights the current gaps in the exploration of this approach. The categorisation of case studies has reframed the concept and shown its potential for innovation beyond raw material recovery. The five categories and associated DfD briefs, or creative triggers, will directly influence the following phases of making.

Second, a textile design-led understanding of blends in regard to recycling challenges has been built from Gulich's initial framing of this context. This presents the redesign task set out in this work as shifting material combinations with permanent connections, to detachable connections, in order to benefit from the combinations in terms of function and aesthetics without preventing recyclability. Furthermore, this section has added both nuance and depth to the description of the category of blends set as the problem and narrowed the scope of this work to treating material combinations rather than intimate blends.



Part 3

This section uses creative textile design to test the findings from the previous parts of the study and provide proof of concept for materials and products using TDfD strategies. The work builds on the in-depth understanding of the issue of blends and of the opportunities available in DfD strategies developed in previous sections to adapt techniques from the inspiration phase to the author's creative textile design practice. This phase is described as exploratory practice, in which the outcome of the making isn't known or planned at the outset. Lessons are learned with each sample and prototype, shaping a better understanding of the potential of TDfD in circular systems.

In chapter 6, a range of ways in which the strategy can be implemented to offer alternatives to the textiles identified as barriers were tested by sampling TDfD assembly techniques following a trial and error exploration process. This draws on the textile designer's ability to judge the value of the samples from an aesthetic and tactile perspective, using the TDfD brief as a trigger to create original assembly systems and materials. As shown in the diagram on the facing page here, one of the key insights from this phase of chapter 6 was to use mapping to demonstrate the thought process associated with designing textiles for disassembly.

In chapter 7, taking the assembly techniques into a garment prototype provides a framework against which to assess the relative success of the TDfD redesign process. With a context for the materials, design process, use, and end of life, the jacket can show an environmental improvement over a conventional reference garment.

6. Exploring Textile Design for Disassembly

The understanding of DfD as a design concept and the identification of different scales of blends were taken into this next phase of practice. The categories of DfD and the one-word briefs which were drawn from them informed the textile sampling, adapting observed DfD strategies to the three textile scales which were identified in the previous chapter. This approach to experimenting with textile assembly techniques follows closely from the creative textile design processes, which by assembling different materials for original effects, create barriers to recycling. Such a mindset is therefore appropriated and adapted to explore solutions to the recyclability issues it creates. This chapter presents the process of sampling and offers a retrospective reflection to draw insights for TDfD.

6.1. Sampling Material Combinations for Disassembly

While the making which led to the visualisation of blends in the previous section is not fully considered as practice, but rather as a making-led way of understanding the issue, this section describes a deep dive into the practice of creative textile design. Free-flowing and iterative making was used to test the applicability of DfD concepts within the textile practice defined by this research and develop techniques for assembly which could allow the components to be taken apart later.

6.1.1. Textile Design Sampling Methods

The approach taken in this sampling is described as free-flowing in the way that it follows the serendipitous findings in each sample iteration. The insights from previous phases of the research are brought together to inform this experimentation. The sample cards from this body of practice detailing the techniques used and the assessment of each sample can be found in appendix 11.1. (p.295). This section outlines the initial triggers and guides given in this practice, states the aims, and also the limits that are set to contain the work.

Design briefs and inspiration

The idea of a design problem in the terms understood by design thinking research (Brown and Katz, 2009; Cross, 2011; Rowe, 1987) is rarely explicit in the textile design process. As argued by Igoe, textile designers tend to "create problems for themselves, for their own satisfaction" (Igoe, 2013:94), further suggesting that the aesthetic component could be the main issue to resolve within this type of practice. Textile thinking in response to complex issues begins "by searching the problem space, gathering information and stimulating the senses." (Moxey, 2000:53). A textile design led delimitation of the parameters of the design brief is yet to be articulated.

This study proposes an outline of the various constituents of the problem and paths that are proposed to overcome it. As suggested by Moxey (2000), this follows from a combination of the insights from understanding the problem. The chapters preceding this one have given three main guides which combine to create the outlines of the problem space.

First, the definition of DfD acts as the starting point for the material experimentation. Throughout this study, the research explores the potential for resources to be combined in detachable ways. This is the overarching boundary of the problem space which is accepted from the start. In this way the first requirement for the practice is to suggest a way in which two or more components can be assembled in ways which will allow them to be taken apart later. TDfD is suggested as a strategy to develop alternatives to blended materials. These are proposed as the main problem to solve, and therefore act as a grounding element in the delimitation of the experimental phase.

Second, based on the initial expert interviews, laminated and stretch fabrics were pinpointed as major barriers to recycling. The practice presented here therefore aims at achieving effects which can be compared to this benchmark in order to potentially replace these problematic textiles with more recyclable alternatives.

Third, the exploration of DfD as a concept has narrowed the theme down and effectively broken it up into categories which, here, act as guides for the different ways in which the strategy can be applied to solve the issue of material combinations. The five triggers – Optimisation, Simplification, Layering, Narration, and Modularity – refer to each of these categories standing as proxies for a selection of case studies which create a definition of the theme. They offer a pool of inspiration to draw techniques and concepts from and adapt these to the scale of textiles.

The practice uses these three parameters as loose boundaries. They guide the making without constraining it, allowing for the potential of playful practice to deliver original outcomes within this space. As put by Marr and Hoyes "uncertain boundaries create a space for innovative opportunities" (Marr and Hoyes, 2016:4). Following this, the outline proposed by the understanding phase supports, rather than limits, the making, thus embracing the findings that originated from mistakes and allowing experiments to stray beyond the original brief.

Furthermore, the research interest is in understanding the effect of these circular economy constraints on the creative process and outcomes. In this experimental phase the reflection on the practice is geared "to understand and experience the value of risk taking and unlearning and to gain insight into the value that textile thinking can bring" (Marr and Hoyes, 2016:5).

Prototyping TDfD

As noted during the practice review, while design for disassembly is relatively established in product design, there are few examples of the application of the strategy to textiles. Indeed, disassembly for recyclability as defined by this study has only been found in the instance of the Interface carpet and the Climatex Duacycle furnishing fabric (see chapter 4 cases 2 and 3 p.99). The production of these samples therefore aims at providing a wider range of precedents which can be analysed as case studies in this field and help take further experimentation forward.

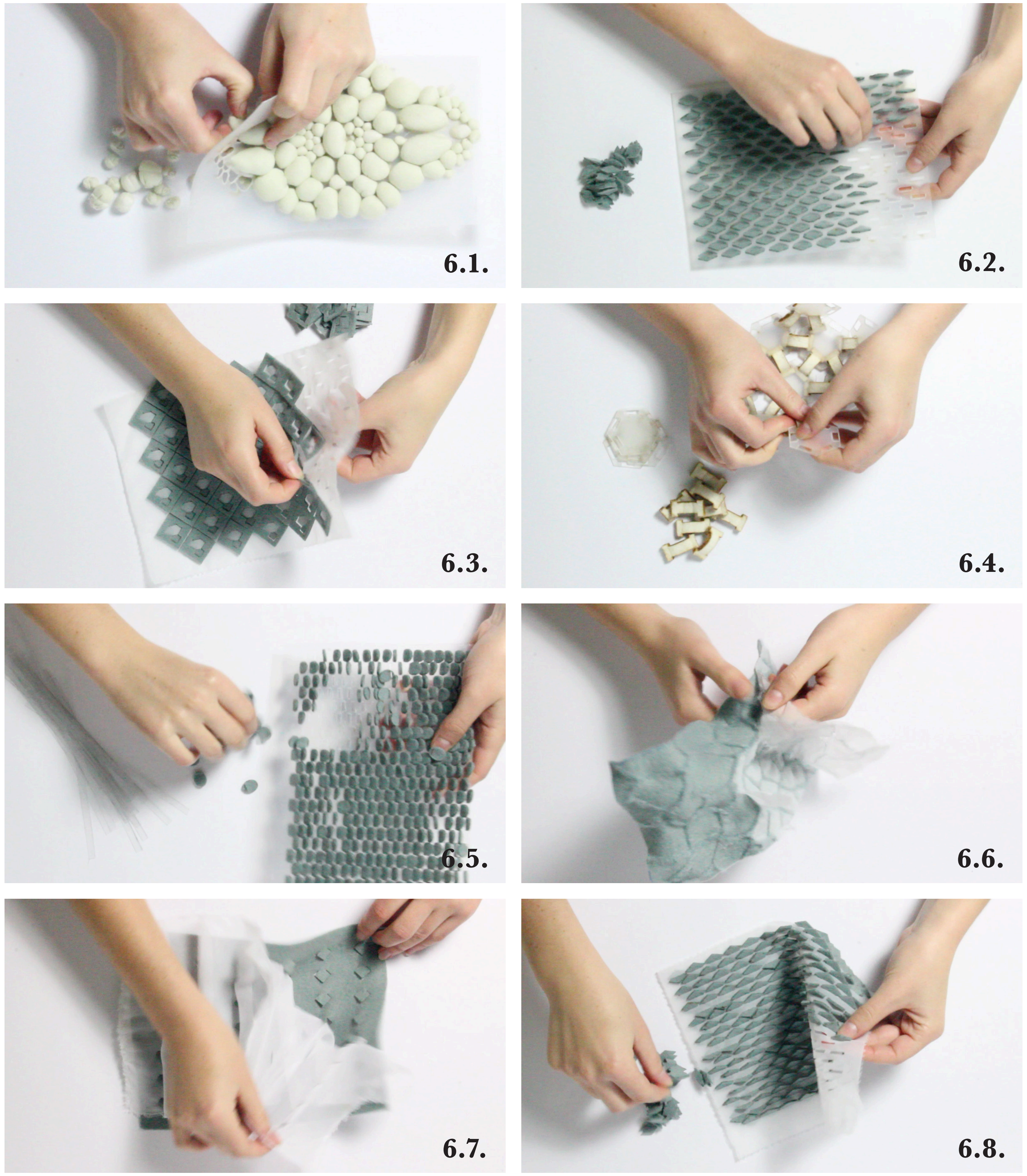
On the one hand, these new cases for TDfD act as proof of concept for the strategy, adding to the corpus of work which argues for the benefits of this approach both in terms of recyclability and of added functionality. On the other hand, they provide additional material for the study of TDfD as a concept in different applications. Indeed, in the same way as the original case studies, which the ideation phase relied on, they are used as inspiration for further iterations within this project and potentially beyond, in a wider application to the discipline of textile design.

While the term is rarely used in the context of textile design, this experimentation is a form of prototyping. These material prototypes, or models, display a range of assembly techniques for TDfD. Brown and Katz (2009), highlight the importance of prototyping as an ongoing process throughout a project, helping to form, as well as present, ideas. This also aligns with Horvath's approach to research by design in which "prototypes have the potential to form the basis for an understanding of the perspectives and practices" relevant to the field (Horváth, 2007:10). Indeed, the production of these test samples is a crucial step towards demonstrating how the DfD concepts defined in the practice review can be transferred to the scales of textile combinations suggested in chapter 5. These large-scale textile combinations, playing with different scales of components, either fibre, yarn or fabric, suggest that the user or end of life handler can take the elements apart either to recover the materials in appropriate streams, or to update worn elements and extend the product's life cycle.

To further test the potential of this approach, the samples were later used in a monitored session of dis- and re-assembly, noting the time it takes for each action and judging the effectiveness of various techniques accordingly. Stills from the videos of the hand dis- and re-assembly process are shown in figure 6.1. to 6.8. on the opposite page. While this approach led to a ranking of the samples by ease of disassembly and potential for reassembly, this cannot be considered as the only criteria for success. Indeed, this quantitative approach steps away from the textile thinking methods used up to now and sits uncomfortably with the focus on experiential qualities which are the backbone of the sampling. This type of measurement was therefore abandoned in favour of an assessment of the relative success of the samples which relies mainly on their tactile and visual qualities as well as on their ability to trigger new creative experimentation or new use scenarios. The success of the samples is therefore not primarily connected to their effectiveness in quantitative terms but rather in their potential as a means to reconsider the structure of blends and suggest assembly techniques to combine materials in temporary ways.

Abstract samples

The position of textiles within the world of design is ambiguous as it is in part a discipline in itself, and in other ways, the results are integrated to



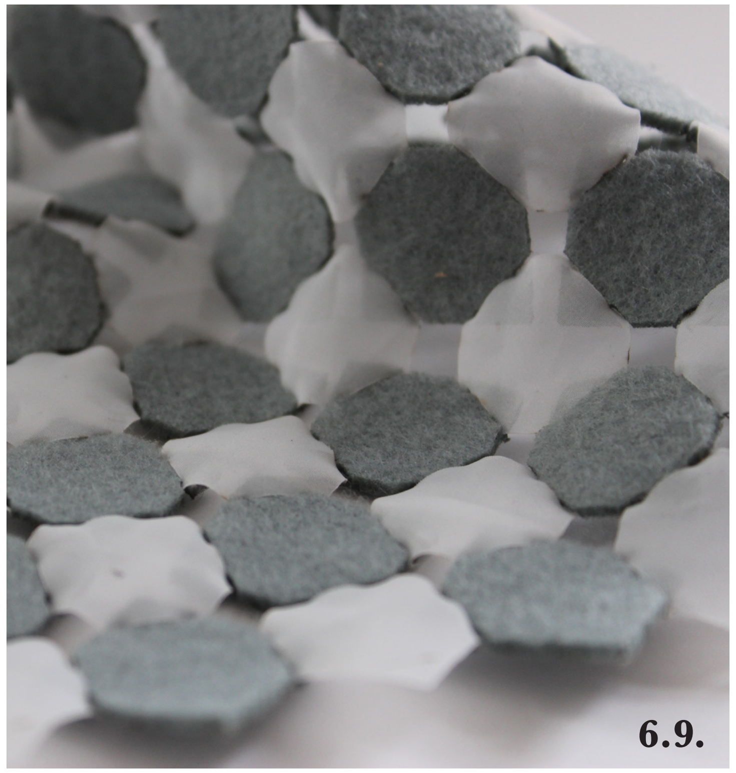
6.1. to 6.8. Stills from the videos taken to record the timings for assembly and disassembly of the samples. The focus was on the samples using laser cutting, as these allowed for reversible disassembly, as well as the felted samples which could be easily replicated. A later session tested the disassembly of the few woven samples which included a soluble thread. All videos are available to view at https://portfolio.arts.ac.uk/project/176414-tdfd-disassembly/.

other disciplines, rubbing out the role of the textile designer in the final outcome which is available to the user (Igoe, 2010; Studd, 2002). Textile designers often produce samples that are adapted to a specific product only in retrospect, thus leaving most of the qualities of the fabrics to be defined by the designer's intuition alone in this ill-defined problem space. The samples thus often have a hybrid role in which they are both the result of a design process, and "representations of ideas, proposals and possibilities" (Morrow, 2014:457).

In this project, this aspect of the discipline was taken on board through the decision to leave the samples open and not to ascribe them to any specific type of use. The samples are demonstrations of the different types of assembly possible at the different scales identified in the review of blends. They focus exclusively on applying the various forms of DfD, identified in previous stages, to materials.

This level of abstraction was complemented by the use of placeholder materials in the sampling. As can be seen in figures 6.9. to 6.12., as well as in following pages, the main materials used were a translucent white polyester canvas and a grey polyester felt as well as other found materials. As was the case with the blend archetype models, the components of the material combinations are codified as two non-compatible parts of a blend designed for disassembly. Thus, the placeholder materials are meant to be replaced by any recyclable materials adapted to the function that is intended for the TDfD combination in its potential user-facing context.

This phase of prototyping therefore temporarily leaves out the tight dialogue with material qualities which is an intrinsic part of textile thinking. As put by Marr and Hoyes, this "fine-tuning of adaptable material qualities lies at the core of the design development. Here the intrinsic knowledge of the behaviour of different textile components – will it shrink or will it scratch? – often informs the selection of the material as it might be worn directly on the body or used within a more permanent spatial environment." (Marr and Hoyes, 2016:26). Using placeholder materials therefore considerably reduces these material considerations in this phase of the experimentation to focus primarily on the construction of the material combinations and the assembly techniques.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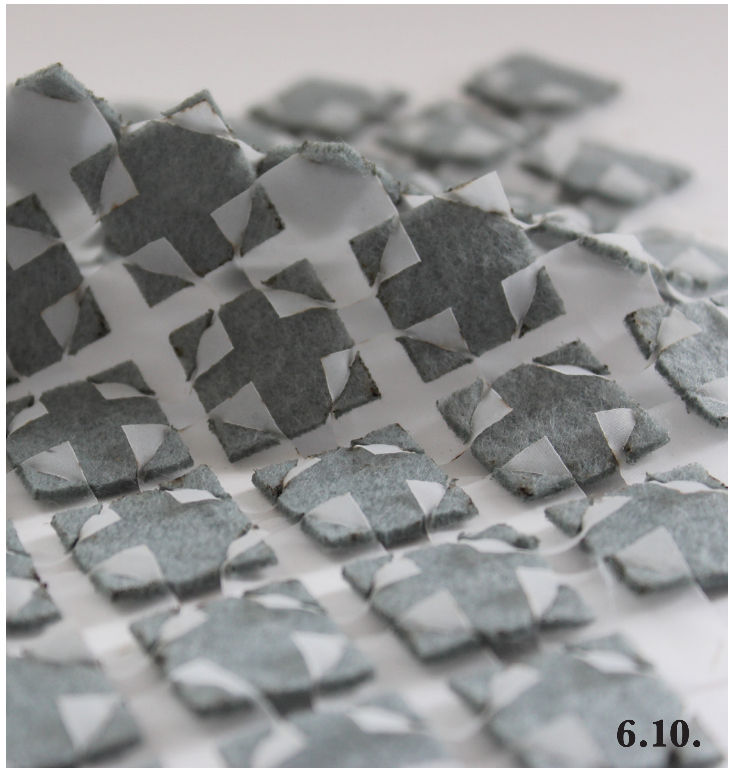

6.10.


6.11.


6.12.

6.9. & 6.10. Pictures of both sides of a tiled laser cut and hand assembled sample. The combination of the felt and translucent canvas makes the material drape and hold in interesting ways.
6.11. & 6.12. Pictures of both sides of a laser cut sample using a dovetail technique to assemble three layers with different stretch properties. The tight transparent canvas is inserted into an elastic fabric, causing it to bunch up and create a wavy effect on one side. The material combination keeps some element of stretch with the solid meshed structure layered over it.

The placeholder materials used cannot, however, be entirely devoid of material qualities. They were selected mainly for contrast effects in the combination or for their ability to perform well under the techniques which were being tested. The latter was the reason for choosing polyester felt and tight canvas in the laser cut samples for instance. These fabrics, as did the others selected in this phase, allowed for the materialisation of an assembly technique which can then be replicated with sensorially richer materials in later phases. Furthermore, the recyclability of the components was not considered at this stage, leaving the selection of recyclable or mono-material components to come as a response to a specific recycling system or design brief. The level of abstraction in the sampling was deliberate to allow for the better adaptability of the techniques and insights to future specific briefs.

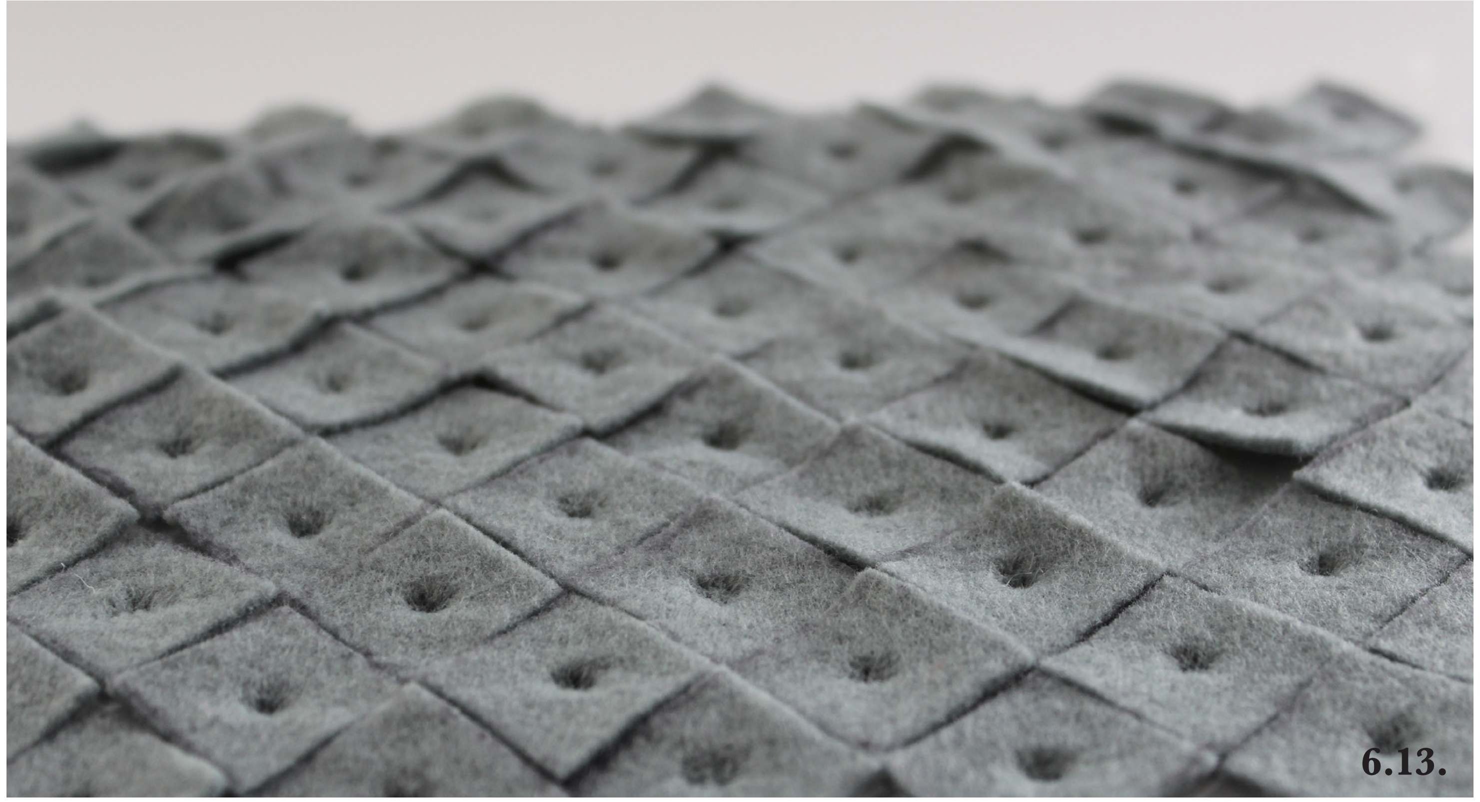
6.1.2. TDfD Samples

This section describes the making of a range of samples which demonstrate the applicability of TDfD to the aim of replicating some of the qualities found in stretchy and laminated fabrics which have been identified as current barriers to recycling. In this phase, the insights from the previous stages come together to inform the practice. The understanding of DfD as a circular design strategy that came from the case studies, acts as a creative trigger and a set of inspiration techniques and concepts to draw from. This is combined with the understanding of scales in textile combinations which came from the case study mapping in chapter 4 and the creation of a hierarchy of blends in chapter 5.

The samples presented here are therefore described under three categories referring to the scale of the components used as defined in chapter 5: fibre, yarn and fabric. The loose relation to the brief and inspiration is described here to demonstrate the influence these parameters have had on the free-flowing experimentation. Additionally, these descriptions show how the five DfD concepts – Optimisation, Simplification, Layering, Narration, and Modularity – can act as creative triggers and take on different forms, depending on the type of scale or combination they are applied to.

Fibre scale

As identified in the previous chapter, this is the smallest scale of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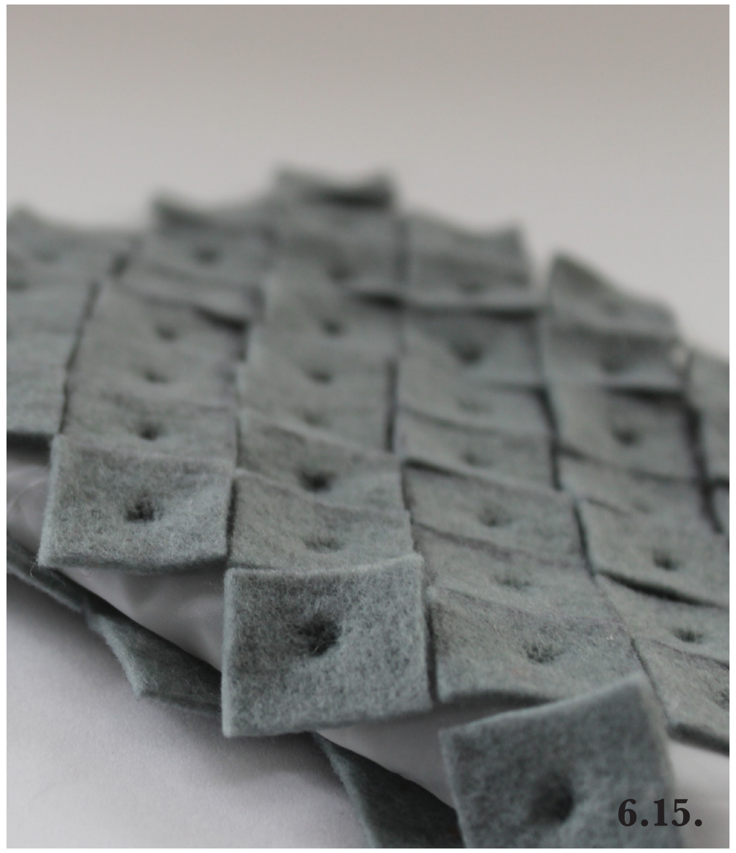

6.15.

6.13. to 6.15. Photos of a hand cut and felted sample demonstrating a tile effect over a base cloth of polyester canvas. Once more, the combination of different materials creates interesting draping properties. In this sample the different elements are assembled at the fibre scale with the needle punching fibres through the tight canvas in a way that still allows the tiles to be ripped off from the base layer.

components which falls within the scope of this research's creative textile design-led understanding of blends. While it usually takes the form of twisted fibres forming a yarn in conventional blends, in this experimental sampling phase, the role of the fibres was slightly changed.

Here the fibres were used to connect two layers of fabric, thus combining two scales of components within one material. The needle felting pushes the fibres from the base non-woven material through the canvas of the top layer, creating a connection which can then be peeled off. The disassembly was found to cause more or less damage to either of the layers depending on the density of the felting pattern and the length of the fibres in the felt. Examples of how this technique is used are shown in figures 6.13. to 6.15 on the previous page and 6.17. here. It was also found that a tight canvas was needed for the top layer so that it sufficiently traps the fibres that are punched through it.

This short series of samples take on board the inspiration from the cases described in the Optimisation and Layering concepts. These two one-word creative triggers and the cases they refer to are represented in the way that the felted fibre joining allows for effective recovery of the raw materials of each layer of the combination.

The destructive and one-step disassembly of peeling the top layer off is inspired by the approaches demonstrated in examples such as the 2-4-1 sample (case 4 p.99) or the Interface project (case 2 p.99) from which the Optimisation brief is extracted. Furthermore, the Layering is directly inspired by examples such as the Strata furniture (case 10) which proposes a layering of functionality. This is then adapted to a textile technique, in this case felting.

In the sampling phase the assembly process was done by hand, as shown in figure 6.16., but felting machines which could speed up this method exist and could easily be deployed. One of the interests in this technique was the fact that the decoration of the fabric doubles up as a connection element, therefore tapping into a design feature to expand the material's properties. The two layers are seen as having potential complementary qualities: the felt layer bringing insulation while the top layer acts as a protection. This approach to TDfD therefore suggests an alternative to laminated materials as identified in the previous sections.

6.16. Process photo of hand felting several layers of material together, punching the fibres through to connect one element to another.
6.17. Felted sample after having been disassembled. This irreversible disassembly shows where the fibres from the white wool felt layer have connected with the blue polyester canvas following the hand-punched pattern. This disassembly leaves only minimal damage on both layers, depending on the length of the fibres in the felt and the density of the pattern.

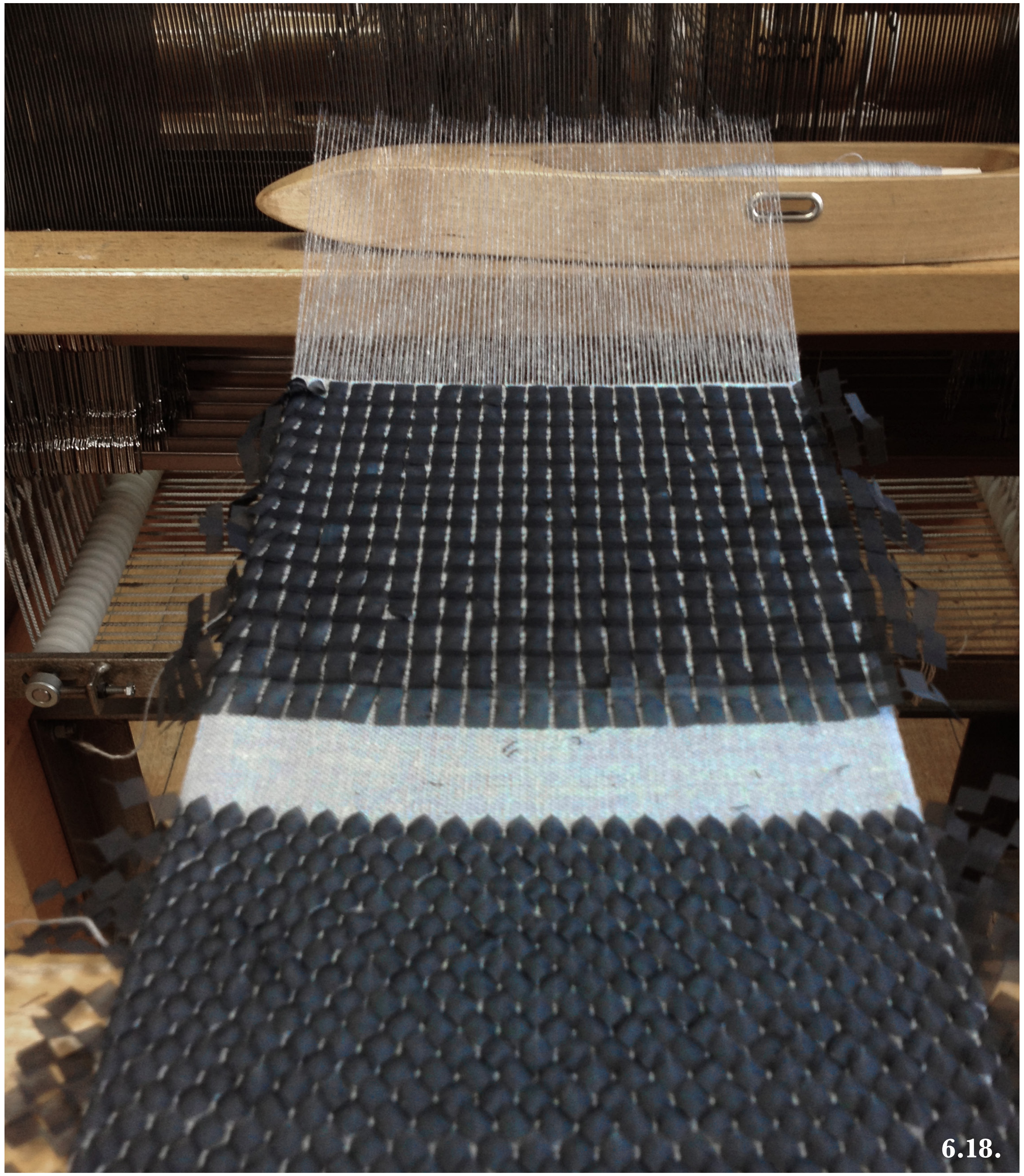
Yarn scale

Textile design practice is very varied in its forms, it can range from the application of colour or pattern to fabrics in dying or printing, to the combination of textile and non-textile elements in embroidery for example. But starting from the yarn scale allows for the construction of the textile from almost what feels as the very beginning of the process. It also guides towards more conventional tools such as the loom or knitting machine which have direct equivalents in industry and could therefore lead to more scalable outcomes than other, more hand-crafted, textile manipulation techniques.

This making phase was a way of experimenting with loose ideas for TDfD in woven materials. Rather than prototyping an already set and drafted concept, the loom was set-up in a generic way to allow for a variety of simple structures. Using a floating weft effect which had already been tested in previous work relating to design for disassembly in the Muto project (see chapter 1 p.19), the sampling aimed to connect these functional elements to a base cloth in ways which would allow them to be removed at the end of life. In all of the samples, a pick (the line of weaving code for a weft thread to be added to the fabric) is added to insert a special weft thread. In the case of stretchy samples this was an elastic rubber thread. For the two-sided samples, this varied from custom-made laser-cut yarn as can be seen in the picture in figure 6.18., to nylon thread.

These samples aim to offer alternatives to stretchy and laminated fabrics. The woven structure externalises these functional aspects and adds them as an extra layer on the top of the base cloth, in a way which will allow them to be detached at the end of the product or material's use phase.

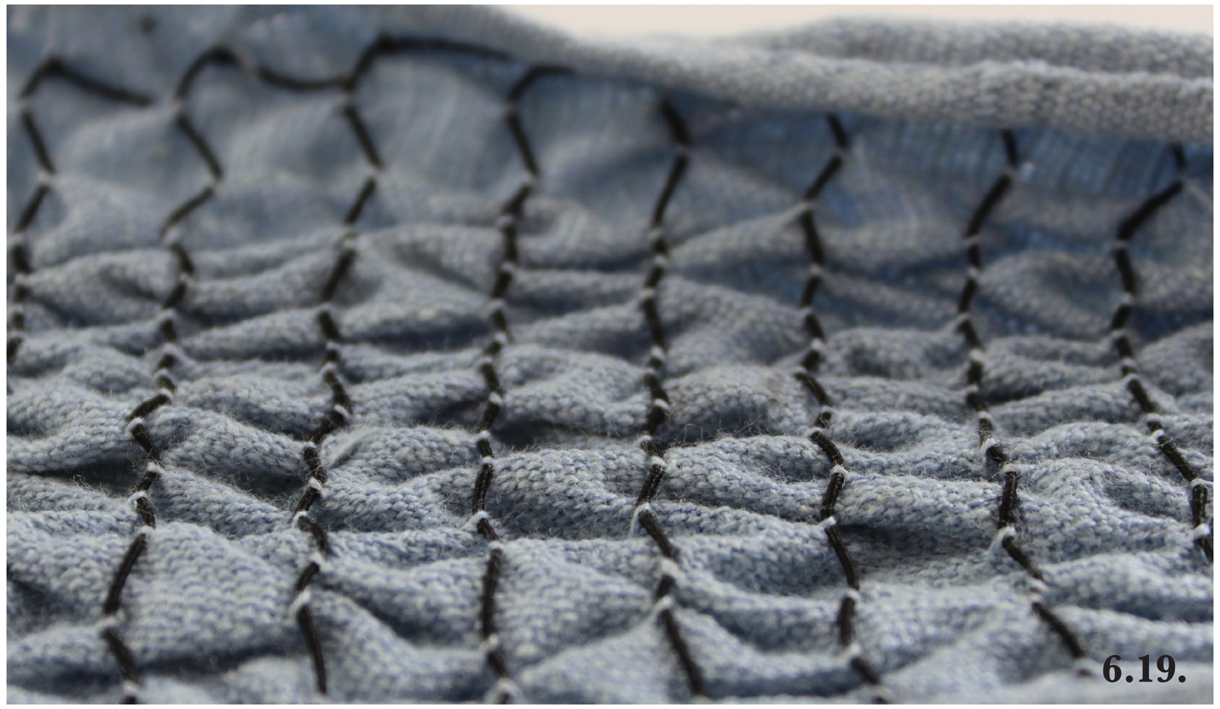
This way of making textiles brought about new aesthetic and haptic qualities. The visual effects, in the case of the stretch samples, was close to what may be achieved using smocking techniques as can be seen in figures 6.19. to 6.22. on the following page. However, the folds can be pulled flat and expand the material, giving it stretch-like properties. The thread which allows for the elasticity, being necessarily incompatible with bio-cycle materials such as the cotton used here, and generally a hindrance to recycling systems, can be removed at the end of the material's useful life.

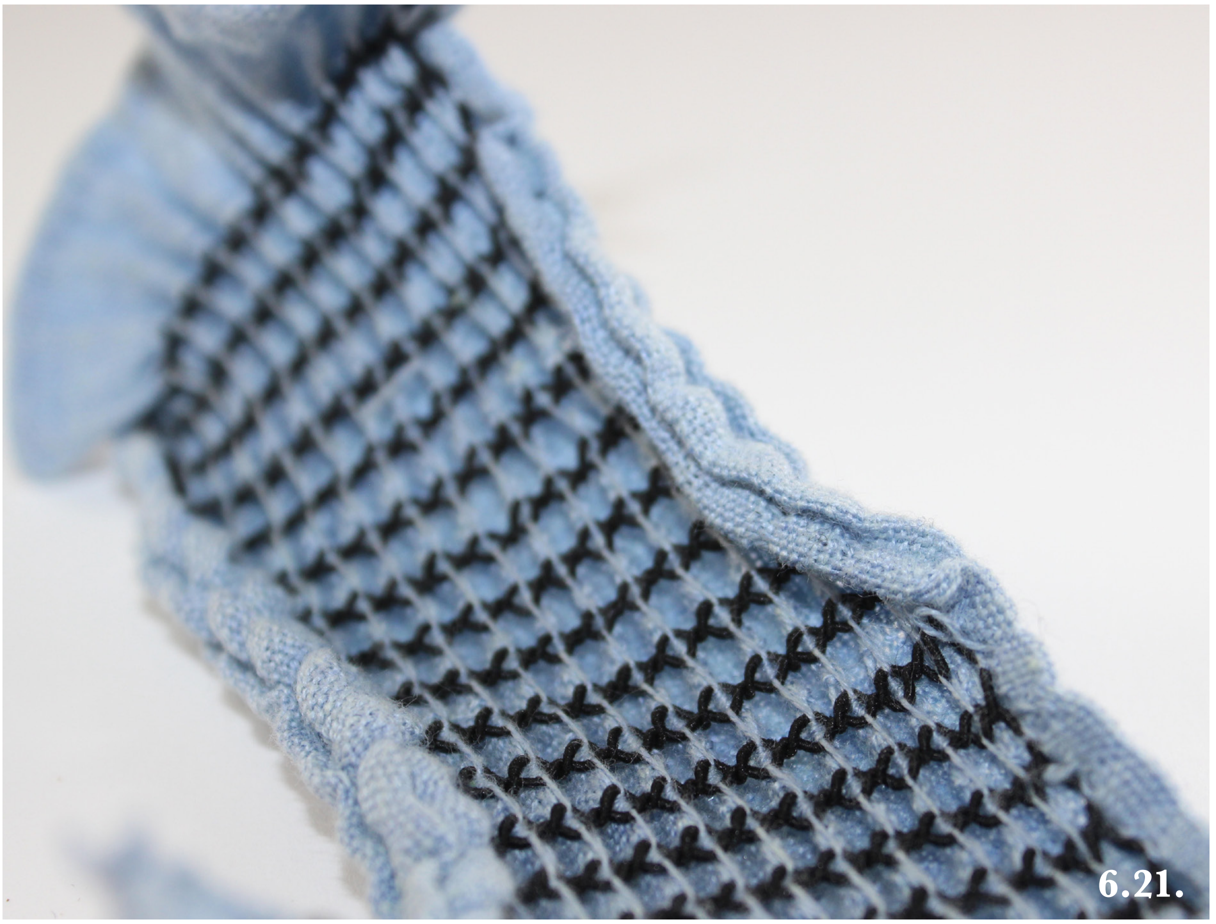


6.18. The woven samples on the dobby loom in Chelsea College of Arts weaving studio. The visible samples are shown again off the loom in figure 6.16. and 6.17.. The weaving technique involves hand threading the laser cut ribbon of polyester between the lifted warp threads to gradually cover the base layer as it is being woven.

These samples draw very directly from the Optimisation brief and the examples such as the Climatex Textile Lock or other efficiency focused case studies presented under this category of Disassembly for Material Recovery. This disassembly can be effected by triggering the change which will dissolve the thread that connects it to the base. In these samples, water-soluble thread was used as a stand-in for other materials that react to conditions that will not occur accidentally, such as hot-melt polyester or other materials such as Wear2's thread (case 6 p.100), which can be dissolved by microwave treatment or even Resortec's heat reactive thread (https://resortecs.com/). Once this thread is dissolved, the base material remains integral and can be used in other applications or recycled as a mono-material. This technique was applied beyond the brief of making stretchy fabrics and the elastic was replaced with other threads such as thick cord or metal thread, as shown in figures 6.26. and 6.27. in the next pages, to explore the potential of this technique in making more resistant materials, yet still externalising this functional component of the blend.

The same technique using soluble thread was applied to the two-sided



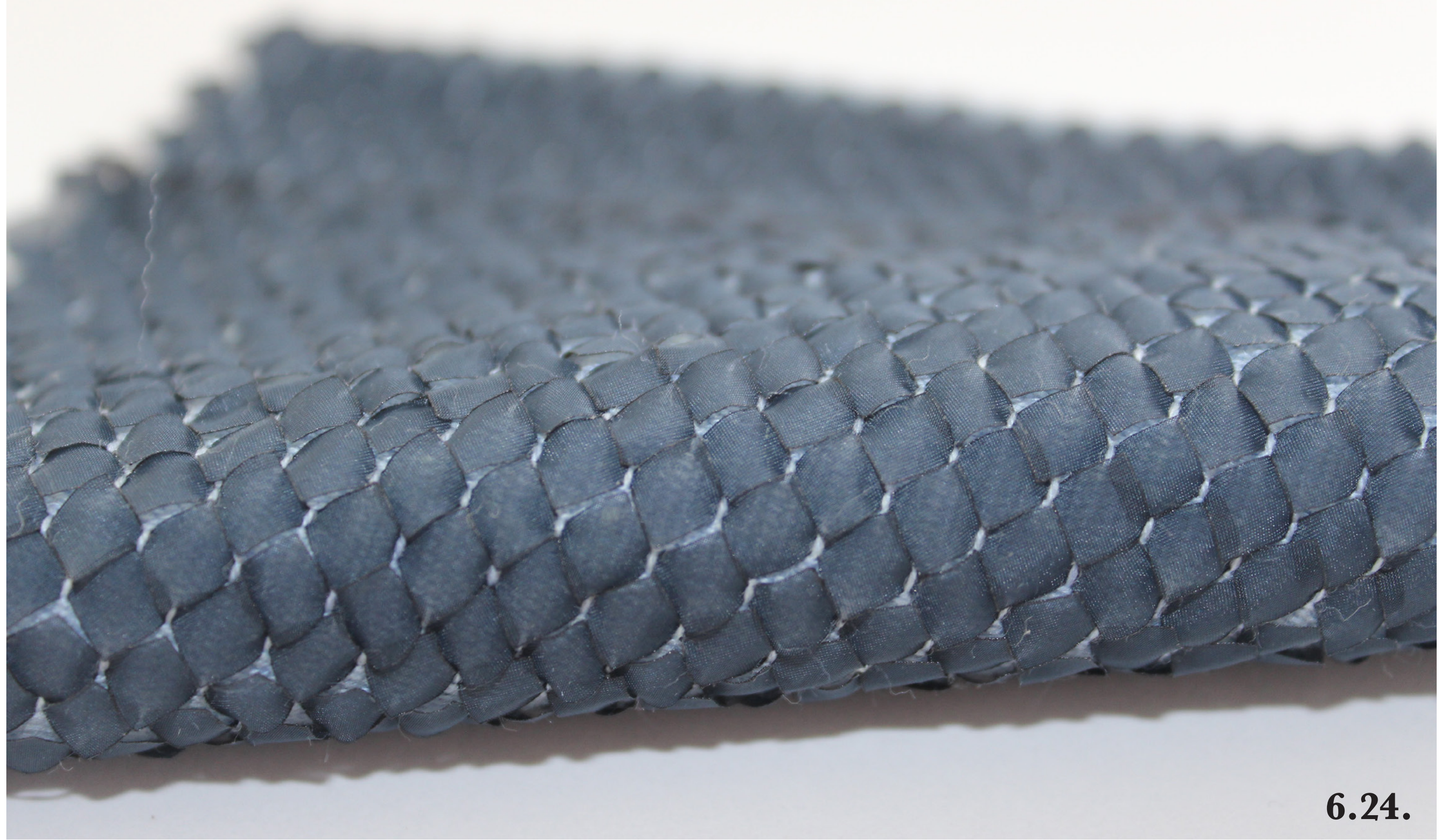


6.19. & 6.20. pictures of both sides of a woven sample integrating a rubber thread. The technique pulls the base cloth together creating a smocked effect that can be pulled out giving the combination some stretch properties.
6.21. & 6.22. Pictures of both sides of a sample integrating a rubber thread. Due to the set-up of the loom, the threads were included as part of the weft and not the warp, making it challenging to achieve elasticity in both directions. Here the elastic threads are intertwined to change the structure of the smocked effect.

samples which suggest alternatives to coated and laminated textiles, allowing the upper layer to be removed without damaging the base. In this case, the lamination effect is fulfilled by a special thread which is designed to cover the base layer through a tiling system. This thread is prepared by laser-cutting a thin but dense polyester fabric in a way that covers the surface when woven to the base fabric. This approach does not necessarily deliver the same properties as a coated fabric since the added thread does not cover the base material in such an air-tight way as a polymer sheet as visible in figures 6.23. to 6.25.. Yet it still provides a form of protection and a double-sided effect. Moreover, the original texture and visual quality that this adaptation of lamination has brought about is aesthetically satisfying. In this respect, this series of samples is successful in having answered to the expectations outlined in chapter 3 for the samples that originate from this exploratory process to generate new and pleasing aesthetics as a response to the circular design brief and constraints.

Such an approach to externalising function is drawn from the Layering brief, inspired by examples at the architectural or product scale such as the Cellophane house by Kieran

6.23.



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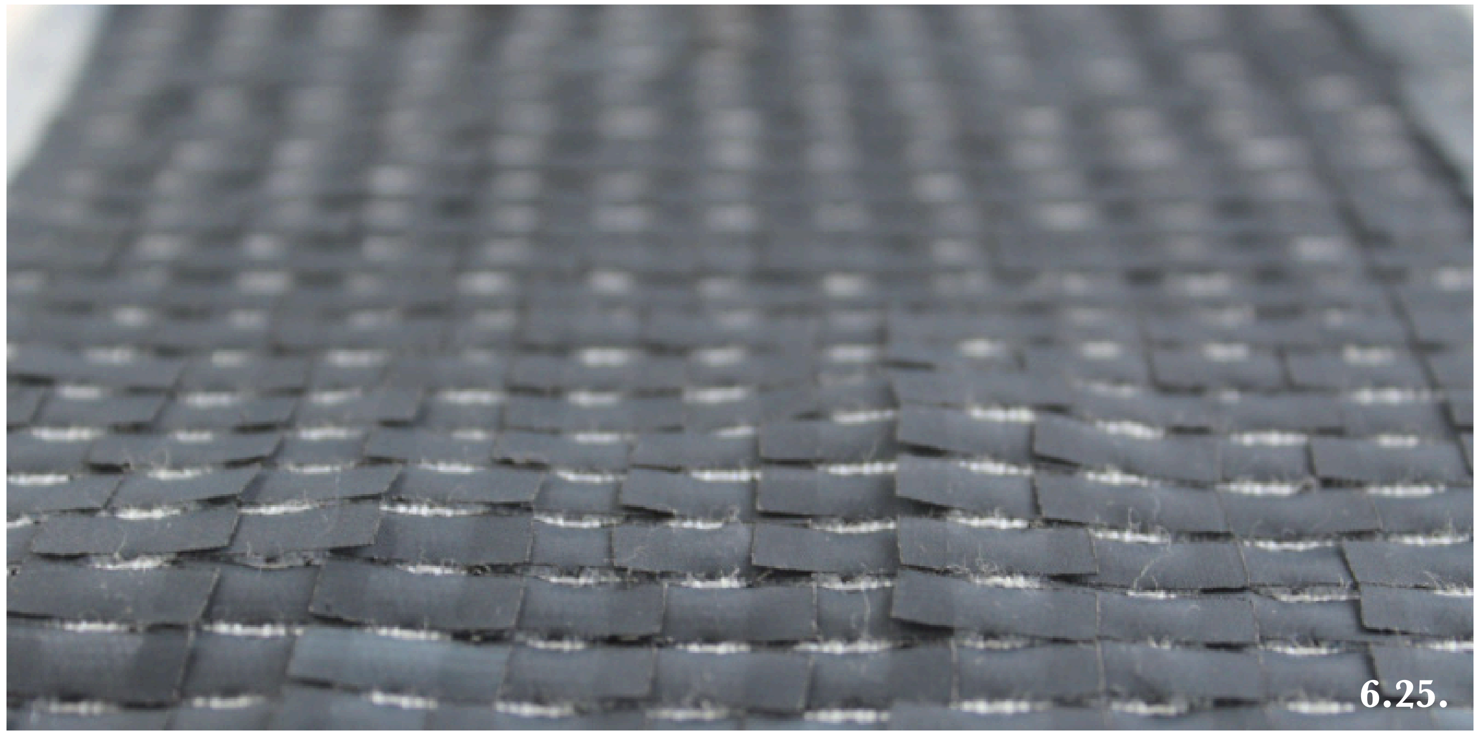
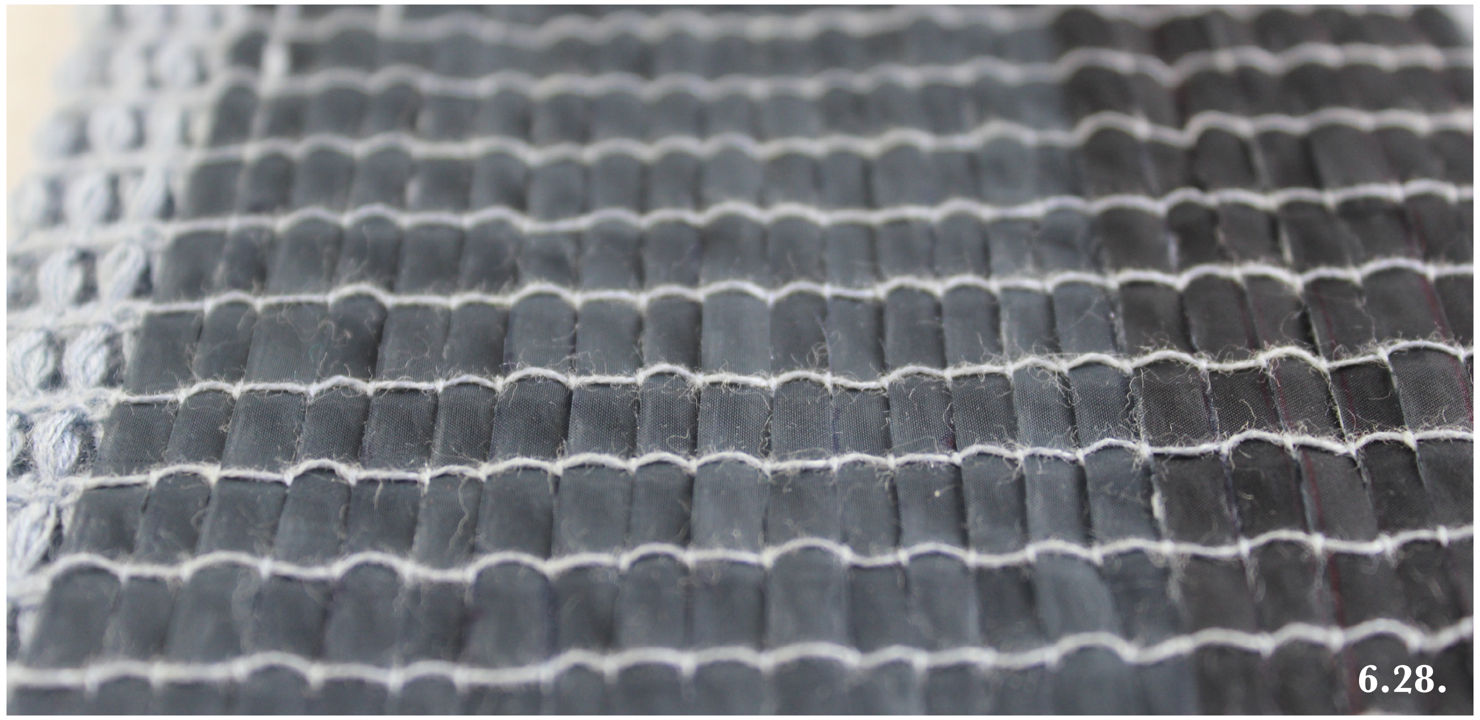


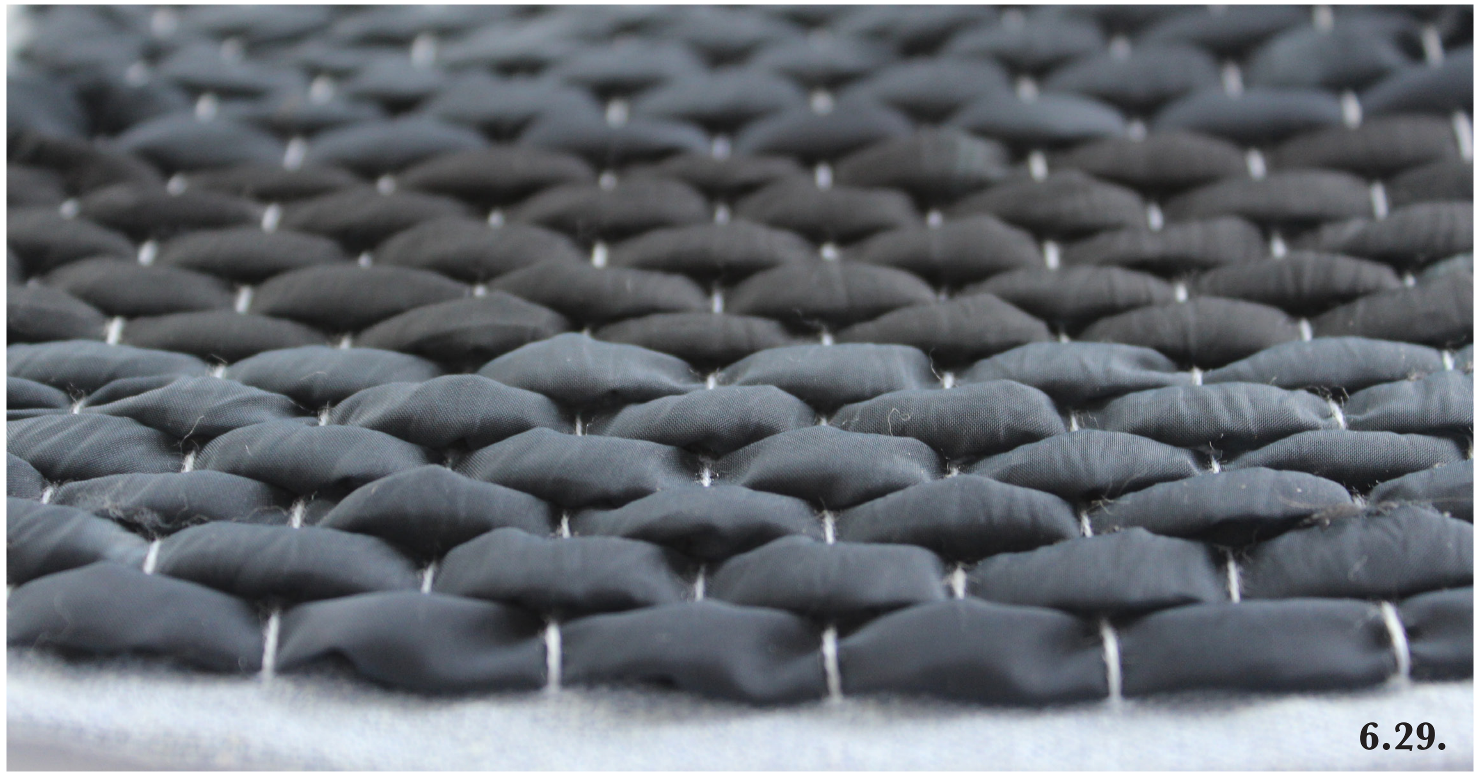
6.25.

6.23. & 6.24. Two views of a woven sample with a cotton base layer over which a strip of diamond shaped scales are woven. The slight pinching of the warp threads trapping the ribbon creates a small gap between the two layers giving the material added texture.
6.25. Woven sample using a similar technique as the above. Here the ribbon is laser cut as a string of rectangles, reducing the pinching effect creating volume. In both cases the samples are designed so that removing the top layer will leave the base cloth integral.

Timberlake (case 12 p.104). At this scale, DfD means allocating specific functional aspects to independent modules which can be recovered independently. Imagining a textile structure which is built like a building with a supporting structure has led to these effects in which the elasticity or the lamination are added on as a functional cladding or structure.

Whether the effect aimed for is elasticity or coating, or even insulation effects as shown in figures 6.28. and 6.29., the samples show some ways in which the narrow constraints of the non-contamination brief shape the outcomes of the work and lead to new aesthetics for functional textiles. Indeed, externalising the functional elements forces a change in scales, moving from combinations which would occur within the thread in conventional blends, to the assembly of mono-material threads, and emphasises the textures with either a smocked or scaly effect. As suggested by Papanek's prediction for a future of design led by considerations for the environment, new aesthetics that are not only guided by a purely stylistic inclination may emerge (Papanek, 1995:243).



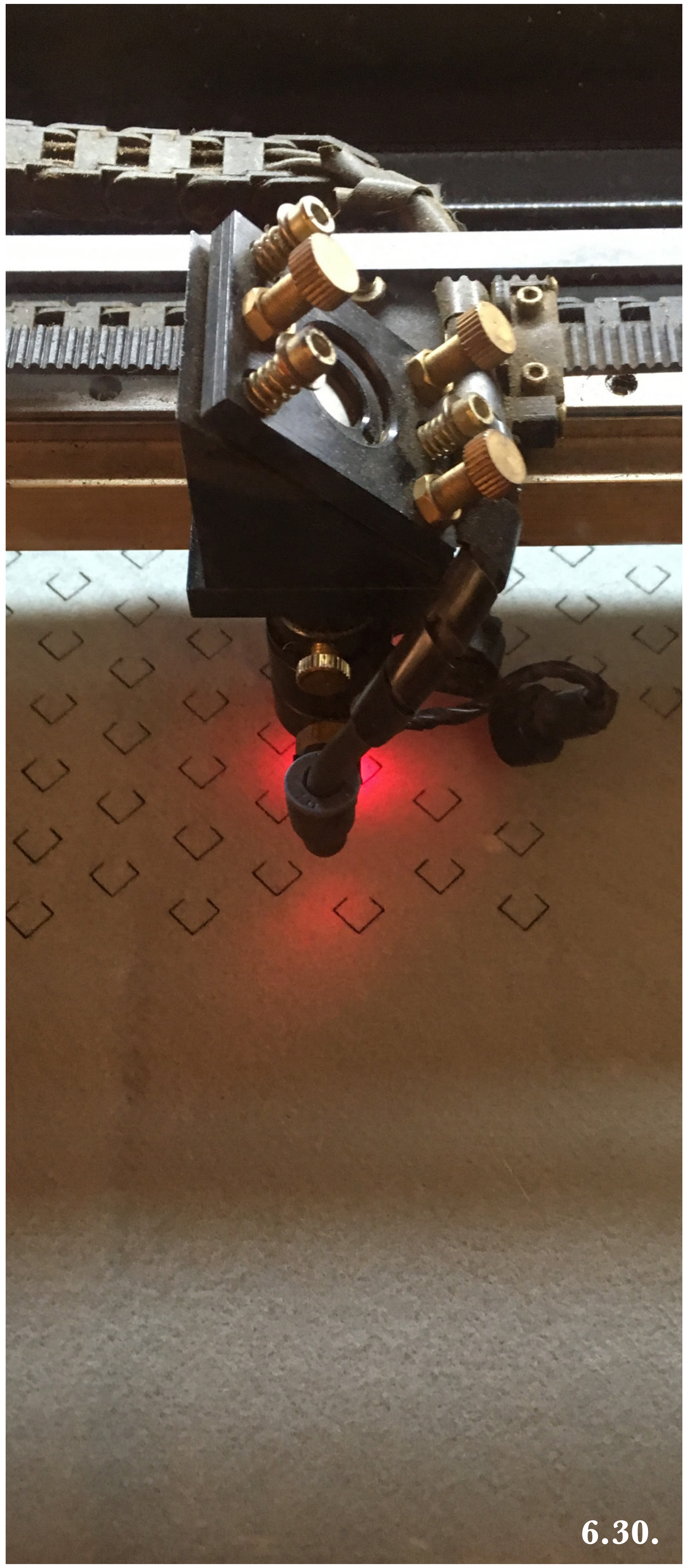


6.26. Woven sample in which the elastic thread seen in earlier examples is replaced by a thin cord. This experimented with the technique to confer a structure and potentially some strength to the combination, testing the combination of the different yarn scales.
6.27. Woven sample with a metal thread running across the surface. This adaptation on the polyester ribbon technique allows the fabric to retain shape while the metal elements can be removed at end of life.
6.28. Woven sample that expands on the effect seen in figure 6.23. in which a gap between the polyester top layer and the cotton base cloth was created. Here a flat polyester ribbon is woven across a honeycomb weave, leaving gaps created by the textured base cloth.
6.29. Woven sample with a tube of polyester woven over a cotton base cloth. This sample further experiments with creating air bubbles in the material combination, considering how this might confer thermal properties.

Fabric scale

This series of samples is based on fabric elements, the largest scale of components represented as mono material or recyclable building blocks for combinations in the blend hierarchy presented in chapter 5. It was made using laser cutting facilities in a local community-led maker-space, followed by hand-assembly of the various components. This section of the sampling specifically reflects free-flowing practice (Marr and Hoyes, 2016; Philpott, 2013) in the way that it emerged in a very organic way from the inspiration laid out during the literature and practice review stage of the research. Indeed, being influenced by inspiring examples of DfD in various applications created an urge to try similar techniques out at a textile scale. Moreover, having free access to equipment at the maker space made the creation of the first few samples very easy and almost automatic. The first samples draw directly on the Modularity brief and mimic the push-through technique and soft and hard contrast seen in Bjorn Ischi's Bone Chair (case 16), and interpreted in the samples shown in figures 6.31. to 6.33.. The techniques then gradually evolved towards a more personal and textile-oriented type of materials.

The drive to adapt DfD strategies



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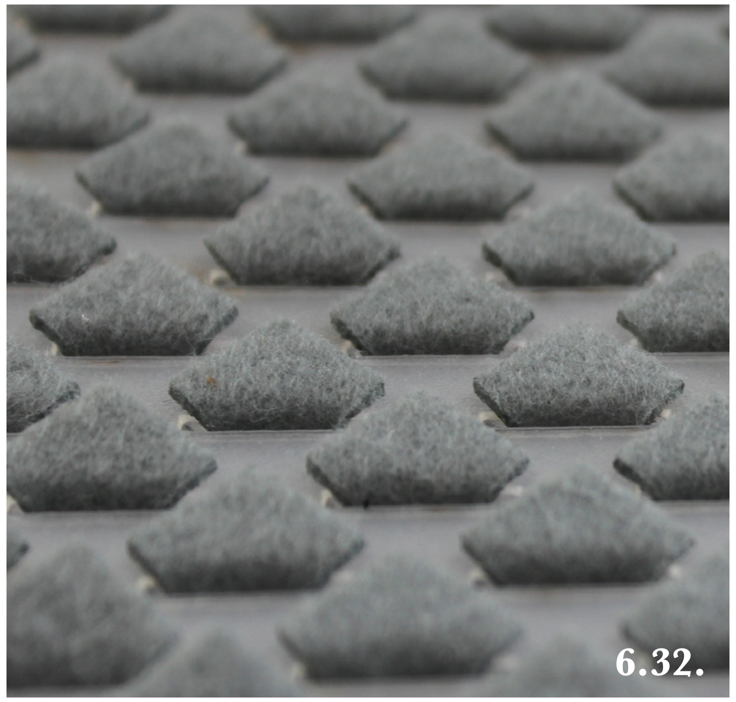

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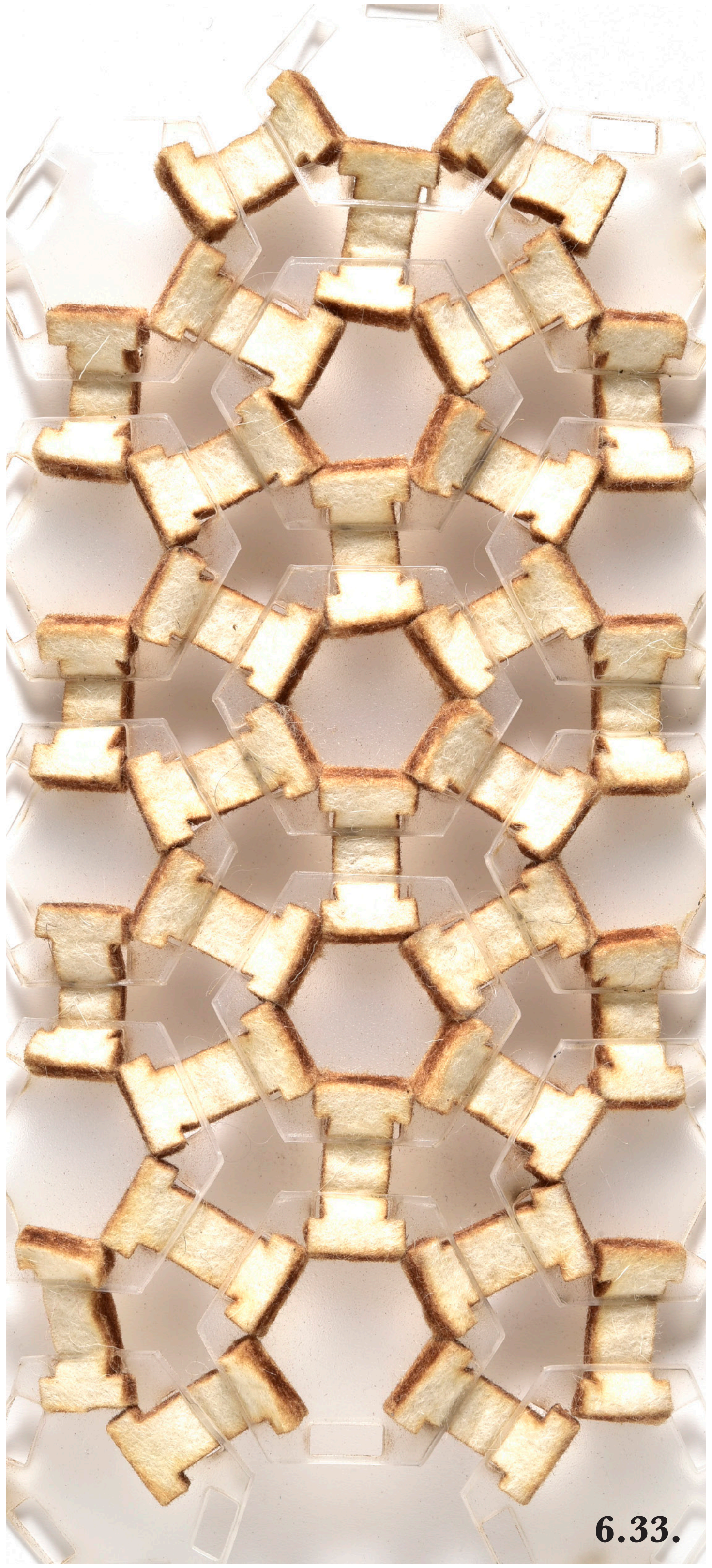
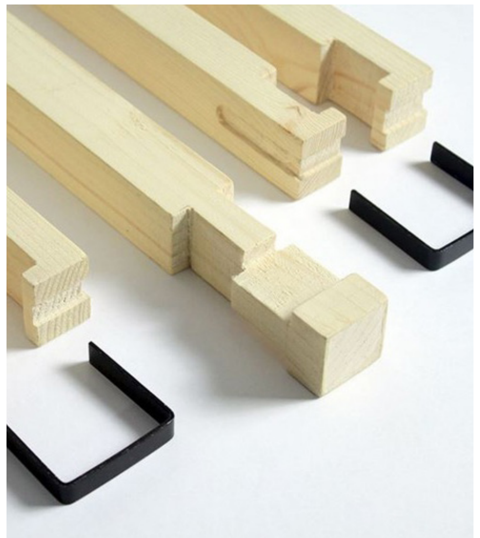


6.33.

6.30. Photo of the CO2 laser cutter in action at the Richmond Maker Lab.
6.31. & 6.32. Two views of the dovetail assembly system with polyester felt flaps poking through a sheet of stiff plastic. The interactions of the different materials and the assembly technique create a 3D scale effect.
6.33. Sample made of laser cut and hand assembled modular shapes: plastic hexagons held together by wool felt Ts. The interaction between the materials' flexibility gives the sample a curve and bounce back to shape which could be interesting for applications in products.

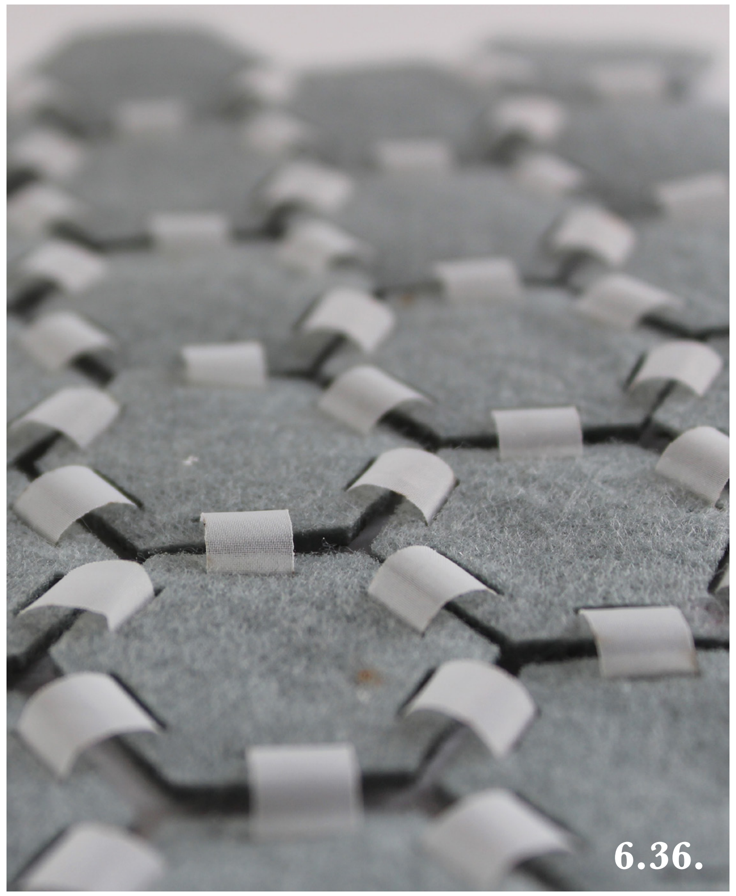
6.34. OOS Collection by Studio 248 (Lei, 2013).



6.35. Nomadic Chair by Jorge Penades (Etherington, 2013).

observed at the product or architectural scale has led to miniaturise the techniques and materials used in those examples and attempt to replicate these effects with textile techniques such as embroidery adaptations or weaving. This experimentation then evolved towards a dovetail assembly system which connects elements in a reversible way. This approach is inspired by the Simplification brief which suggests better visibility of the assembly system for users to engage in the disassembly of the components. The larger scale of the elements in this series of samples allows for simple disassembly by hand in the same way that the Make Use Dress (case 9 p.101) uses apparent seams for users to upgrade their garments.

The laser cutting suggested the use of a form of dovetail assembly, directly derived from larger scale DfD approaches in product design such as with woodwork. Reference examples of this type of assembly are shown here in figure 6.34. and 6.35.. These assembly systems, inspired by product scale examples, are translated into textiles by drawing inspiration from the Disassembly as Play category with examples such as EunSuk Hur's modular textiles (case 18 p.108) or 3D printed examples (case 19 p.108) which put the Modularity brief into practice.



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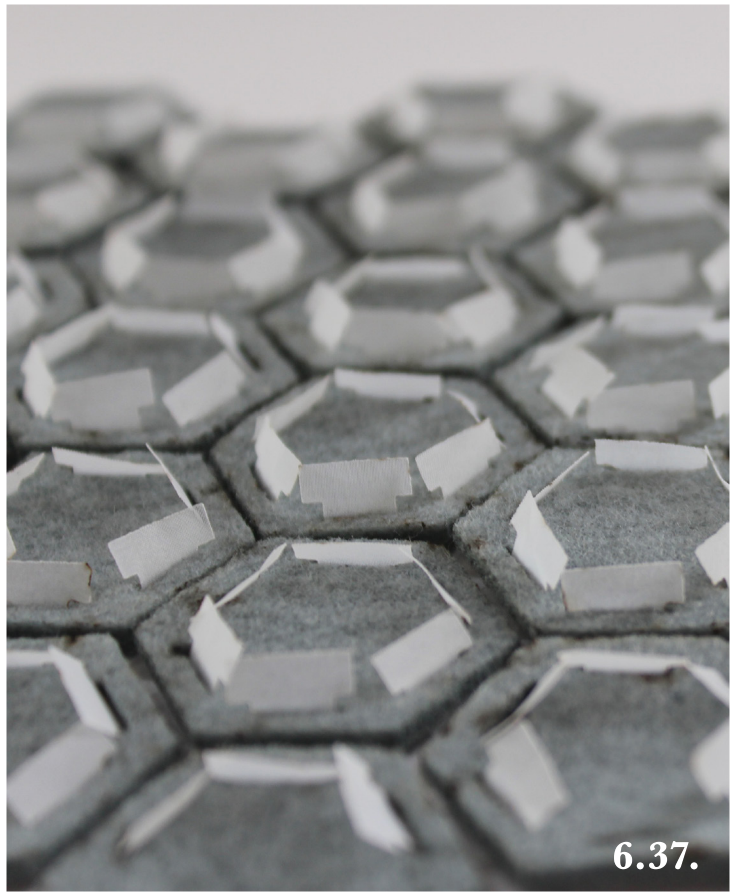

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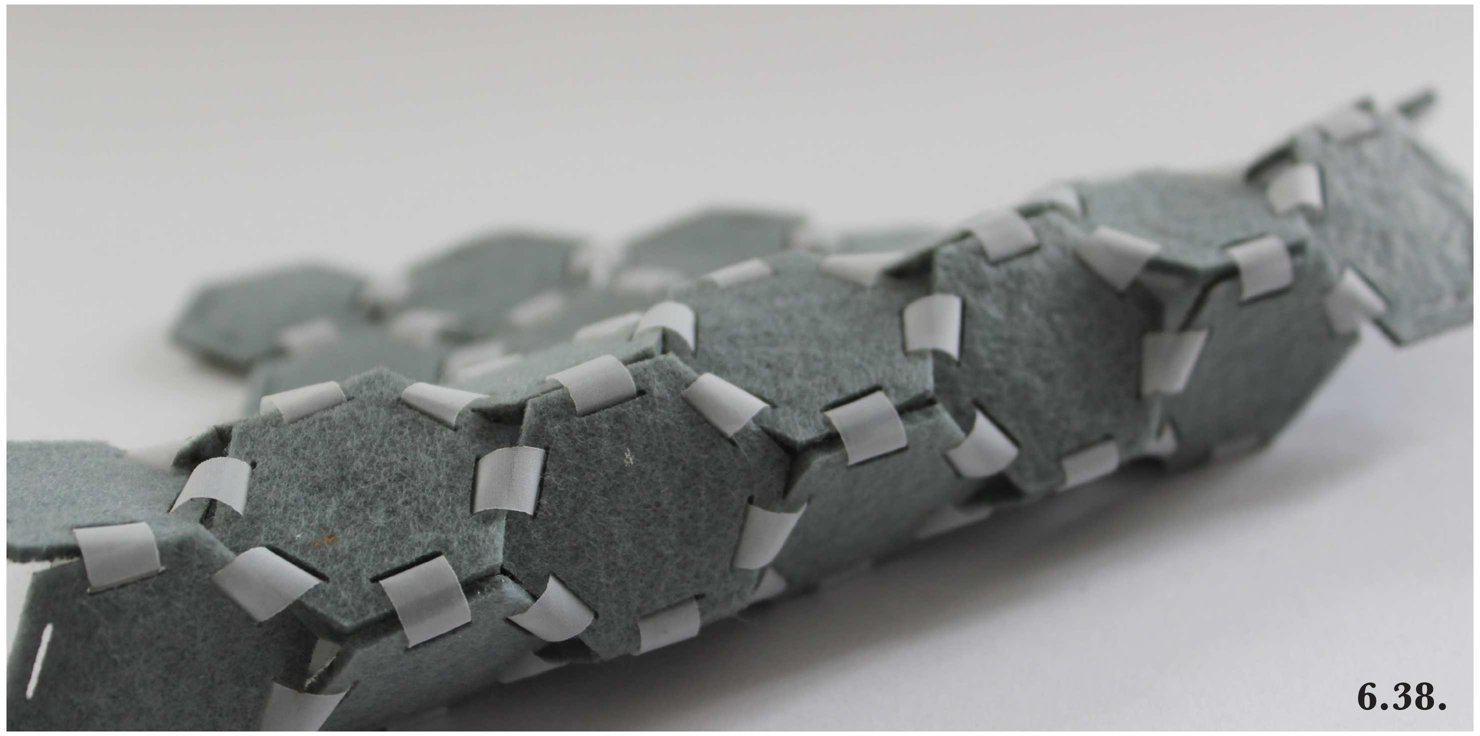


6.38.

6.36. & 6.37. Pictures of both side of a laser cut and hand assembled sample using the same pattern as the sample in 6.33. but adapting the technical width and size of slits and connectors to polyester felt and canvas. The connections draw very directly from the larger scales of DfD observed in woodwork or other product design examples.
6.38. Photo of the same sample as in 6.36 & 6.37. demonstrating the new draping quality conferred by different materials from the original plastic sheets and wool felt.

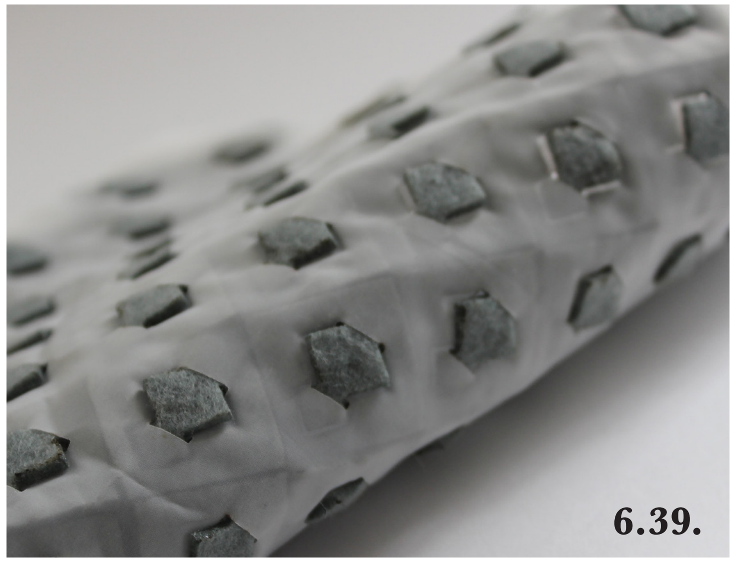
In the case of the layered fabric samples, drawing once more from the Layering brief, the type of assembly defined by the laser cutting meant that the two materials would interlock rather than cover one another in the way of laminated textiles. This prevented a straightforward covering of the base material and led to multiplying the layers of fabric to increase the covering of the felt, which collaterally created interesting mesh effects examples of which can be seen in the samples in figures 6.39. to 6.43.. These types of serendipitous findings are an essential part of textile manipulation and practice-based research. These material tinkering processes "have an active role by suggesting ways of interaction and manipulation" (Parisi et al., 2017:s1170). This leads to designs that emerge organically from the trigger (Studd, 2002) at the start of the making phase.

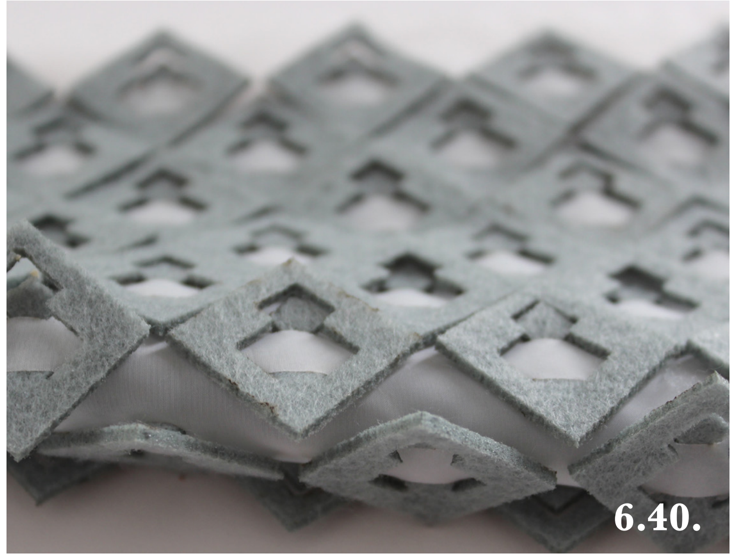
The same dovetail assembly systems were used to assemble pieces of fabric in a tile or patch-like way. Once again, this approach was closely derived from the product design case studies which use modular principles. In these cases, the interactions between the linking elements and the tiles created interesting effects due to the varying thickness or stiffness of the materials, thus generating combinations that either drape in specific ways, as in figure 6.40., or have a spring in a given direction. The quality of the outcomes from this process are thus judged on their ability to appeal to a designer with the potential for applications or further developments.

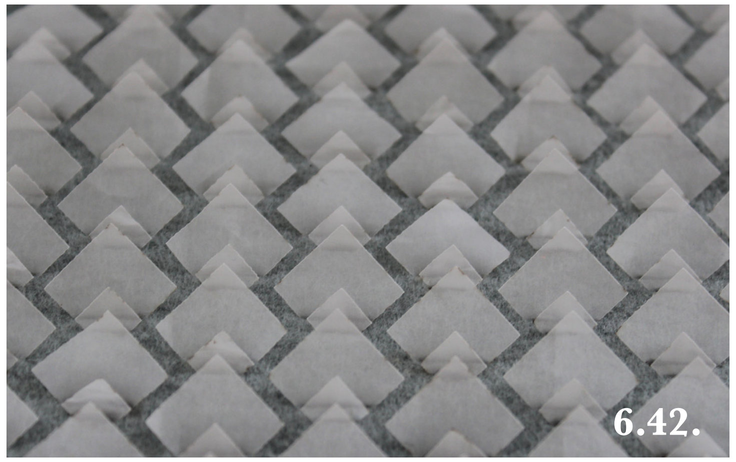
This type of assembly creates zones of the material that can be detached from the main body of the fabric, therefore hinting at the possibility of replacing used parts for extended lifespans in the products in which this material assembly systems is used. Such assembly and disassembly approaches were strongly inspired by a combination of the Simplification brief, which pushes towards materials and products which can be taken apart for upgrade, and the Modularity brief, which uses the potential for user-led disassembly as a way of enabling playful customisation.

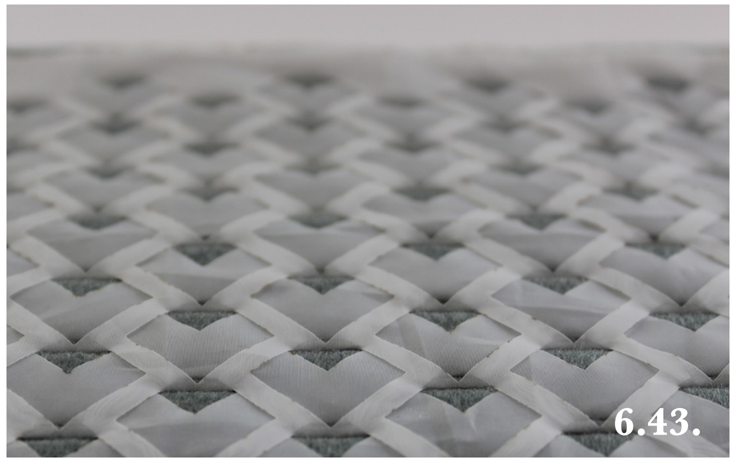
New scales of textile combinations

While the samples are presented following the three scales of recyclable or mono-materials which enter the types of blends which are addressed in this research, the experimentation has transcended the normal interpretation







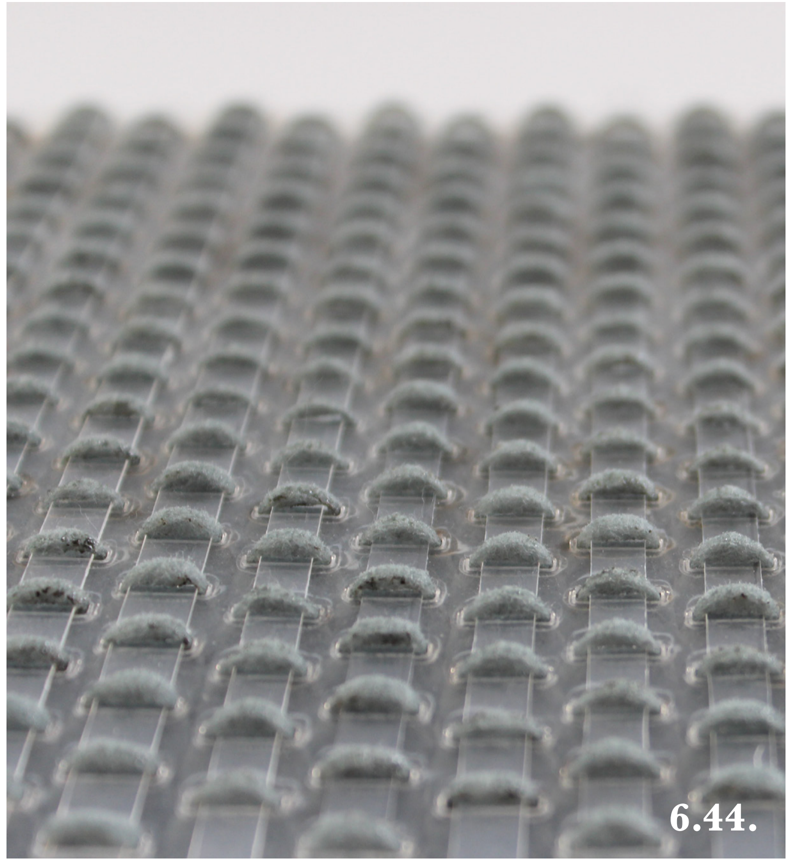


6.39. & 6.40. Pictures of both sides of a laser cut and hand assembled sample with modular diamond patches attached to a base of polyester cloth. The deliberately large scale of the components can be seen creating a tile effect which breaks the drape of the fabric.
6.41. Laser cut and hand assembled sample interlacing three layers of fabric with a dovetail technique.
6.42. & 6.43. Pictures of both sides of a sample using a similar technique to the one in 6.41. with a slightly modified interlacing, 6.36. shows the lattice effect created by the combination of three layers.

of these scales. Indeed, all three categories use textile components in novel ways, whether it is with fibres being reallocated to a connection element, or with fabric pieces becoming modular tiles.

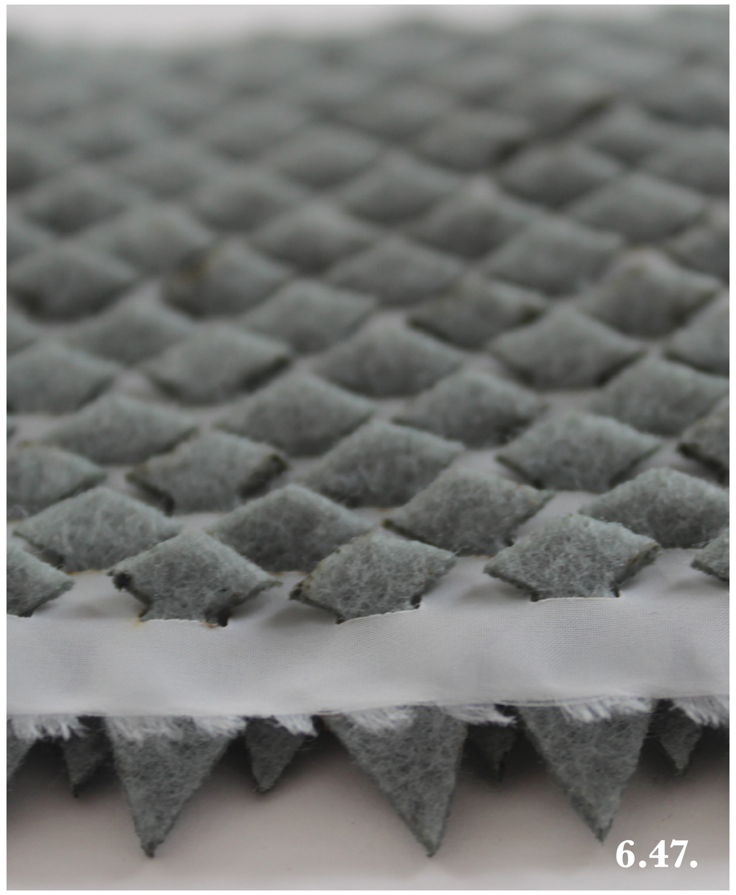
These macro-textiles can be related back to the large-scale models of blends created in the understanding phase (chapter 5). While these three scales have been identified as parts of conventional blends, the scope of this experimentation has been redefined as exploring material combinations. The nuance in the difference between these terms suggests that the connections take effect at larger scales than in conventional blends in which connections are invisible to the naked eye.

These new combinations offer a break from the conventional approach to textile blending to challenge the way this status quo is currently creating barriers to recyclability. While the samples may not be direct translations of conventional unrecyclable blends, such as with the samples in figures 6.44. to 6.48. using a scale effect to replace lamination, this zoomed-in scale offers a deliberate examination of the issues in current


6.44.


6.45.


6.46.


6.47.


6.48.

6.44. & 6.45. Pictures of both sides of a laser cut and hand assembled sample threading strips of plastic through felt 'sequins' to lock them in place in a scale pattern over a sheet of plastic. The felt pieces can be removed by sliding the strips out.
6.46. & 6.47. Pictures of both sides of a sample using a dovetail assembly technique with long felt components to cover the base layer with a scale effect. The density of the felt elements give the sample an appealing heavy feel.
6.48. Close up picture of a sample in which laser cut felt elements are inserted and held by the variation in their width into a base polyester cloth.

textile design practice.

6.2. Using the Samples as Communication Tools for TDfD

In the same way that the initial case studies have inspired the making of these samples, they have in turn, been instrumental in inspiring further practice and in communicating the research to various audiences. This section reports on the ways in which using the samples in conversations fed back into the research. This use of the samples acts as a bridge towards understanding their role in a product context, which will be developed in the next chapter.

6.2.1 Validation Interviews

In this dissemination phase, the samples were used as boundary objects to facilitate conversations with experts in the field of the circular economy who already had an understanding of the potential of DfD for their own practice. This tested the hypotheses of TDfD against their judgement and experience in the field.

Communicating on TDfD

In the early stages of the research the use of semi-structured interviews (Ayres and Hall, 2008) has proven efficient in understanding the context of textile recycling (see 2.3.1. p.49). While their anecdotal nature cannot lead to generalised principles, they provide accounts of experience in specific situations along the path to material recycling. These are useful tools in the development of design solutions to the problem of material circularity. The first series of interviews thus aimed at gaining an understanding of the complex recycling streams for textiles in existing systems and pinpoints how various materials pose barriers, or present opportunities for textiles in the circular economy.

The second series of interviews, occurring after the practice-based experimentation with TDfD (see chronology of methods in figure 3.1. p.67), aimed at complementing the assessment of the success of the approach, and to benchmark it against existing technology and products. These therefore looked through a more holistic lens on a circular economy for textiles to assess the potential for innovation brought by TDfD.

The samples developed in creative textile design practice were first and foremost a means to test different assembly techniques for detachable material combinations. Materialising these ideas was a powerful driver for the ideation process, but beyond this, it provided valuable props to guide the conversation in the expert interviews.

Firstly, it anchored the author’s position as a creative textile designer, giving the interviewee a better understanding of the approach and skills used in this research, helping in steering the conversation away from areas which are beyond the limits of this project such as overly technical matters and expectations of extensive expertise in chemical aspects of textiles and recycling. With the creative textile design approach clearly defined as a central element of the research, it became possible to frame the conversation within these limits. As put by Morrow: “discussion around an artefact helps to overcome issues of differing culture and professional language, allowing each contributor to reveal their interpretation, preferences and imaginations. Maquettes effectively function in this instance as a neutral third party” (Morrow, 2014:257). In this way, having concrete examples of the types of textile manipulation and construction that are part of the practice involved in this research focussed any comments towards the scale which they address, achieving more efficient feedback and avoiding straying beyond the framework of the project. The experts could also comment on potential applications they would imagine for the samples.

Beyond what the samples represent in terms of technical or aesthetic outcomes for a TDfD process, the conversation benefits from the props the tactile samples provide. Bringing the conversation around circular design back to materiality can help in making sense of broader systemic issues. Indeed, the issues connected to designing for a circular economy are broad and complex, involving multiple stakeholders from a range of backgrounds (RISe, 2015). Developing tools to facilitate conversations is therefore an essential aspect of this work. Wilkes et al. (2016) describe the use of ‘boundary objects’ which satisfy the requirements for information of each of the participants in a discussion. In this sense the samples, using tactility over words, can bridge multi-disciplinary language barriers (Earley and Hornbuckle, 2017).

The approach to textile design in this project is led by a playful and free-flowing method which mainly relies on the tacit knowledge of the designer. Opening this process to outside criticism is therefore crucial in grounding these experiments within the realities of circular design. Using the samples in these conversations checked whether the vision for TDfD aligned with existing approaches to circularity and if they could be used to communicate it.

The circular economy and design for disassembly experts

The expertise sought at this stage of the project was closer related to the specifics of DfD and the three interviews drew on the skills and experience of experts in the design of products and materials for circular systems.

Ina Budde, founder of Circular Fashion Systems, winners of the 2019 Global Change Awards, is a consultant in circular fashion and has developed a line of clothing along these principles which includes a coat which is made of materials from different cycles and is designed for disassembly. Fredy Baumeler is the CTO of the Swiss contract furnishing textiles manufacturer Climatex, and invented and implemented the Duacycle Textile Lock, which is, as of now, the only commercially available example for DfD applied to a textile scale (see case 3 p.99). This is a patented system for the combination of different yarns within a weave which allows them to be separated for recycling as well as improving performances during the use cycle. The textile lock uses the company's expertise in terms of woven structure to reimagine how textiles can circulate in a circular economy. The Coopérative Mu team's expertise is mainly focused on life cycle assessment and eco-design, consulting for various clients in fields ranging from fashion to POS displays.

All three of these experts (for this purpose, the Coopérative Mu team is referred to as a person) had experience in developing design and technical solutions to identified environmental issues and in assessing their relative success. Finding out about the details of their own journeys through DfD and the challenges and opportunities they involved, provided a comparison to the approach taken in this project.

This confronted the craft-based experience of TDfD to some of the parameters of designing in an industry setting. This research focusses on presenting the possibility for the creation of material combinations which can be taken apart. The recycling systems and modes of recovery involved in regenerating the components from these combinations fall beyond the scope of this study. Nevertheless, these conversations enabled a better understanding of the potential of TDfD beyond these limits. The variety of approaches to recovery and regeneration, whether with the product service system developed by Climatex or with the connection to a repertoire of recyclers for Circular Fashion, situated this work within a broader context.

The main insight across these three conversations concerns the potential for innovation through the application of TDfD strategies. Indeed, the samples proved to be valuable props to start imagining ways in which TDfD could be used in the type of products that the experts had some experience with (garments, fabric, and shoes respectively), thus offering new perspectives on issues that they may have encountered in their own work. This reflection phase, as defined in the methodological model, fed into the development of product prototypes in this research. Moreover, opening the research up to outsider points of view allowed a return to the work with a fresh perspective and challenged some elements which had been taken for granted from the beginning of the project, such as for example end of life recycling as the ultimate aim of the disassembly.

6.2.2. Workshop Tools

The samples were also used to help other designers understand the potential of TDfD and apply it to their own practice in a series of redesign workshops carried out by the author in different settings. The workshops iteratively tested the ways in which the brief and tools were articulated, leading to better understand the mechanics of the TDfD methodological framework.

Communicating TDfD strategies

The textile samples were used in various instances to nourish workshop activities with different groups of participants, students and general public with varying degrees of knowledge in the field, who were asked to implement TDfD strategies into a product redesign activity. Having been informed of the different recycling routes available for textiles and the challenges pertaining to each of them, the participants were asked to redesign complex products in ways which would allow for the different components to be recovered for recycling. In some instances, the samples were displayed and available to handle throughout the exercise, and in others the participants were only provided with the inspirational case studies to illustrate the concept of DfD. This difference showed the influence of the samples on the results of the redesign activity. Indeed, the groups which didn't handle the samples suggested improvements over the product and modularity concepts were implemented at a user-focused approach, whereas the participants who had access to the samples challenged the structure of the materials themselves, also suggesting design concepts which displayed TDfD with more clarity. They effectively used the techniques presented in the samples in their own designs, adapting them to suit their needs and to replace the functionality and aesthetics observed in the blended materials of their reference products. While this sample of participants is not large enough to draw systematic lessons from the workshops, it points at future opportunities and demonstrates the value of the samples as tools. In a similar way to the small number of interviews carried out throughout the research, these workshops complemented the theoretical scaffolding of the work and provided opportunities to articulate the insights to new audiences. As outlined in the chronology of methods in figure 3.1. (p.67) these workshops contribute to the reflective phase of the work, guiding toward insights for the overall value of TDfD concepts.

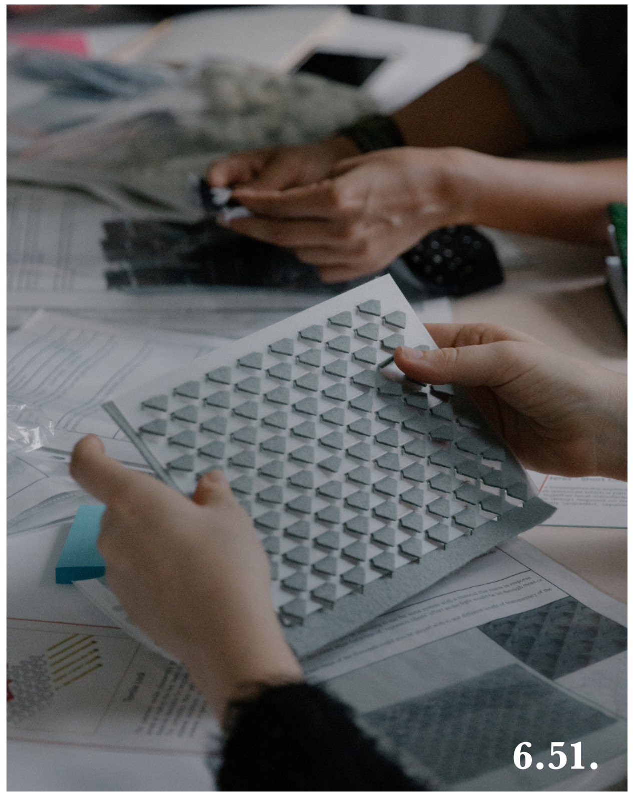
Based on the idea that "every object made by man is the embodiment of what is once thinkable and possible" (Manzini and Cau, 1986:17) the samples illustrate a new realm of possibilities for material combinations. By using them as input in a redesign processes, innovation can be propelled to a further level by building on the suggestions of TDfD material combinations.

Triggering deeper redesign processes

The concept of design driven material innovation has been trialled in contexts such as in the Trash2Cash project. This approach suggests that materials should be developed in the lab with the final use in mind from the outset. "Aiming for designing properties for unknown material and futures innovations" (Tubito et al., 2019:14) in this way deeply challenges the design process. This approach to design is taken on in this work in the way that the materials developed in sampling TDfD drive the innovation and suggest new and more circular use patterns.

6.49.

6.50.



6.51.

6.49. Picture of the samples laid out alongside inspiration cards at the start of a redesign workshop.
6.50. & 6.51. Students handling samples in the ideation phase of the workshops.

Moreover, the samples are instrumental in breaking down the barriers between design disciplines and encouraging a product designer to design the materials that go into the objects they make rather than selecting them from available lists. This increased agency of the designer in all fields can steer deep changes in the ways products are made and enable the development of circular systems. Parisi et al. also argue that starting a design process with material tinkering rather than from the object concept is "a practice that may drive innovation and uniqueness in design" (Parisi et al., 2017:s1168).

The use of the samples as models in workshop settings shows how this textile design-led understanding of TDfD can guide the outcome towards circular systems. The aim of this research is therefore to provide insights and a methodological framework to follow for the implementation of TDfD in this material development stage of the design process, allowing for core innovation which enables ease of recycling.

6.3. Tracing the Thought Process in Making TDfD Samples

While the making process resists an explicit description (Harrison, 1978; Igoe, 2013; Philpott, 2013), the samples that are created act as markers of the thought paths taken in the activity. As this study focuses on the role of designers in exploring solutions to blend recyclability, the processes used to achieve this are analysed to provide the most appropriate outline for the transferability of this approach. In this section, the paths of the exploratory practice are retraced to understand the stages and challenges encountered when designing and making textiles for disassembly.

6.3.1. Understanding the Evolution of Assembly Techniques through Practice

The mapping presented in this section shows how the samples have evolved the concept of TDfD from the initial triggers embodied in the case studies to iterative versions of textile samples. As defined in the overarching methodological framework, this phase combines a mapping and reflective approach to draw transferable techniques from the making of samples. The approach to this retrospective analysis of the process, and of the insights for TDfD which come from it, once again, is closely tied to the specifics of creative textile design practice.

Mapping samples

As well as formulating hypotheses, the samples are a way of keeping track of the thought process involved in the making. Indeed, techniques and concepts can be traced back chronologically through the various iterations, showing how the use of the TDfD brief influences the design process. In several instances whether in the laser cut or the woven samples, the evolution of the techniques can be traced from the initial inspiration found in the case studies, through several iterations to adapt the scale and function of the components to the materiality of textiles. The experimentation with different types of combinations carries on until the idea runs out of breath, or a level of satisfaction or of frustration in the results is achieved, that allows a shift towards a new concept.

As the approach to textiles taken here relies heavily on tacit and experiential knowledge (Igoe, 2013; Karana et al., 2015), it is articulated verbally only with difficulty (Harrison, 1978:45). These samples therefore help in materialising the journey through the design process and act as a form of journal to be reflected upon and retrospectively understand the causality between ideas, thus carving a path to replicate this process rationally. This thoroughly examines the stages of the design process without interfering with the flow of the activity in the making.

There is a form of thought which is specific to the craft process involved in sampling textiles. The repetitive and sometimes painstaking process of assembling small parts by hand or of weaving on a dobby loom, which generates a state of mind, labelled "productive monotony" by Poynor (2016:62) is a key aspect of textile making and a contributor to the creative process. This meandering can however be limited by heavy notation and documentation in the act of making. Indeed, textile design researcher Rachel Philpott describes how enforcing a protocol over the activity inhibited the creative process and froze the progress of her research, making it "too risk-averse, constrained and rigid to develop innovative and original ideas". She goes on to describe how "the challenge of documentation disrupted the flow of the studio practice leading to a loss of spontaneity in [the] making processes"(Philpott, 2013:2).

To extract insights from this loose creative process, a retrospective study of the samples was instead used to understand how the concepts evolved. The mapping of the samples presented in figure 6.52. lays out the results from this experimental phase with anotations concerning the ways the sampling evolved to yield four TDfD assembly techniques.

The insights gained from this process provide a clearer understanding of how the circular economy brief shapes the practice of textile design. As can be seen in figure 6.52. the samples are clustered in groups in which the same technique is applied in very similar ways. The description of the transition to a new cluster and the way the technique evolves is annotated along the arrow which connects these groups in a chronological progression away from the initial sample.

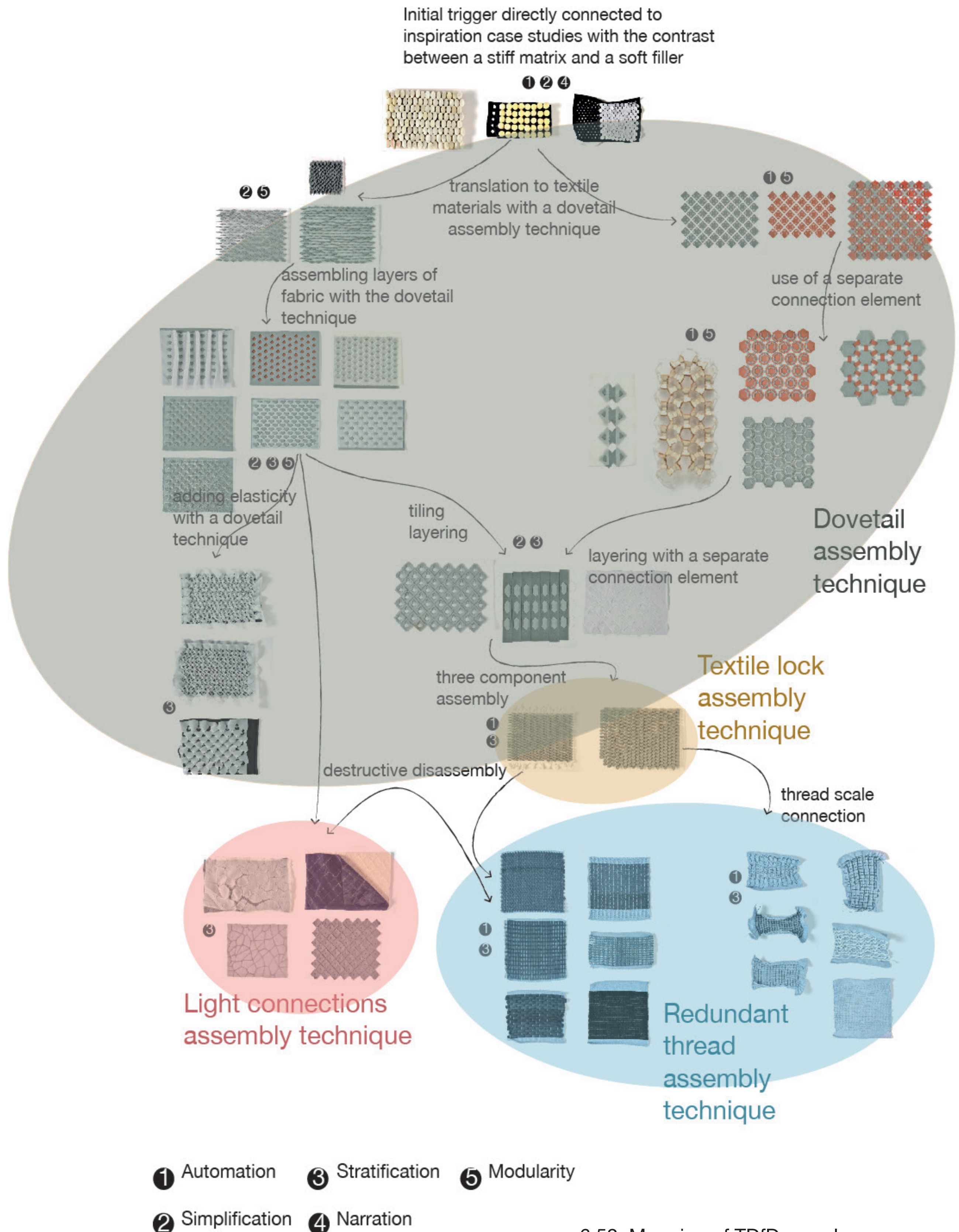
Additionally, each group of samples is connected to the design briefs with the numbers referring to each of them highlighting their influence as an inspiration. This understanding of the mechanisms of the free-flowing and exploratory sampling process is instrumental in the development of a framework which can help in replicating this approach to TDfD in other practices.

Tracing the evolution of techniques

The mapping shows the chronological evolution of the samples and the associated techniques which they embody. Following Manovich's description of direct visualisation which "rather than representing text, images, video or other media through visual signs such as points or rectangles" builds "new relationships out of the original media. Images remain images, text remains text"; in this case, samples remain samples (Manovich, 2011:41).

It is worth mentioning at this point that the visualisation represented here was first carried out using the real samples laid out on a long table to show the different stages of the work, relating them to each other with descriptive labels and arrows. This use of real space "to represent key differences in the data and reveal patterns and relations" (Manovich, 2011:36) is here translated onto the page to show how the trial and error process progressed.

The first samples made as part of this project are therefore placed at the top of the visualisation. The first sample made following the DfD brief was



6.52. Mapping of TDfD samples.

directly inspired by Bjorn Ischi's bone chair (case 16 p.107), following the idea of having a stiff matrix with soft elements that are compressed to stay in place within this grid. The technique was only slightly adapted from the product inspiration, as it was reduced in scale and plain foam was used instead of the upholstered cushions in Ischi's design. The sample triggered a series of experiments loosely derived from this technique. In the following iterations it can be seen that an effort was made to miniaturise the connection elements and to make the samples more textile-like. The assembly technique was also transformed into a dovetail shape, inspired by examples of DfD in other types of product design, most noticeably using wood as was recorded in the private blog.

From there on it can be seen how different approaches to textile assembly techniques branch off and evolve and, at times, converge again to create new effects. At each stage, the briefs extracted from the DfD categories as well as the concrete examples given by the case studies have fuelled the creative experimental process, here marked with numbers referring to each trigger.

The patterns in the evolution of techniques can be observed through this mapping. It can be noticed that the different sampling techniques used, whether this was felting, weaving or laser cutting, led to different types of progression of the ideas in the series of samples. The weaving process, for instance, is linear. The samples are made one after the other, with each sample finished and tucked away in the rolled-up warp before the next one can be started. This led to a fairly contained series of samples in which a clear chronology of the evolution of the technique can be traced. On the other hand, in sampling with fabric components, the creative process was less linear. The making was undertaken in sporadic spells of access to laser cutting facilities and subsequent assembly by hand. This meant that several ideas were pushed forward simultaneously. The influence of this difference in process can be read in the evolution of the sample iterations laid out in the mapping.

6.3.2. Four TDfD Assembly Techniques

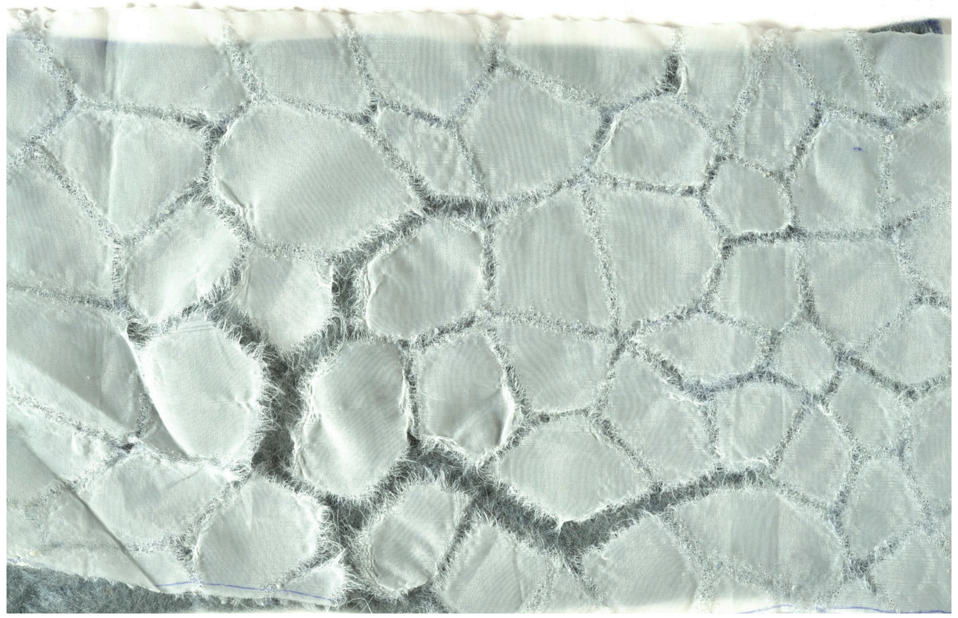
The mapping has provided a comprehensive view of the samples which highlight four main types of assembly. This body of practice is essentially aimed at developing assembly techniques for detachabe textile

combinations. Through the free-flowing textile sampling carried out here, a range of ways to connect different components was developed. They are presented grouped into four categories which are named and described in this section. This offers a focus on the ways in which the samples demonstrate assembly techniques which can be replicated in new contexts for TDfD.

Light connections

Following the incentive to replicate qualities found in laminated and coated textile, this assembly technique suggests ways in which a layer can be attached to a base fabric using felting as a connection. The felting works as a replacement for sewing between two or more layers in a quilted type combination. The fibres punched through the top layer provide sufficient fastening for the layers to be held in place, but is light enough to let the layers be peeled apart when needed. The fibres coming through the top layer create a pattern that can be designed in a variety of ways, as long as the connections achieve a balance between their solidity and their ability to be undone. This technique uses fibres as the connecting element between two layers of fabric, therefore crossing over between two scales of components as described earlier (see 5.2.3. p.136).

As can be seen in figure 6.53. this type of assembly method leads to a destructive disassembly in which the top layer can only be recovered for recycling rather than reuse. The lower layer, dependant on the material



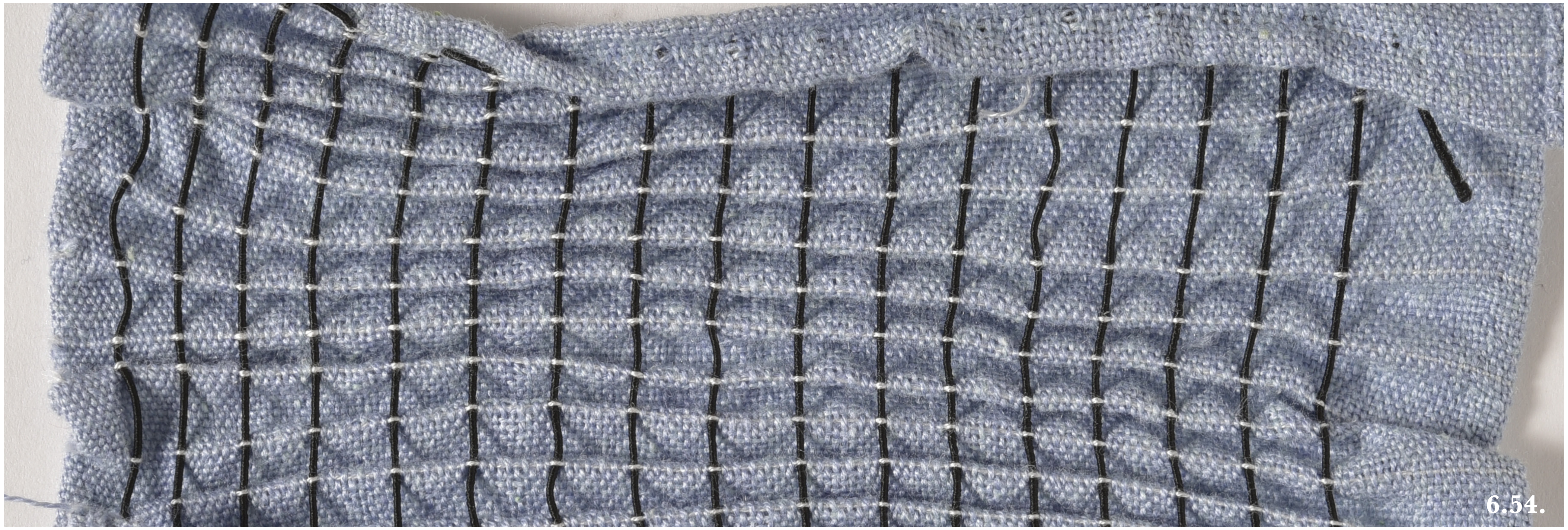
6.53. A two layered felted sample after being disassembled. The punching has damaged the upper layer making it impossible to reuse. The felt base layer shows minimal traces of the disassembly and both layers can be recovered for recycling.

it is made of, can be recovered with only minimal traces of the connections.

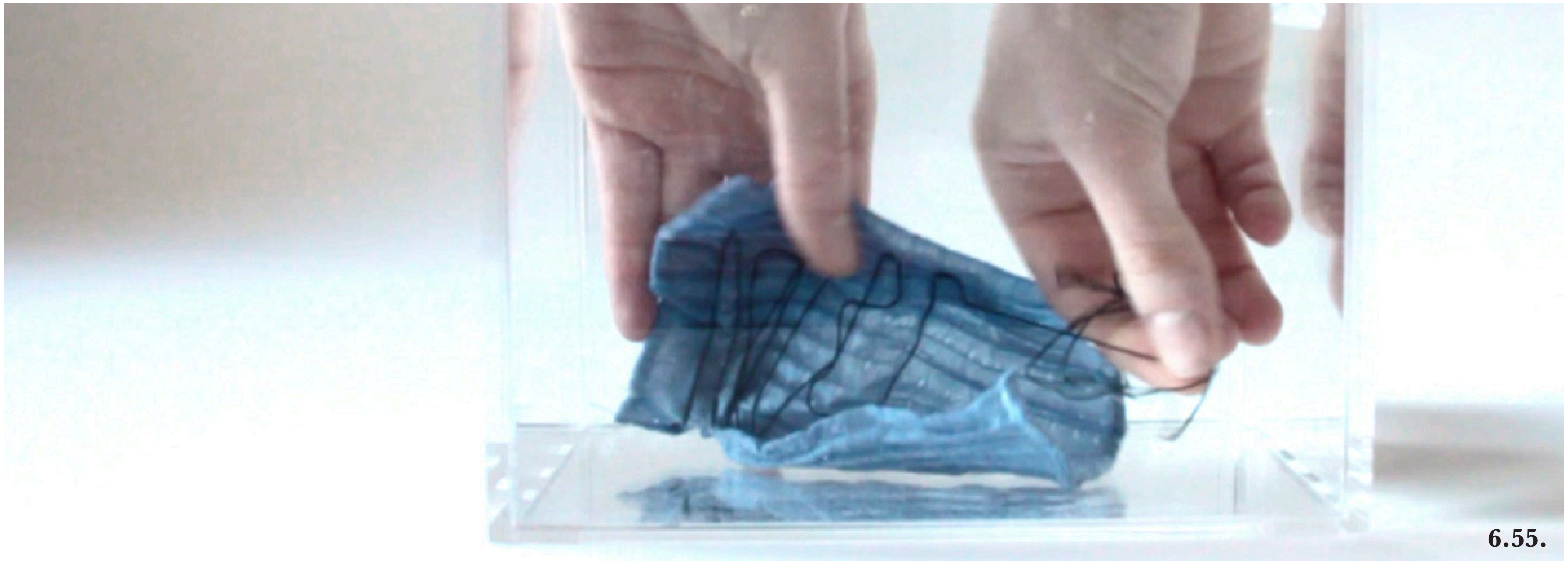
Redundant Thread

In weaving, it was found that the structure of the weave could be adapted to double up as a connecting component. By integrating a small variation in the pick for a soluble thread to run alongside the main weft yarn, this could be used to secure an additional layer on top of the base canvas. In the samples presented here this additional layer is either a thread which can cover, add structure or elasticity to the cloth, or an entire woven layer.

In this type of assembly, the connection elements are embedded within the structure of the fabric as redundant threads which are not integral to the structure of the cloth. This uses the thread scale of components defined in chapter 5. This intricacy of the connection will lead to a partially destructive disassembly in which the additional layer will only be recovered at the thread scale, making it suitable for recycling but unlikely to be effective for reuse. The base cloth however is engineered so that the disassembly doesn't impact its structure and can be reuse as a simple mono-material cloth. The still from the disassembly video of a woven sample shown in



6.54.



6.55.

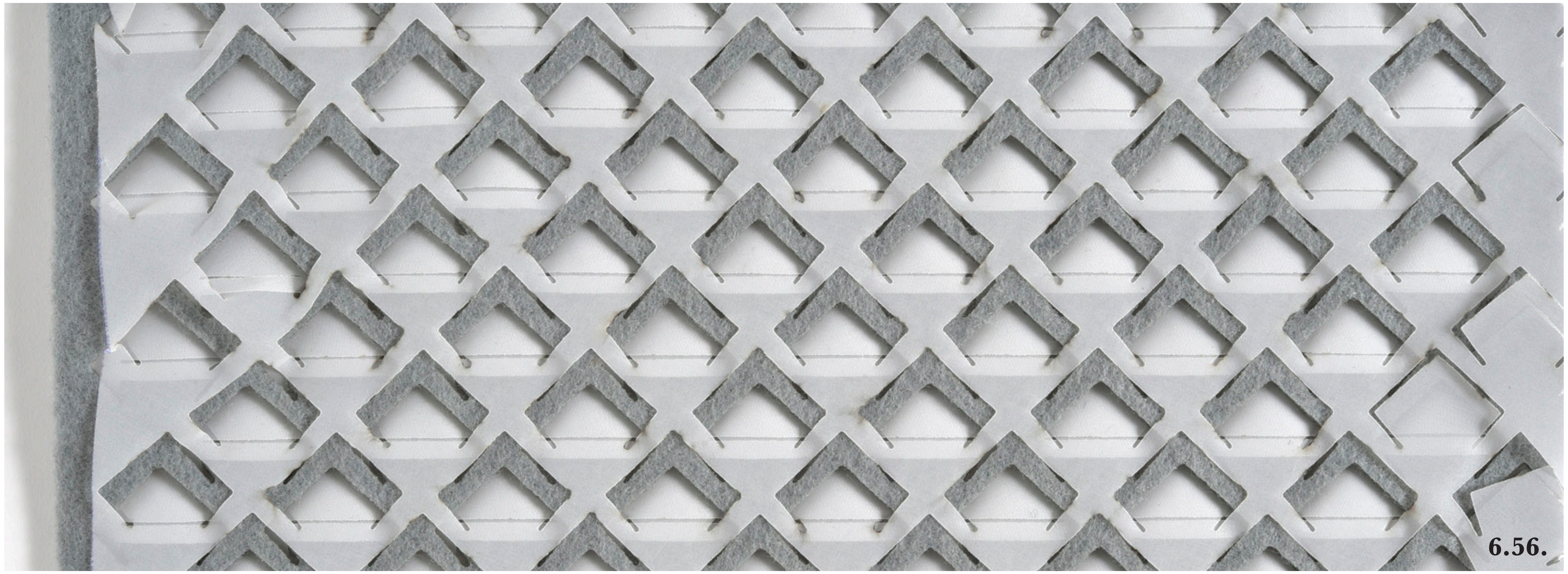
6.54. Woven sample with an elastic threaded vertically and trapped in warp threads giving the combination a smocked effect conferring elasticity.
6.55. Still from the video recording of the disassembly of the sample in 6.45. The elastic thread is connected to the base cloth with a soluble thread that can be dissolved in water as demonstrated in the video.

figure 6.54. demonstrates how the elastic is recovered as a thread whereas the base cloth stays intact.

Dovetail

The samples made using laser cutting almost all used a variation on a dovetail assembly system which allows the different layers to lock into each other and only rely on the widening of the connection elements beyond the slit in which they are inserted to hold the elements together. In a similar way to the light connections felted samples the Dovetail assembly allows the layers to be peeled apart by hand. However, this assembly system is purely effected at the scale of fabric as defined in the chapter 5 (see 5.2.3. p.136).

Such an assembly method leads to a reversible disassembly and can be carried out by the user at any stage of the product's lifecycle. As shown in figure 6.57. the layers can simply be peeled apart by hand. This technique has also led to a variety of aesthetic effects as the connection elements double up as embellishments in a way which



6.56.

6.57.

6.56. Three-layered laser cut sample with a dovetail assembly system.
6.57. Disassembly process picture for a laser cut sample demonstrating how the layers can be easily peeled apart with no specialist tools simply by holding on to the edges of the material and pulling, the dovetail automatically releases the slitted layer.

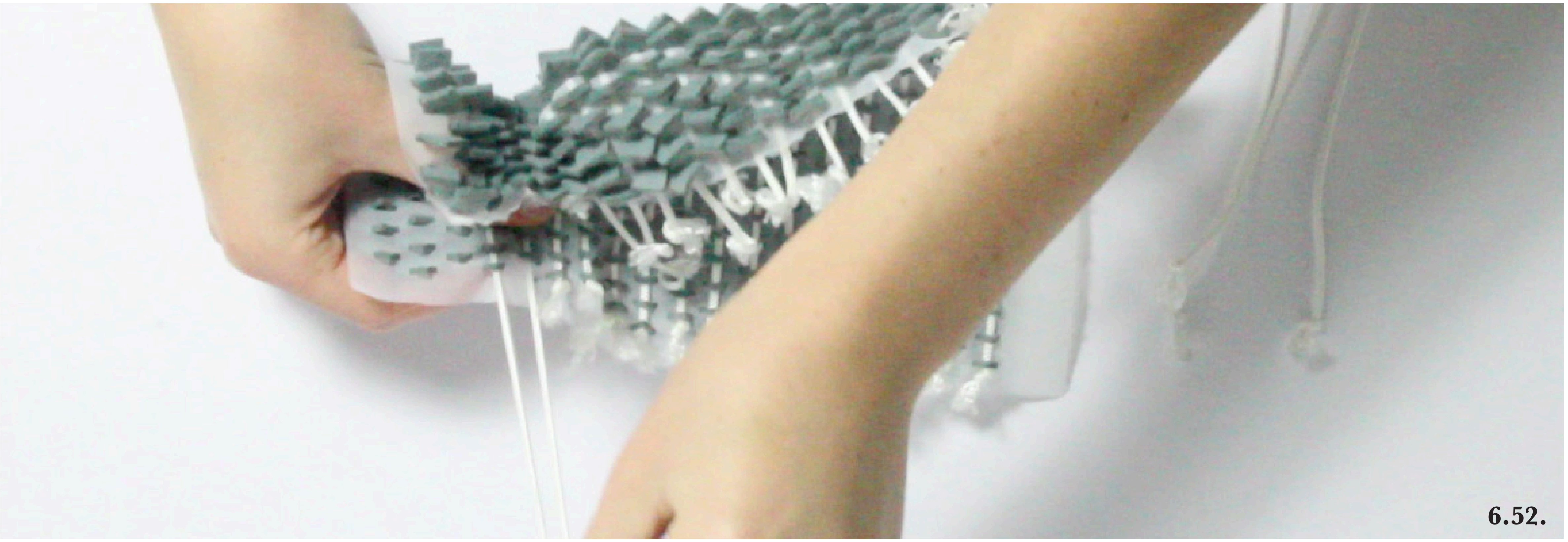
reminds one of sequin effects or embroidery techniques.

Textile Lock

The Textile Lock is a variation on a Dovetail assembly system, but it is relevant to address it separately as the lock here becomes a third element in the textile combination. The scale of assembly can vary between threads and different sizes of fabric pieces. Making the connection systems a third element can make the top layer cover the bottom one, which was more difficult to achieve with the earlier versions of this technique described above.

This approach to connecting different elements can also lead to a reversible type of disassembly, however the intricacy of the connections in the samplespresented in figure 6.59. for example may make it less accessible to a lay person and requires some skill and dexterity which are usually part of the expertise of a textile designer. In later iterations of this technique the locking system was simplified to make it more available to users as

6.51.



6.52.

6.58. Close up picture of a sample made of felt 'sequins' threaded through with a cord locking them in place against a polyester cloth.
6.59. Still from the video showing the disassembly of the sample in 6.58. It shows how the sequins are removed after pulling the cords out by hand.

will be demonstrated in the next chapter.

6.4. Conclusions: TDfD Techniques for Detachable Material Combinations

This phase of exploratory making has put into practice the understanding of the issue described in previous chapters. This deep dive into the mechanics of textile sampling articulates the potential of this approach to problem solving and shows the TDfD process in a reflective mapping.

Proof of concept for TDfD

The adaptation of DfD concepts observed in the practice and literature review to the sampling of textile combinations has proven the potential for this strategy within creative textile design practice. Where very few examples existed prior to this research, the portfolio of cases has now been expanded to include various types of TDfD at the fibre, yarn, and fabric component scale. These samples prove the technical feasibility of TDfD with conventional textile sampling equipment. The samples demonstrate the effects that can be achieved with TDfD techniques through the filter of the author's practice. Filling a gap in knowledge where very few examples of DfD at the textile scale existed, the samples propose a new corpus of practice for the field which shows the applicability of the approach at the three scales of components detailed in chapter 5.

Samples as tools for discussion and ideation

The samples also turned the practice outwards by exposing the reasoning for TDfD to experts in the field of circular design and generating new ideas in short workshops. The samples proved to be valuable boundary objects to express with more precision what TDfD can be, and to act as a starting point for innovative concept development. This material-driven approach to designing for a circular economy not only challenges the ways in which we design products but also allows designers to take the creation of new materials within their own hands. The samples are left open in terms of the materials that can be used in the combinations they suggest and demonstrate techniques which can be further adapted for a set brief. This partially resolved quality is aimed at allowing for easy appropriation by other designers to adapt TDfD for their own practice.

Insights from tracing the thought process

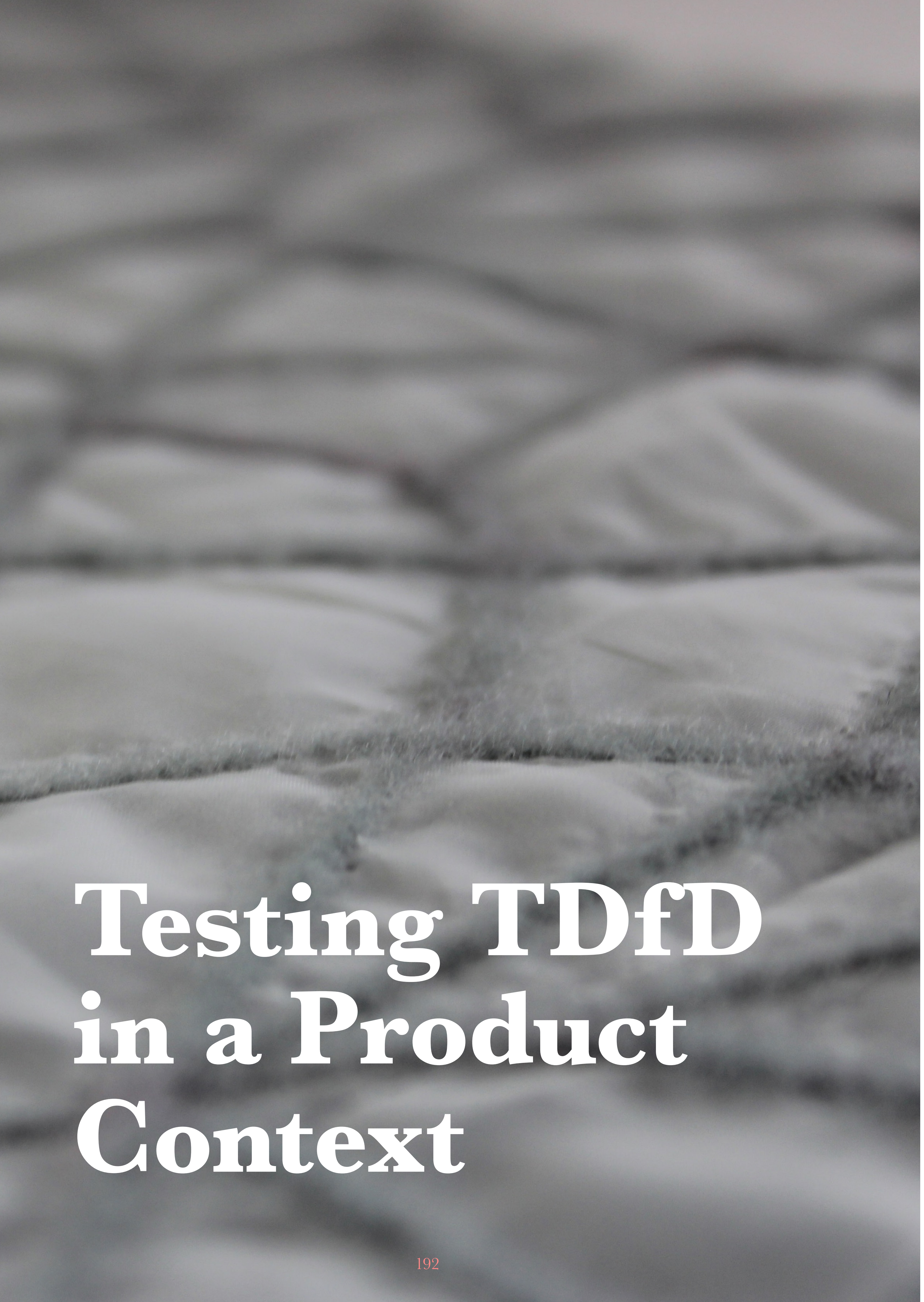
While textile design as practiced in this research is a craft-based process, heavily reliant on tacit knowledge which resists articulate description and analysis, the materialisation of concepts in experimental sampling and the subsequent mapping and reflection allows for a better understanding of the process. In laying out and grouping the samples, four types of assembly for detachable connections at the fibre, yarn and fabric scale are represented. In this round of sampling the benchmarks to reach were propositions for alternatives to stretch and laminated textiles. The exploratory practice has shown how this process may lead to original effects which reach beyond a strict replica of the reference problem blends. Following from the focus on the designer's perspective throughout this work, this chapter has offered insights regarding the process involved in TDfD.

As defined by Tufte (1990), visualisation assists in the recognition of patterns and generalisations, already an inherent quality of the human brain. This highlights the mechanics of exploratory creative textile design practice. The mapping of the samples created in this experimentation with TDfD has shown different patterns in the evolution of ideas, whether considering weaving or laser cutting practices. Indeed, the linearity and chronological aspects of the weaving have led to a more step-by-step evolution of the use of TDfD with subsequent merging of different approaches, whereas the more simultaneous generation of samples with laser cutting has shown the effects of testing at multiple scales and of allowing for higher failure occurrence.

Insights for TDfD

This chapter has highlighted the potential for textile design practice to offer valid insights in the development of circular design solutions. In laying out the brief for the textile sampling and the way in which it loosely guides the making process, this offers a framework for the transferability of this model to other practices.

This study thus reframes textile sampling techniques in a TDfD context for a circular economy. By showing how these adapted techniques emerge, through textile practice, as answers to a circular design brief, this work suggests a path for innovation that can reach beyond this context. Moreover, the phases of unrestricted exploratory making followed by reflection on action demonstrate the effectivity of this textile thinking approach to problem solving.



7. Testing TDfD in a Product Context

Building on the insights from making TDfD samples, this chapter goes into the detail of the exploratory work which tests the applicability of the techniques described in chapter 5 to a product context. The samples inform the redesign of a jacket reference product, the techniques enable the creation of detachable connections in two iterations on this product brief, one within the context of the context of the Mistra Future Fashion project, and the other as a return to solo practice. The variations between the two jacket prototypes are then reflected upon to understand the effect of TDfD on the design process and outcomes as well as on the systems they embody.

Using DfD approaches as part of garment construction has been explored in many different ways across the field. As put by Sandy Black, the question “Could interactive clothing, designed for disassembly into its component parts point the way to positive solutions for sustainable fashion in the future?” (Black, 2012) has driven practice in the field for a number of years. The fashion examples shown in chapter 4 represent but a small portion of the research in this area. Other designers, such as Hussein Chalayan with his series of transforming dresses as shown in figure 7.1. or Jonna Haeggblom (2017) who’s modular garment concept is demonstrated in figure 7.2., have used magnets or woven strips as a way of assembling different product or garment components and enabling disassembly, transformation, or customisation. Other more high-tech approaches, such as Naila Altani’s bio-protein strip assembly system, used to make the garment shown in figure 7.3, are engineered for repair and disassembly for recycling.

TDfD offers a material-driven (Karana et al., 2015) approach to blends which is complementary to these construction-focused examples. This phase of prototyping offers a new perspective on the potential of TDfD by moving into a product context only once the sampling has shown the range of available techniques. Instead of suggesting a solution to a specific product problem, the samples show a repertoire of techniques that can be applied to various different products. This chapter shows how TDfD was applied to a jacket concept in the context of a collaborative

7.1. FW 13/14, Hussein Chalayan (Blanks, 2019).

7.2. Unfinished Stories, Jonna Haeggblom (Haeggblom, 2017).

7.3. Seam Unseam, Naila Altani (Central Saint Martins College of Art and Design and MA Material Futures, 2019).

research project as well as in a second iteration on a similar jacket brief, but which was removed from this collaborative context. The insights from this process feed into the development of a methodological framework for TDfD which can reach beyond this product type.

7.1. Making the Service Jacket

The product redesign brief offers an opportunity to test the TDfD approach in complex products and material combinations which can later be taken apart into recyclable components. The first iteration of this brief shows how TDfD was incorporated into a wider research project to act as an enabler for the multiple remanufacturing stages of a long-life circular garment concept, the Service Shirt. As a large research project, the Mistra Future Fashion programme provided a wealth of insights regarding LCA results or even new business models which offer a detailed perspective on the potential for TDfD in product context.

7.1.1. The Service Shirt Context and Brief

The Service Shirt suggests an ultra-long-life garment system which starts with a white polyester shirt which is overprinted with new patterns three times before being transformed into the lining of a jacket to further extend its use as a garment without creating any barriers to its later transformation into jewellery which in turn will be fed into a regenerative chemical recycling system so that the whole cycle may be repeated 50 years after the white shirt is put to market. Each stage is the work of a different designer. This section lays out the context for the project before narrowing the focus to the jacket transformation which relies on a TDfD approach.

The Mistra Future Fashion Context

The service shirt concept was developed by Professor Becky Earley as part of a design-researcher in residence program within the Mistra Future Fashion consortium based on learnings from longitudinal practice using shirts as a vehicle for sustainable design strategies. The Mistra Future Fashion program is a Swedish research program involving a consortium of over 60 partners across Europe. The program's aim is to challenge the fashion system beyond the choice of fibres and propose systemic improvements to achieve a future positive fashion industry. The program involves scientists, user behaviour experts, academics and brands across four themes looking at design, supply chains, users, and recycling. The University of the Arts London was mainly involved in the Design work package and it is within this framework that the work described here took place. The author was brought into the project in the final stages of prototyping the concepts for a circular fashion system exploring different speeds of production and use. This part of the program explored the idea of fast and slow fashion as complementary strategies for sustainability within the industry. This design researcher in residency program used workshop methods to challenge the way in which designers within the brand create garments for a more circular economy (Pedersen et al., 2018). Filippa K, the Swedish brand involved in this partnership is already committed to best practices within the field and has a dedicated line of "frontrunner" products designed to pioneer these improvements in the form of commercially available garments. In the workshops, the brand developed two concepts side by side: an ultra-fast garment and an ultra-slow garment (Earley and Goldsworthy, 2015), while the brand was pushing to take these concepts to a commercially available product stage, the design-research team took the project into a more concept-led and future-probing direction, freeing themselves from the constraints of immediate profitability and industrial efficiency. The service shirt therefore explores the possibilities offered by an ultra-long-life garment system.

The Service Shirt concept

The Service Shirt concept suggests an extended lifecycle for an ultra-slow fashion garment. This is enabled by multiple transformations throughout the garment's life. The DfD strategies come into play to facilitate one of these transformation phases. It enables both remanufacturing, and future disassembly to let the garment access the next stage of its life cycle. This application of TDfD to a framework that is already developed into other aspects, such as the business model or prior life cycles for the garment, helps to achieve the aims of this study by proving the validity of TDfD strategies beyond the textile samples and in the context of a circular economy. While the samples provide an inspirational source of possible TDfD techniques, the application to a specific product context gives grounds on which to assess their environmental benefits. Furthermore, this application to products tested the feasibility of the sampled techniques to product prototyping scales, the lessons from this exploration are later reflected on to draw insights for other practices.

The increase in value afforded by the multiple transformations through several shirt patterns, a jacket, and then jewellery, upgrades the product to a new use phase when it would otherwise be discarded for being worn or out of fashion. The effort to renew the interest of the consumer in this second-hand, yet new, product and keep the materials in constant use is a driving element of the concept. Waste is often defined as a failure in the relationship between the object and its user (Chapman, 2005), this system therefore uses this remanufacturing approach to maintain interest in this product relationship. Such a strategy has been developed in Earley's longitudinal practice with shirts and sublimation printing as well as with projects which show ways of transforming a shirt into a jacket (www.textiletoolbox.com). The Twice Upcycled project (Earley, 2008) specifically demonstrates the potential for creating emotional value and extending the lifecycle of a garment through over-printing and remanufacturing in successive phases. The Service Shirt builds on Earley's experience and expertise in this field and expands the process to new business models and collaborative practices. The holistic approach to the system avoids one of the pitfalls of upcycling or remanufacturing, which is that the transformation stage often incur a contamination of the resources, and while it extends the lifespan of the product, it ultimately prevents effective recycling. Here all the elements of a circular fashion system have been considered in coordination to allow for a fully regenerative life cycle.

This model proposes a system in which the highest value for the materials involved can be recovered and profited from by the brand. Rather than new materials, it is the time spent by the maker in upgrading the product which creates the added value. In a circular economy where the creation and circulation of value is decoupled from resource extraction, this treatment of products in order to retain their economic value is essential. Walter Stahel goes on to describe how in a performance, or loop economy, man power can substitute energy and material extraction (Stahel, 2006:71). This circular garment system thus suggests a way in which this can be applied to textiles.

This work took on a future probing approach to exploring patterns for production and consumption of long-life garments. Several aspects, such as the detail of the commercial profitability of the system were left beyond the scope of this project. The Service Shirt concept nevertheless offers an understanding of the potential of multiple remanufacturing loops as a way of reducing the environmental impact and increasing the circularity of a garment system. Moreover, in the context of this study, it offers a framework for the evaluation of TDfD in circular fashion systems.

As shown in figures 7.4 to 7.9. the aesthetic of the garment is renewed with each transformation, going from a basic white top, to variations on colour and texture, a textured black, then transforming into a jacket, and finally a set of necklaces. With the same initial set of raw materials, six completely different fashion experiences are made possible.

As part of a trans-disciplinary research project, the design concept was assessed through life cycle analysis (LCA). The environmental improvements from an extended 50-year life-cycle shirt were quantified to assess the relative success of the model in reducing a garment's impact. LCA provides a framework to compare the impacts concerning a selection of indicators such as global warming, resource depletion, or energy consumption, against a reference product with equivalent functions. It acts as a judge of the real improvement that the suggested innovation delivers.


7.4.


7.7.

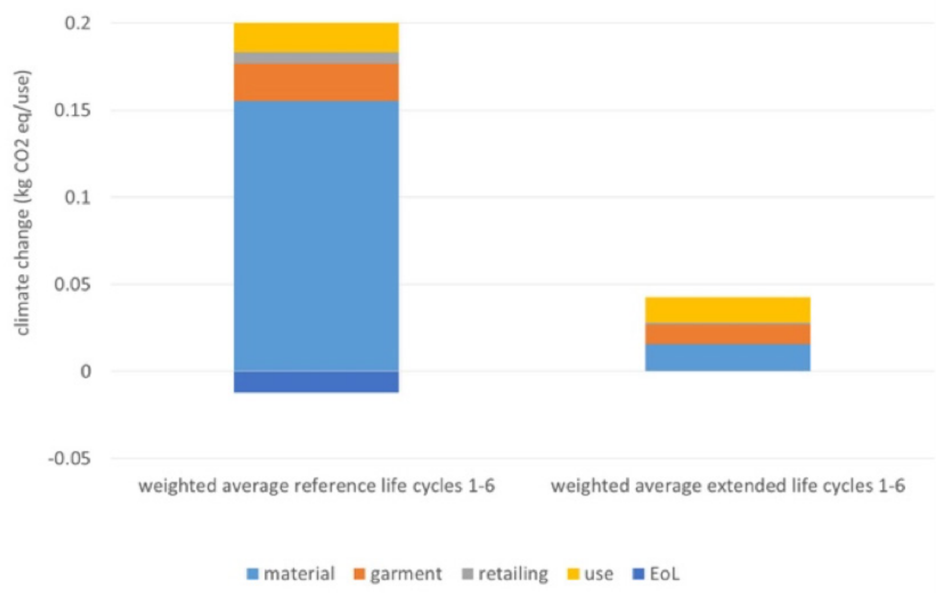

7.5.


7.6.

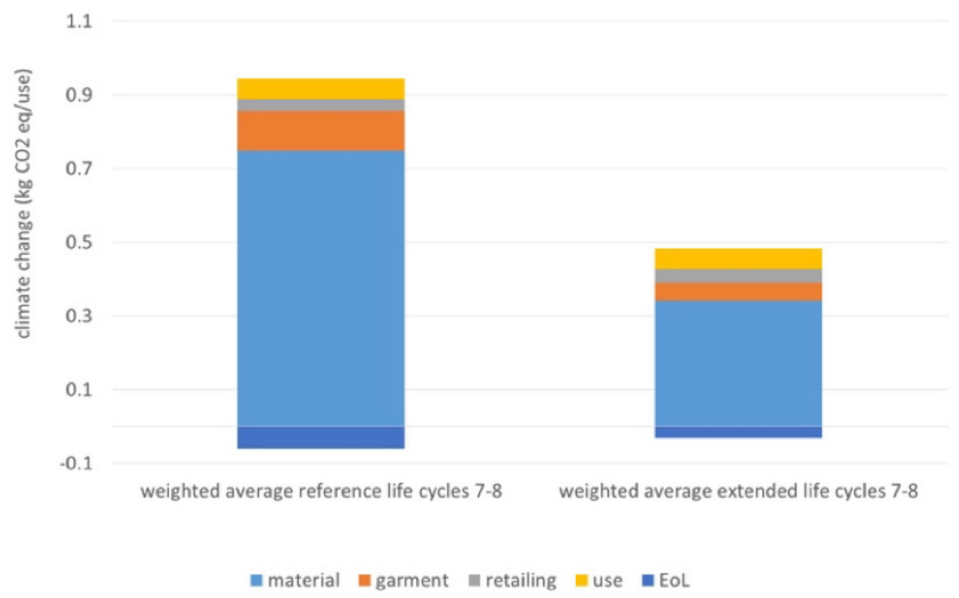

7.8.


7.9.

7.4. The Service Shirt as a white top.
7.5. The Service Shirt after the first over-print, a light and eye-catching pattern.
7.6. The Service Shirt after the second over-print, creating more complexity with the dark over-print through which flashes of colour can be seen.
7.7. The Service Shirt after the third over-print, turned to black but still with a deep texture, the result of the over printing.
7.8. The Service Jacket.
7.9. The jewellery made from the jacket, looping the polyester felt to create a statement piece.



7.10. LCA Results for the shirt over printing (Peters et al., 2018).



7.11. LCA Results for the jacket transformation (Peters et al., 2018).

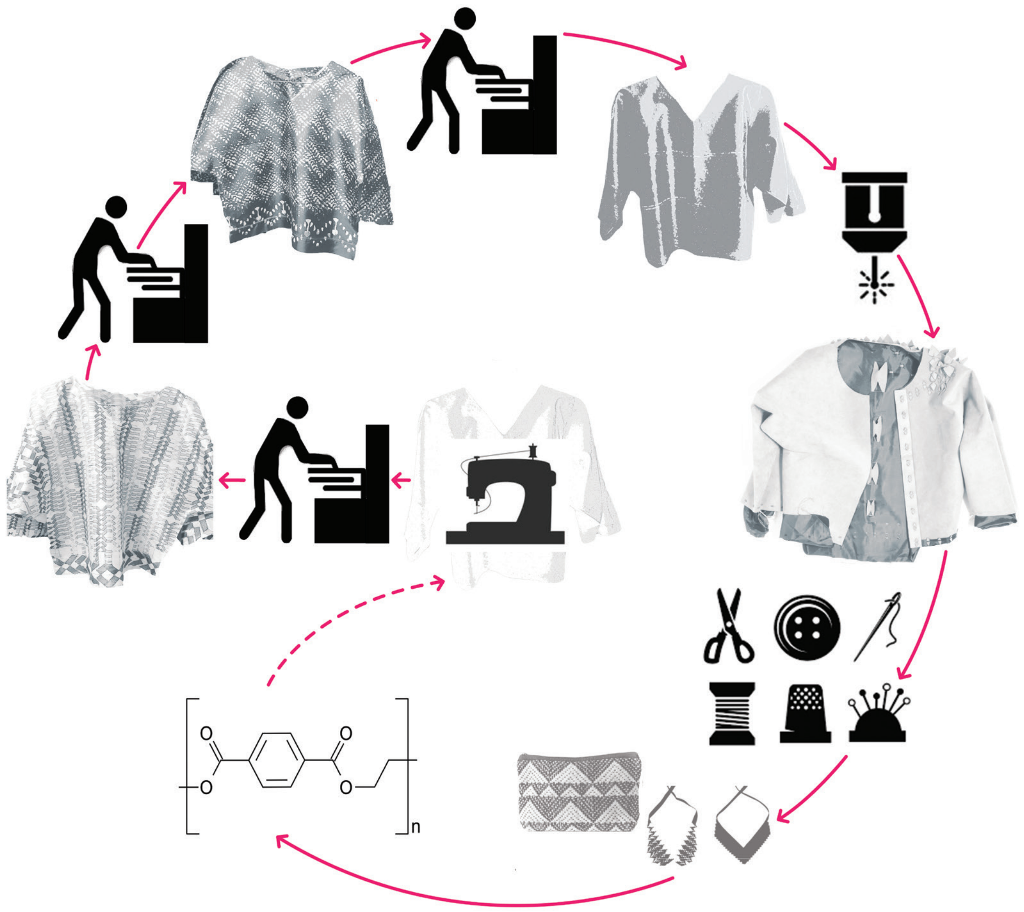
In the case of the Service Shirt concept, the LCA shows that the improvement over a reference polyester shirt that is replaced entirely for every time that the Service Shirt is reprinted, is considerable. Indeed, it is acknowledged that using the same materials to provide the use of a 'new' shirt will lower the overall impacts. As stated in the LCA review of the concept:

> "The extended long-life garments considered in this assessment are superior to reference long life garments of the same mass according to this assessment. This superiority is primarily a consequence of avoided garment production via reprinting and reassembly of the initial garment to extend its useful life" (Peters et al., 2018:51).

When applying LCA to the transformation of the shirt into a jacket, the addition of virgin materials is considered as opposed to the shirt overprinting which required very few new materials. However, this new life replaces a jacket rather than a shirt, allowing for environmental benefits over a reference jacket made of equivalent materials (Peters et al., 2018:44). Moreover, the input of new materials allows for a dramatic transformation of the garment which extends the life cycle and use of the shirt materials beyond the overprinting effects.

As put in the Mistra Future Fashion LCA report, the long and short lifecycle scenarios presented are "essentially explorative rather than attempts to model an existing business or behavioural pattern" (Peters et al., 2018:51). As such, they offer insights for future circular systems. The results from the LCA suggest that the Service Shirt concept can propose a valid scenario for environmental benefits through extended product lifecycles. While the value of such a model is explained further elsewhere (Pedersen et al., 2018; Peters et al., 2018) it is here mainly used as a framework for the assessment of the success of TDfD for remanufacturing and recycling.

Figures 7.10. and 7.11 demonstrate the environmental gains over the two assessments. In figure 7.10. the improvement achieved by replacing the need to produce new shirts with over printing is shown with a very clear difference in material extraction impacts. Figure 7.11. shows the difference between the production of a new jacket from all virgin materials against the transformation of the shirt into a jacket. There is a clear reduction due



7.12. The Service Shirt remanufacturing process (Pedersen et al., 2018).

to the use of the recovered resources from the shirt becoming the lining, but as there is still a need for a virgin material outer layer, the results are less impressive.

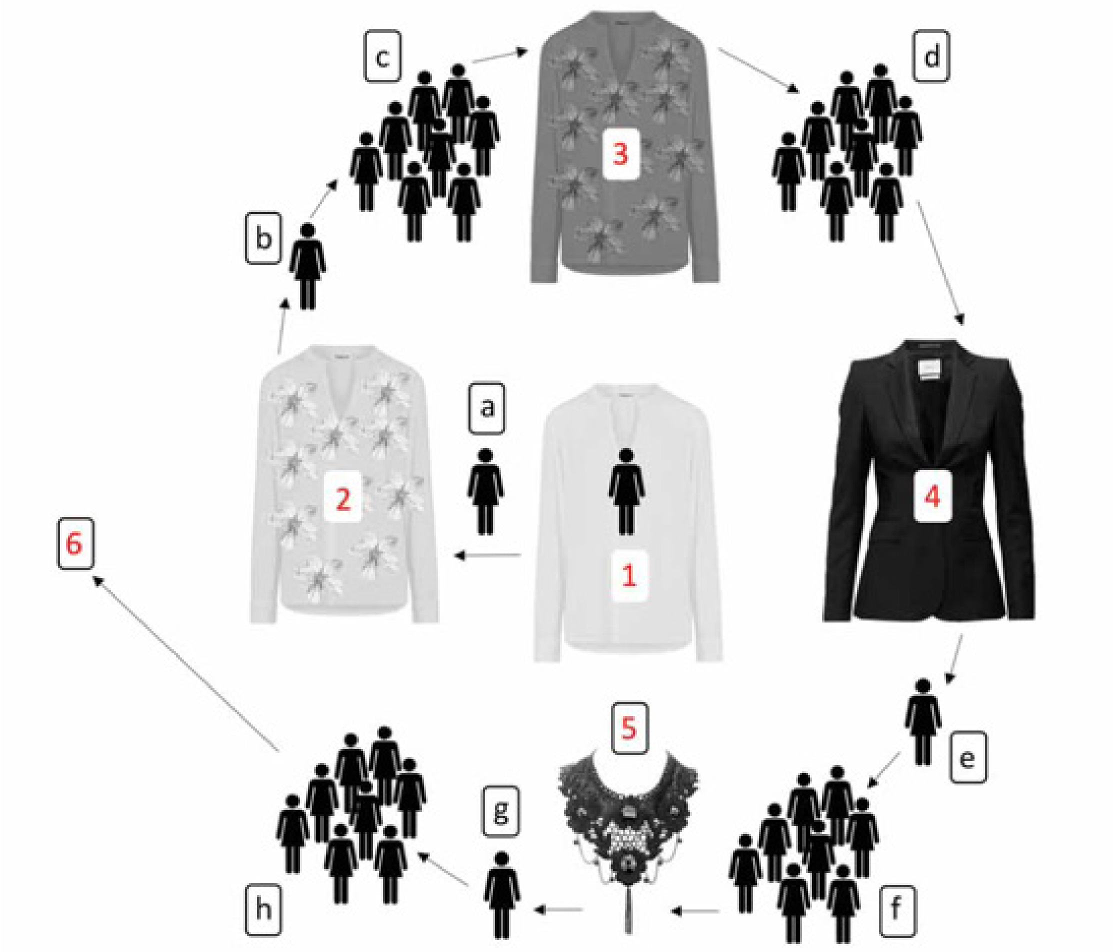
Using LCA assesses the success of TDfD and highlights the way it reduces the environmental impact of the product. In this case TDfD enables the light touch assembly of the shirt to the outer layer of the jacket, removing the need for raw materials in the creation of the lining. Furthermore, it enables the use of the jacket as a resource for the creation of jewellery, offsetting the need for virgin materials there also. The use of TDfD assembly techniques finally allows all of the materials to be recycled chemically without any barriers created by contamination with other materials. The positive results from the LCA therefore confirm the validity of TDfD in reducing a garment's environmental impact.

The Service Shirt business model

The Service Shirt model suggests a 50 year-long life cycle for a polyester shirt which undergoes several transformations as described in the introduction to this section. Throughout these 50 years, it changes form and hands several times, thus keeping the materials in use while the product itself changes. This approach which suggests repeated recycling in which "a certain number of reuse and fabric/fibre recycling loops, followed by a certain number of polymer/oligomer/monomer recycling loops" take place is described as cascading (Sandin and Peters, 2018:363). Such resource circulation strives to conserve value embedded within the product or materials as much as possible despite the inevitable degradation and aging of the materials through wear.

In the case of the Service Shirt, this approach also incorporates several remanufacturing stages as represented in figure 7.12. As put by Rudrajeet, "what differentiates remanufactured fashion from upcycling is the focus towards process-level industrialization to reach certain degrees of scalability. Fashion remanufacturing is achieved through efficient reverse logistics and product development" (Rudrajeet, 2019:2). Such a strategy takes on a mixed approach to remanufacturing as it also incorporates craft based processes which increase the value of the output in an upcycling framework, but maintain a scalability rationale (Child, 2016:270).

The manipulations at each remanufacturing stage are controlled so that



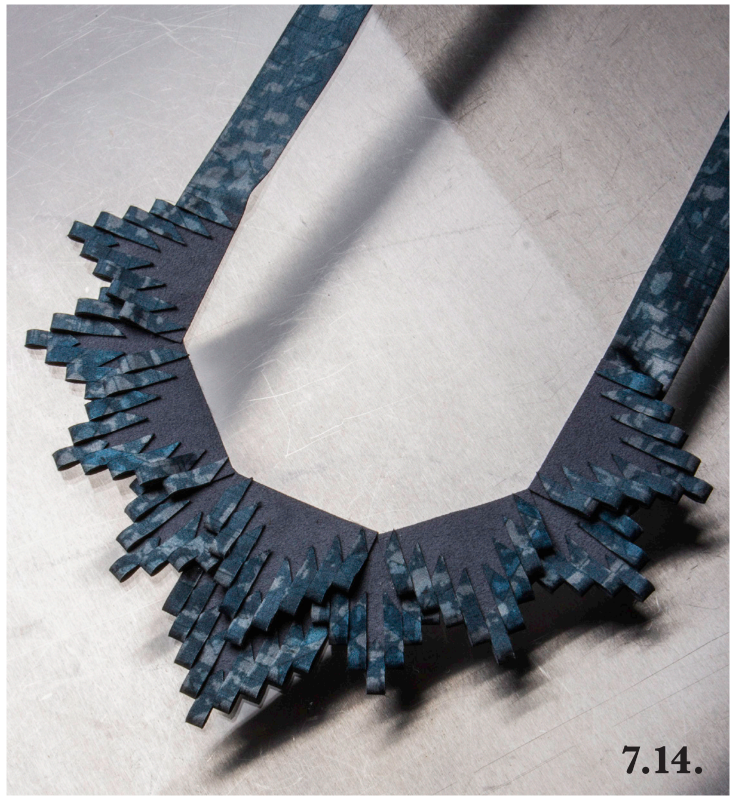
7.13. Service Shirt life cycle, from singular to plural (Pedersen et al., 2018).

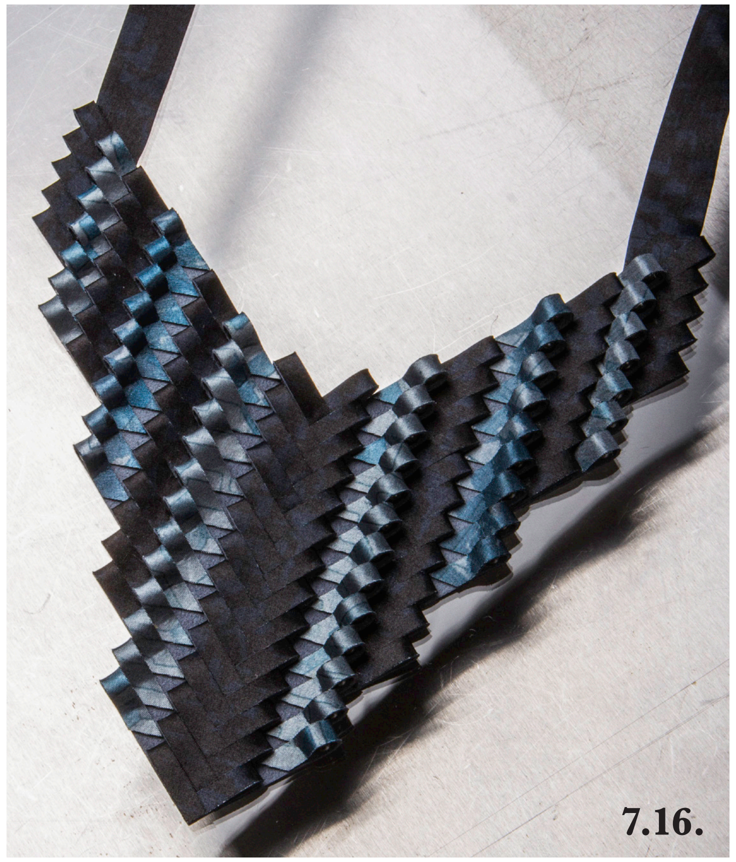
no contamination occurs, and that despite combinations of materials through the sequence of lifecycles, they can be fully regenerated in an ultimate chemical process. This approach positions itself in opposition to traditional upcycling methods in which the quality degradation which occurs through time is offset through material combinations and finishes which create contamination. The application of TDfD to this product system therefore demonstrates that this remanufacturing process from a shirt to a jacket can be effected without contamination.

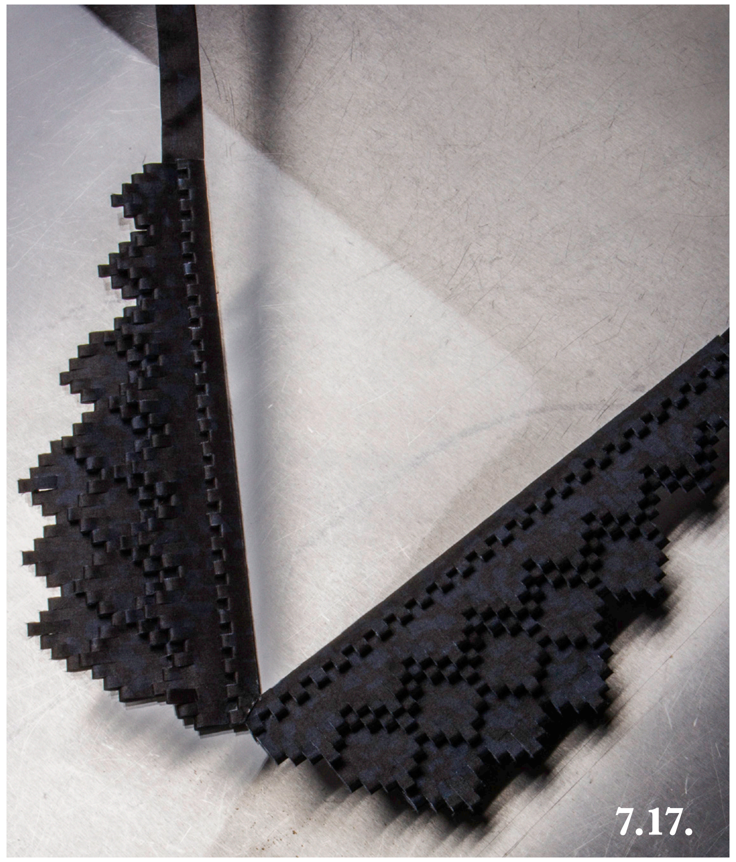
The Service Shirt suggests an extended circular business model which relies on these successive stages of remanufacturing as part of the brand offer. This speculative design concept envisages a business model in which the fashion brand embeds a remanufacturing facility within the retail space to offer on-demand over-printing of the shirt. It suggests a new relationship to customers with the interaction with the brand extending well beyond the initial purchase. This overprinting remanufacturing service extends the products' use several times before it becomes a jacket, at which point the TDfD techniques come into play. The following excerpt and figure describe the full journey of the garment through various ownership phases:

> "Figure [7.13] shows the original purchase by user 1 (1) and the first sharing moment between mother and daughter (a); the first overprint (2) and then handing on to a friend (user 3) after a period of wear (b); the friend trades in the garment to a rental store, where it goes on loan (c) and later gets the second overprint (3). The reprinted garment goes back out on loan (d) before the next recycling process occurs (4). The jacket goes out for private use (perhaps even back to user 1) (e), and then to rental service (f). The next recycling is into an item of jewellery (5) for private use (user 2) (g) and then out for rental (h); before the polyester item gets chemically recycled to reclaim the fiber (6) and the fiber gets used to make new fabric for Fashion Alpha." (Pedersen et al., 2018)

At each stage of the garment's transformation, a different remanufacturing process is used, as shown in figure 7.12. After the first three over-printing stages transforming the shirt from a simple white top, to a bright colourful summer piece, to a bold textured one, and then to a deep and subtly textured black top, the transformation becomes more drastic. It is







7.14 to 7.17. Four prototypes of necklaces made by Katherine Wardropper for the Service Shirt project. Wardropper's artisan technique involves cutting up strips of fabric which are then coiled to create textured effects for craft couture jewellery. The usual techniques were slightly modified through iterative testing to fit the materials and technical challenges of the full circular garment concept.

expected that at this stage the garment is no longer suitable to be used on its own and it therefore becomes part of a more complex article of clothing as the lining of a jacket. In this new phase an Alcantara outer layer is associated to the lining to create a jacket.

With each step in the transformation, the value of the garment increases, giving it a more complex and detailed pattern, or making it into a heavier piece. The scenario plans for a decrease in the intensity of wears, going from a basic which is worn very often to more statement pieces which are highly valued and worn on special occasions. This is therefore represented in the types of techniques used. As opposed to a relatively immediate change with the sublimation printing process, the transformation into a jacket requires more intricate and artisanal manipulations.

Combining technology with craftmanship to create luxury pieces is well represented in the work of designers such as Iris van Herpen (www.irisvanherpen.com), Danit Peleg (danitpeleg.com), or Clara Daguin (claradaguin.com) with laser cutting, 3D printing and wearable technology respectively being associated to hand-crafted textile processes. Here the combination of laser cutting and hand assembly in the transformation from shirt to jacket generates aesthetic effects which contribute to the increase in value of the piece. Furthermore, the transformation from jacket to jewellery such as shown in figure 7.14. to 7.18. is fully artisanal and suggests a luxurious application of the materials.

Collaborative design and prototyping

The remanufacturing stages of the Service Shirt concept involved different designers. The printing and shirt design are by Professor Becky Earley who headed the project and directed some elements of the other phases. The jacket design and TDfD principles are by the author of this thesis. The jewellery design and making is by Katherine Wadropper.

With each stage of the garment's life cycle following the over-printing being enacted by a different designer, it became important that they should collaborate to understand how the previous and following transformations would impact their own practice in the context of the Service Shirt system. Professor Becky Earley, as the instigator and leader of the project, was involved in all the stages of the design and prototyping, either as the main designer or as an expert to provide insights in other

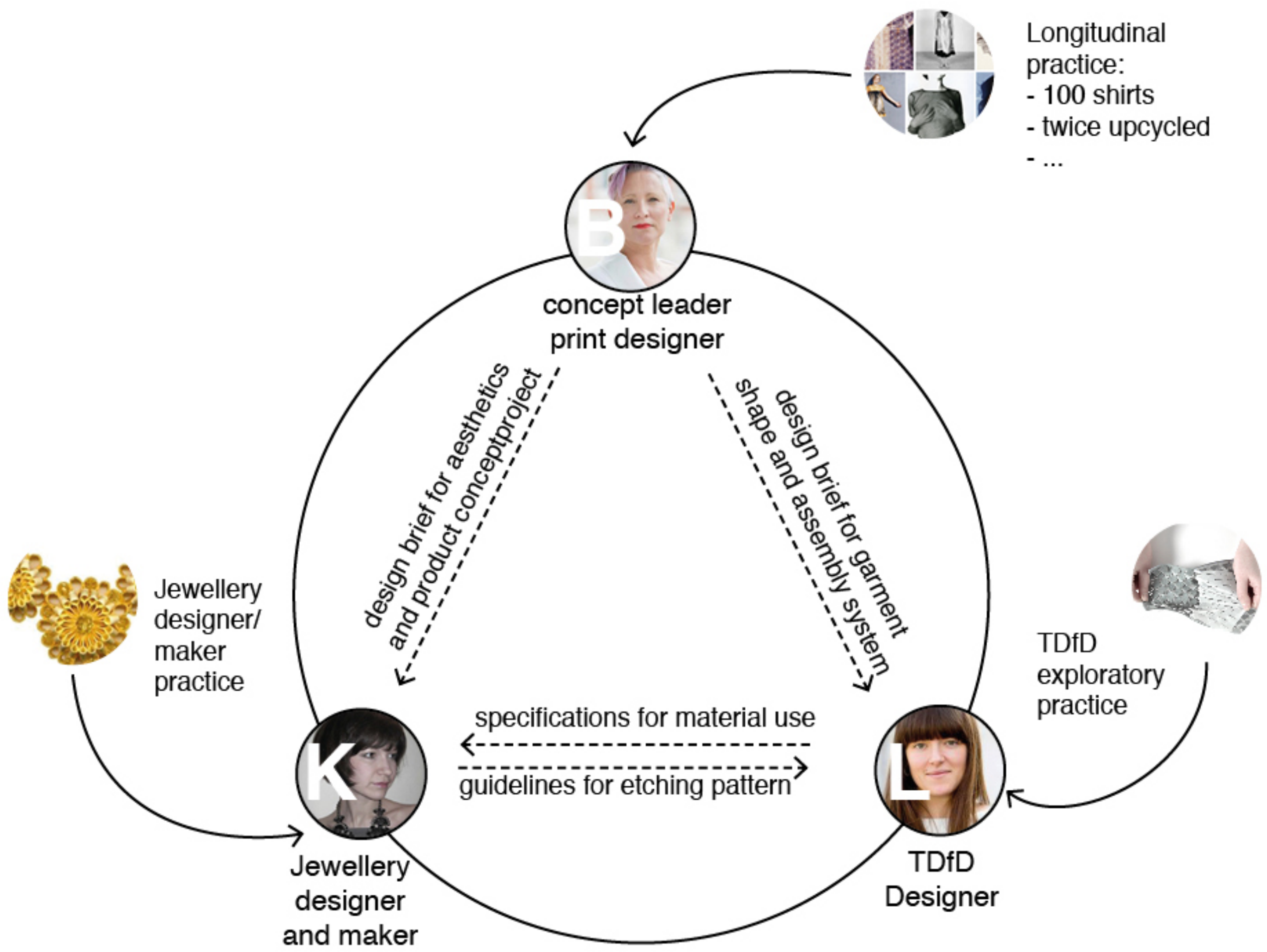
Project phase	Main Designer	Additional input
Genesis (2008-ongoing)	Becky Earley	Kate Goldsworthy
Business model development (2011-2019)	Becky Earley	Kirsti Andersen
Shape of the shirt (July-September 2018)	Becky Earley	Kay Politowicz, Laetitia Forst
Shape of the jacket and locks (July-October 2018)	Laetitia Forst	Becky Earley
Shape of the jewellery (August-October 2018)	Katherine Wardropper	Laetitia Forst, Becky Earley
Print design (October 2018)	Becky Earley	Katherine Wardropper, Laetitia Forst
System mapping (September 2018) see appendix	Marion Real	Becky Earley, Laetitia Forst

Table 7.1. Project task repartition.

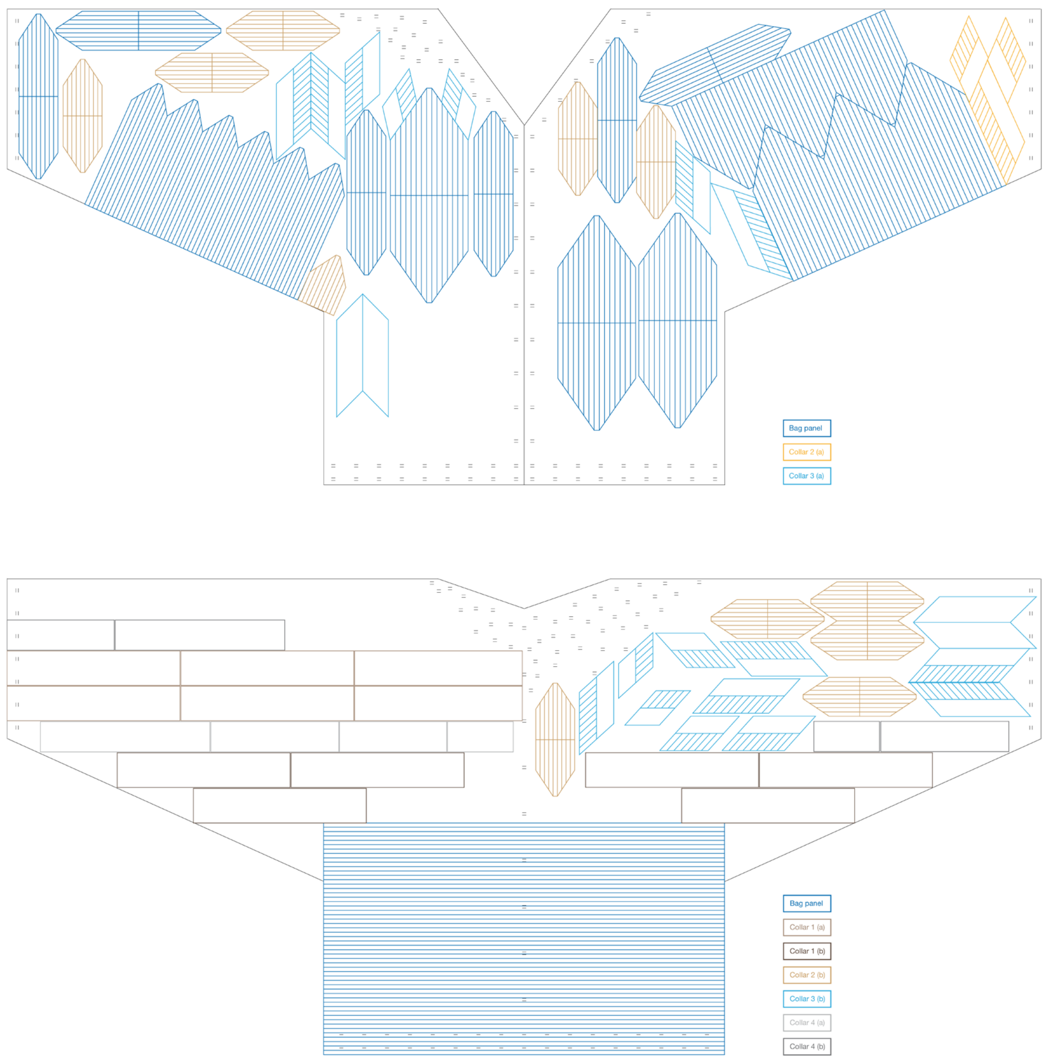
stages. The author was called in to the project in June 2018 to develop a TDfD system for the connection of the shirt to an outer layer to create a jacket. Katherine Wardropper was contacted shortly after to start discussing the possibilities for making jewellery out of the jacket. Table 7.1. shows how the various people involved in the project influenced the different stages.

The experimental nature of the Service Shirt concept meant taking on board advice from a variety of experts. However, the main design decisions regarding the different product stages were taken by the three designers involved in the prototyping: Becky Earley, the author, and Katherine Wardropper. The service shirt system suggests interspersing manufacturing stages in between use phases and taking the end of life as the beginning of a new cycle. Therefore, decisions had to be made concurrently over all the stages of the garment's life cycle, leading to a highly collaborative structure of the project and an ongoing dialogue between the three designers in an iterative, circular design process.

The diagram in figure 7.18. demonstrates the various interactions between the stakeholders in this process. Each designer comes onboard the project with their own baggage of practice. Moreover, in the case of Earley (B) and of the author (L), the previous stages of the work were informed by consultation with experts on the development of business models and the validation of TDfD techniques respectively.



7.18. Collaborative design and prototyping process.



7.19. Laser etching lines for the creation of jewellery pieces. The technical drawing shows how the pieces for the necklaces are included as part of the decoration of the jacket

Working in a circular system rather than the conventional linear approach to fashion production and consumption has led to develop a circular collaboration and design process. Following from circular economy principles (Royal Society of Arts and Innovate UK, 2016), the end of life of each product version becomes the starting point for remanufacturing. In terms of the design process, this meant that the collaboration and effective communication between the three designers and makers was crucial. Each stage of the remanufacturing is closely connected to the one before and included the requirements for the one following it. For instance, the etched pattern on the jacket shown in figure 7.19. becomes cut lines for its transformation to jewellery. This meant that the design concepts for each stage of the shirt's lifecycle evolved simultaneously, feeding into each other in terms of technical parameters but also of aesthetic inspiration.

Using a constructed garment rather than lengths of fabric for the creation of the jacket for instance had a strong impact on the way the TDfD techniques were adapted. Moreover, the jacket was designed for the effective use of the materials in its transformation into jewellery. These considerations guided the aesthetics of each phase of the jacket lifecycle, tying the three designers' practices together into this circular garment story.

This enquiry into a collaborative circular design process has provided a better understanding of the challenges of designing for recycling or remanufacture which are described further later on in this chapter (see 7.1.3. p.223).

The Service Jacket

While this section has offered an overview of the context of the Service Shirt project, the jacket part of these materials' life cycle is the main focus of this study as it is there that the TDfD strategies developed in the sampling phase were tested in a product context.

The Service Shirt project was not initially built to demonstrate the potential for TDfD, as originally the transformation into a jacket was meant to be effected through Dr. Kate Goldsworthy's mono-material laser welding techniques (Goldsworthy, 2012). The unavailability of the equipment for this technique led the project team to consider alternative ways of

7.20. The Service Jacket.

attaching the shirt to a jacket outer layer. The samples described in chapter 6 were influential in making visible the potential for TDfD to allow for the combination of jacket layers without contaminating the recyclable components. The Mistra Future Fashion project and the research environment that this project has been part of therefore serendipitously became the context for the exploration of the techniques developed with laser cutting and assembling layers of fabric to be taken into this prototyping phase.

The jacket is made of an outer layer of Alcantara polyester suede which is cut along the same pattern as the Service Shirt which then becomes the lining. This is slit down the middle and turned inside out to make the outside face the skin of the user as shown in figure 7.21.. The lock elements attach the two layers through a series of double slits placed in strategic places around the cuffs, bottom and neck of the garment. These locks also double up as decoration elements, creating a dramatic asymmetrical ruffle around the neck. In terms of the assembly of the two layers, the textile elements that lock the materials together provide a light-touch alternative to stitching or gluing, which enables end-of-life disassembly and recovery of the individual parts.

7.21. The Service Jacket with the shirt as a lining.

This prototype context offers insights for the potential of TDfD as part of a remanufacturing system. Allowing the two layers to be taken apart means that they can more easily be transformed into another type of product, in this case jewellery, at the end of life. This offers an expanded understanding of circular economy systems. As defined in chapter 4, DfD can offer benefits beyond the recovery of raw materials. The type of cascade recycling described as part of the transformation of the shirt into the Service Jacket pushes back the ultimate breakdown of the product into its raw materials through the successive remanufacturing stages which preserve as much embodied value as possible before enabling the ultimate chemical regeneration. This chemical recovery of the raw materials can be treated as the very last resort for a product when it can no longer be kept in circulation as such (Sandin and Peters, 2018). Stahel backs this approach in suggesting that to maintain the highest possible value, only the smallest possible part of the product should be replaced or treated (Stahel, 2006:71). By enabling easy disassembly, the jacket system allows for a light-touch process in the transformation into jewellery.

The Service Jacket is therefore embedded within this multiple-remanufacturing system. It is a new product in the way that the transformation into a jacket suggests a different type of use. The additional work and craftmanship involved in this transformation increase the material value of the product, and the more dramatic aesthetic effects point towards a garment which will be worn on special occasions rather than as an everyday piece. The different use creates a new type of relationship with the user. This added value has been defined as a way of increasing the emotional durability of the piece (Earley, 2008; Earley and Goldsworthy, 2013) and therefore postponing its disposal, reducing its overall environmental impact and keeping the materials in circulation.

The Service Jacket demonstrates how TDfD can enable the creation of complex garments while not impeding their ability to be remanufactured or recycled at the end of the product's life. Beyond this, it is interesting to note how the TDfD techniques have been adapted to the Service Shirt system and concept for transformations from one use phase to the next without impeding recyclability. This context also shows the impact of this set product brief on the TDfD design process.

7.1.2. Journey from Sample to Prototype

This section describes the iterative process of testing the potential of TDfD techniques and adapting them to product contexts. The placeholder materials were replaced by the textiles selected for the Service Shirt recycling scenario, and the lock techniques were adapted to the product type and design.

Adapting to new materials

In the Service Shirt system, the lining was made of a pre-existing garment, which as described earlier in this chapter, has been overprinted several times. For the outer layer, a new virgin material needed to be sourced. The selected fabric for this was Alcantara, as it presented interesting resistance qualities alongside a suede leather-like effect which fitted the application as a jacket well. It was also believed to be a fully polyester mono-material felt. However, further investigation into this matter revealed that it was in fact a polyester-polyurethane mix, which poses serious issues to recyclability. Given the limitations of impeding deadlines for the delivery of the prototypes due for an exhibition presenting the research, and the impossibility of starting the prototyping again at that point in time, it was chosen to carry on using this and to question the use of such a material from a theoretical stance. This will be further discussed in following sections (see 7.2.1. p.226).

Once these two materials were selected, they then needed to be run through a series of tests for their adaptability to the TDfD techniques developed earlier with polyester felt and canvas. Indeed, given the fact that the base materials used in making the jacket came from a manufactured garment, the scale at which the assembly and disassembly would occur would necessarily be fabric elements over thread or fibre. The Dovetail and Textile Lock techniques were used as starting points to explore TDfD in this context. The heat and speed of the laser cutting machine were then readjusted to the new materials, and the techniques were rectified in terms of the spacing between slits and the size of the locking elements.

At first the Alcantara and R-Pet samples were replicated in the exact way that they had been made with placeholder materials. As described in chapter 6, the TDfD samples are starting points and tools for redesign processes. Following from this the original textile lock and dovetail techniques were used as a base to experiment with the materials set by this product brief. In this way, the change of material was used as an opportunity to explore the variations on different lock systems further, staying alert for effects which emerged from the use of these new materials which could have extra benefits in terms of function and aesthetics, and be taken forth in new iterations.

Experimenting with locks

The first step in this process was to explore different types of assembly based on the initial range of TDfD examples, experimenting with crosses between the different techniques. The techniques chosen derived from the Dovetail assembly but took on the concept of the Textile Lock assembly in the way that the connection is effected by a third element attaching two layers of fabric together. Samples in which the connection points between the two layers created different patterns were made. These also attempted to connect layers that were cut at different scales, making the fabric bunch up between the different connection points.

The textile lock technique allowed for minimal modifications on the parts that constitute the lining and outer layer. This was meant to ease the process of later transforming these materials into jewellery. During a meeting with Katherine Wardropper it was understood that the fabric needed to be cut into strips to be coiled and made into jewellery. The parallel cut lines which allow for the textile lock technique therefore seemed the most adapted to this remanufactured product system.

The type of connection that stood out the most was initiated from the consideration of the jacket as a fashion piece. This led to the association with existing styles of jackets and therefore to the idea of the connections as studs, as seen in customisation of leather and denim jackets in punk and grunge styles. This approach combines the shape of the dovetail assembly with the system from textile locks in which the connection is a separate component. This therefore creates a three-component combination rather than integrating the assembly system within the layers themselves as was the case in many samples, showing how the TDfD samples can be taken on and adapted in a product context.

The effectiveness of this locking system, particularly in the way that it leaves both layers almost integral while offering a strong but detachable


7.22.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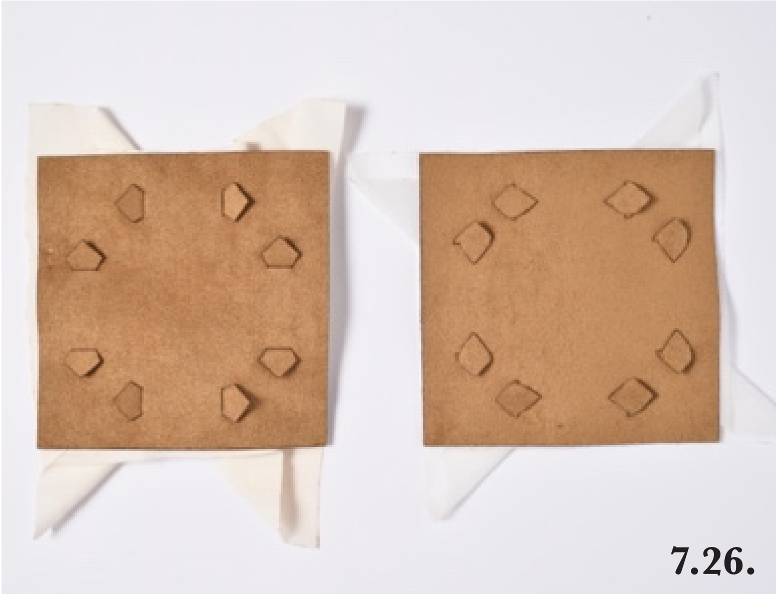
7.25

7.22. to 7.25. Examples of samples adapting the techniques developed in previous sampling with place holder materials to Alcantara felt. With the transformation into jewellery in mind, the technique was also adapted to leave the outer layer as integral as possible so that it could be cut to the shapes needed for the necklace designs.

connection, led to select it as the optimal answer to the service jacket design brief, and to therefore take it further with additional experiments. These were intended to fine tune the technique and explore its aesthetic potential for use as a functional and decorative element in a jacket design. Indeed, the textile lock elements could be shaped in any way desired, thanks to the use of the laser-cutter which gives substantial freedom in the design of patterns. This led to a series of samples, a selection of which are shown in figures 7.26. to 7.32., exploring the range of effects that could be achieved. The decorative potential of the lock, or stud, elements was tested with 3D folded effects, aiming towards a dramatic effect for selected areas of the garment such as the collar or cuffs. These elements were also modified to test different levels of solidity of the connection, different levels of ease of assembly and disassembly, and so forth.

An infinity of options for the shape of the locks were available at this point, but with no aesthetic requirements coming from the brief, the shape eventually returned to a similar one as was first experimented with, albeit optimised for assembly and disassembly, and with a 3D effect inherited from these different experiments. The shape of the lock



7.26.

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7.32.

7.26. to 7.32. Examples of Alcantara lock shape tests experimenting with ways of making the lock elements take on decorative characteristiques. The aim was to create volume from the flat shapes made in the laser cutter. 7.28. shows a test with laser etching as a decorative element on the surface of the Alcantara which later led to including the necklace cut lines in the jacket.

was made so that it would be as easy as possible to insert in the slits cut in the two layers of the jacket and that a slight tension within the slit would make the shape curl and gain more volume.

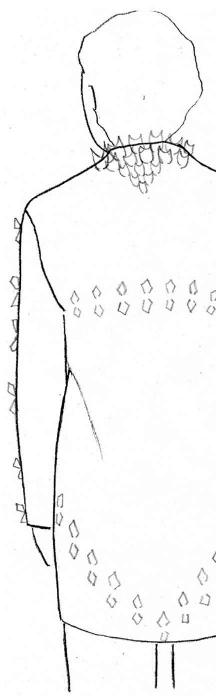
Despite the author’s expertise being in the creation of textile samples and not of full garments, it was found that sketching the way in which the locks would be distributed over the garment, depending on necessary technical connections or areas which are more prone to be decorated such as the collar and cuffs, was helpful in developing the samples.The sketches in figures 7.33. to 7.36. show how a pattern is created with the lock elements over the surface of the garment. The key connectors are first placed around the cuffs and collar, then the pattern is developed to create an original aesthetic effect. As described in chapter 6, the TDfD process places material design at the centre of the redesign process. Sketching garments therefore makes the sampling progress simultaneously to the product concept development. This holistic approach to the design of a circular fashion system is representative of the evolution of the work under the influence of the Service Shirt brief and the subsequent stepping out of the comfort zone in terms of creative practice.

The sketching was also instrumental in the collaborative design process of the jacket, allowing the designers to communicate while visualising the elements of the garment as shown in figure 7.37. and 7.38.. The drawings led to imagine what sizes the lock elements should be to connect the two layers and function as decorative elements.

The evolution of the TDfD techniques in response to the Service Jacket brief shows how the samples produced in the exploratory phase offer a vision for the potential of TDfD techniques and can be taken on in a redesign process. Using the selection of assembly techniques as inspiration, the samples are modified to fit the requirements of the product context.

Challenges of scaling up to garment

The textile designer’s perspective to product redesign was highlighted in the creation of the prototype. Indeed, the three collaborators on this project were all textile designers with a micro approach to the material, or more focused on the sample scale of this discipline. The decision not to involve another designer or technician who may have expertise in pattern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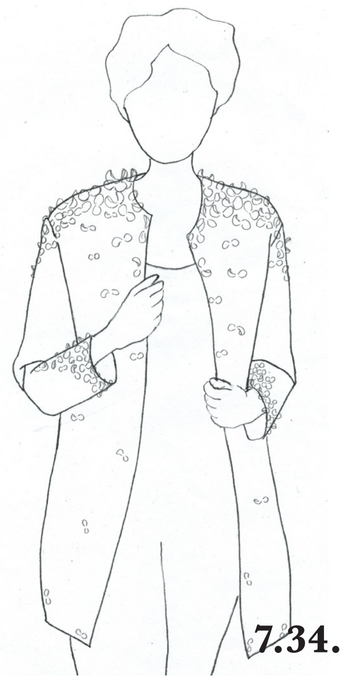
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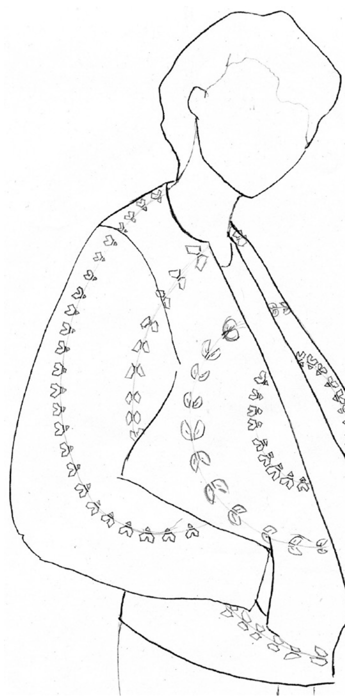
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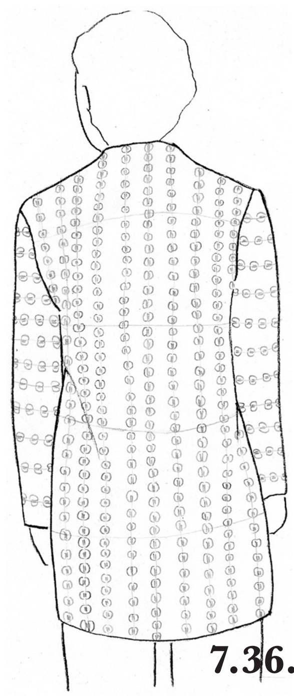
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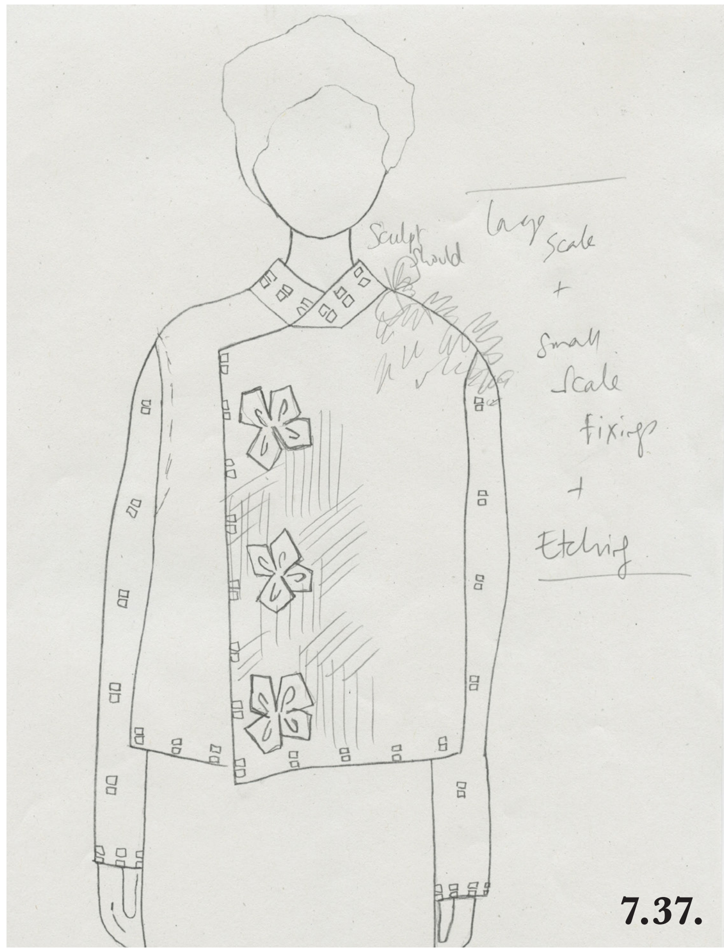

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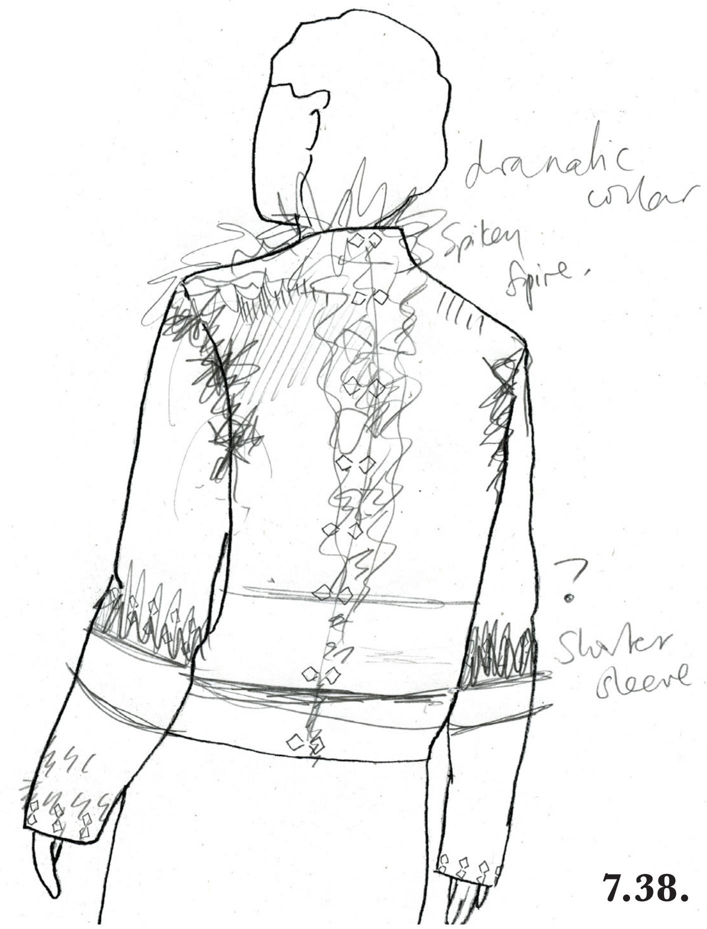


7.38.

7.33. to 7.36. Sketches for the distribution of locks on different jacket shapes.
7.37. & 7.38. Sketches with annotation from Becky Earley. The drawings served as a basis for a conversation around design decisions for the placement of locks as decoration elements and of etching on the jacket surface.

cutting was made consciously, to avoid both the difficulty that may come from coordinating a bigger team, and to explore the specific approach a textile designer may have to these issues.

To be consistent with the overarching aim of reducing the environmental impact of the garment, a zero waste (Rissanen and McQuillan, 2018) approach was chosen concerning the shape of the shirt and jacket. This type of garment construction eliminates resource waste at the garment design stage, but also entails a series of challenges.

The extension of TDfD principles, which had been tested at the sample scale, to an application as a full garment showed some limitations for specific techniques. For instance, the puckered effect achieved by changing the scale of the different layers did not function in combination with a zero waste pattern. While it seemed to offer interesting potential for an application as a jacket due to the pockets of air created, a possible insulation method, the simple shape used for the shirt did not allow for the difference in scale between the two layers. This points at the limits of applying a textile sample directly to a predefined garment shape and suggests that these should be developed simultaneously.

A further challenge in the transfer from small textile samples to a garment was related to the laser cutting technology. Indeed laser cutting, while having existed since 1967 (Hilton, 2007), is still a marginal form of prototyping and machines are not widely used in the textile industry they are instead limited to R&D facilities (Kane et al., 2015). The machine accessed for this research was held by a small community maker space in South-West London, and while rather large for such a machine, the laser bed was limited to a 50x70cm area. This meant that the garment could not be laid out flat and cut and etched in one go. Instead of this, the pattern had to be fragmented so that the sleeves and body of both the front and the back of the garment would be done separately. This meant that the process had to be staggered and the laser re-set and aligned every time a new section was started, leading to challenges in matching the pattern edges. This is typical of the shift from working with small sample sizes to larger garment requirements. Once again it suggests that prototyping at the final scale should be encouraged from the early stages of the project.

While most of these challenges are only technical hitches which can easily be overcome with further testing and adapting the techniques, it is the accumulation of this type of hurdle all through the design process that has led to grasp the complexity of designing for a circular system in such a way. Indeed, the collaborative and multi-angle approach to the work meant that these types of issues hindered the progress of other segments of the prototyping.

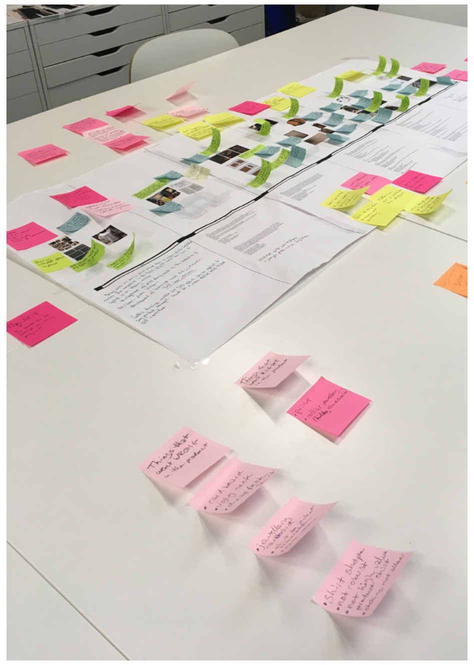
The new challenges brought on through applying TDfD to a garment have highlighted some technical challenges which did not occur in the sample development phase. This outline of the process of transferring TDfD techniques to full garment prototypes shows the framework which this exploratory work aims to make available for future practice. The use of the samples has been proven as beneficial to the development of circular concepts, and flagging the main challenges in the transfer to product contexts can enable better appropriation in further work in this area.

7.1.3. Analysing Challenges and Opportunities through the Prototype

Beyond the analysis of the issues in transferring TDfD principles from samples to product, the Service Shirt concept as a whole was subject to a reflective review of the challenges encountered in the prototyping phase. As with the other bodies of practice presented in this thesis, the main insights were achieved by moving through the phases of the methodological model, first scoping, making, mapping and then reflecting on the outcomes. This reflection was summarised in a paper co-authored with the project leader Becky Earley (see Appendices 11.3.4.) and led to a deeper understanding of the challenges and opportunities of designing fashion in a circular economy. The methods and main findings from this review are laid out here.

Annotated portfolio and after-action review

In a similar way to tracing thought processes through the sample mapping as described in the previous chapter, visual evidence of the work was used to retrospectively clarify the different stages of the design and prototyping process. To understand the design journey that took place in this collaborative work, a combination of after-action review (Morrison and Meliza, 1999) and annotated portfolio (Gaver and Bowers, 2012;



7.39. The adapted annotated portfolio method. A timeline of the actions contributing to the prototyping process was laid out to form the basis of a conversation around the challenges encountered along the way. The annotations were then characterised into four categories.

Sauerwein et al., 2018) methods were used. At first, a selection of photographs were laid out in the chronological order of stages of the work they referred to. This helped detail and communicate the various steps that made up the design and production process for the prototypes. It fuelled a conversation between the two authors of the paper in which four focal points for the challenges encountered in the process were identified: collaboration, design challenge, production, and material selection. Based on these four categories, an after-action review was carried out to describe the challenges and future opportunities for improvement along each of these aspects.

Everything that went wrong

This analysis found that the main challenge was in the collaboration and in the communication of circular concepts between the members of the team. For instance, the zero waste brief for the shirt was not understood by the seamstress making the garment in Sweden. In terms of the jacket more specifically, the main shortcoming was seen as the boxy shape which resulted from the zero waste pattern combined with the slightly ill-suited material. One of the main unresolved issues concerned the shape of the garment, using zero waste pattern cutting led to using a kimono type shape. The zero waste kimono shape used was also useful when considering the printing process: the pattern can be laid out flat, which meant it could be over printed with minimal creases. However, this constricted the final aesthetics of the jacket and prevented it from draping in the pleasing ways the designers would have imagined. This reflects an overarching acknowledgement that none of the members of the team had expertise in pattern design and cutting, and that in any future iteration, this expertise may need to be brought in despite the initial decision to focus on textile design skills. It was also considered that aiming to add a zero waste approach to the work could over-complicate the message, and that the focus could be narrowed to the circularity and upgradability of the fashion concept.

The aim of this review of the Service Shirt prototyping was to draw new knowledge concerning circular design that could be used to fuel future projects. The context of the Service Shirt work was defined by the Mistra Future Fashion project, however the insights from the review of the process are applicable beyond this framework. Moreover, the analysis and classification of the different challenges involved in the work succeeded in making each aspect easier to understand, and provided steppingstones to improve them. From the frustrations of this first iteration, clear steps to the next and improved version of the jacket were drawn. This understanding of circular prototyping therefore led to a second iteration of the process, this time removed from the Mistra Future Fashion context and more specifically geared towards the aims of this research, as will be described in the following section.

7.2. Making the Split Jacket

Building on the assessment of the Service Jacket prototype, the remarks and suggestions for improvement led to designing a second jacket which addressed some of the issues brought up in the annotated portfolio exercise. This second version takes the testing of TDfD techniques and concepts further and also shows how the different variables of the product and of the design process can be adjusted to produce a circular garment in a new context. Extending the redesign process to a second prototype focuses on the reference product as presented in chapter 1 (see figure 1.8. p.26). This iteration refines the response to the challenge set out in this study.

7.2.1. A New Brief for a Leather Jacket

While the Service Jacket was embedded within a complex system and business model, this new iteration on the jacket brief suggests a focus on the combination of incompatible recyclable mono materials in ways which allow them to be detached. Removed from the context of the Mistra Future Fashion project, the brief for the Split Jacket puts TDfD at the centre of the prototyping.

A leather jacket

Understanding the shortcomings of the Service Jacket prototype through the annotated portfolio and after-action review methods provided a wealth of insights for the application of TDfD concepts. Building on the insights from this process, this new jacket explores the transferability of the findings from the Service Jacket review. The brief was therefore adapted to explore different scenarios for the use of the samples as redesign tools. Solutions to the technical and conceptual aspects that were left unresolved in the first jacket prototypes are therefore tested in this second iteration on a circular jacket concept. This was later called the Split Jacket in reference to its ability to be separated for recycling.

The Service Jacket provided a full lifecycle concept within a technical cycle in a circular economy. While this approach gives a roadmap for the circulation of resources in extended remanufacturing loops, it was not originally intended to show how different materials can be combined and still returned to separate recycling streams at their end of life. A second version of the jacket concept was designed to support this essential claim of the research. This new iteration was removed from the collaborative and multi-lifecycle aspects explored in the service shirt concept and only retained some of the key elements of the initial brief. The Alcantara, which had proven to be a barrier to recycling due to its polyurethane blend, was replaced by leather as an outer-layer material. This biodegradable certified leather was provided by Santori Pellami, an Italian tannery.

The use of leather as an outer layer for the jacket grounds this new version in the reference archetype of a leather jacket as presented at the outset as a problematic complex product to be redesigned. It also is a strong example for a material in a bioeconomy (McDonough and Braungart, 2002; Ribul and Motte, 2018). Indeed, while this is not the case for all

leather, the material selected here is fully biodegradable (Accinelli, 2018).

As presented in the review of the Service Shirt prototyping, one of the frustrations with the jacket outcome was the unresolved aspect of the garment shape which did not drape well with the materials used. This partially came from the acknowledged lack of pattern cutting expertise in the team of designers involved in the project. After testing an intermediate garment shape shown in figure 7.40., a conventional bomber jacket shape was chosen as a good fit with the style suggested by the leather. The challenge of using zero waste pattern cutting was removed by using a pre-existing, conventional garment pattern. In this way, the bomber jacket shapes could be adapted to the techniques developed in the samples, therefore developing the TDfD techniques within the garment shape.

This new brief leaves aside some of the elements of the Service Shirt work, such as the remanufacturing processes before and after the jacket stage and focusses solely on the jacket phase of the material lifecycle. This means that some of the complexity and richness which came with the fully developed business model and use scenario

7.40. Intermediate testing of garment shape in placeholder materials. The constructed garment shape does away with the zero waste pattern cutting applied in the first jacket iteration to refine the shape and make the garment more wearable.

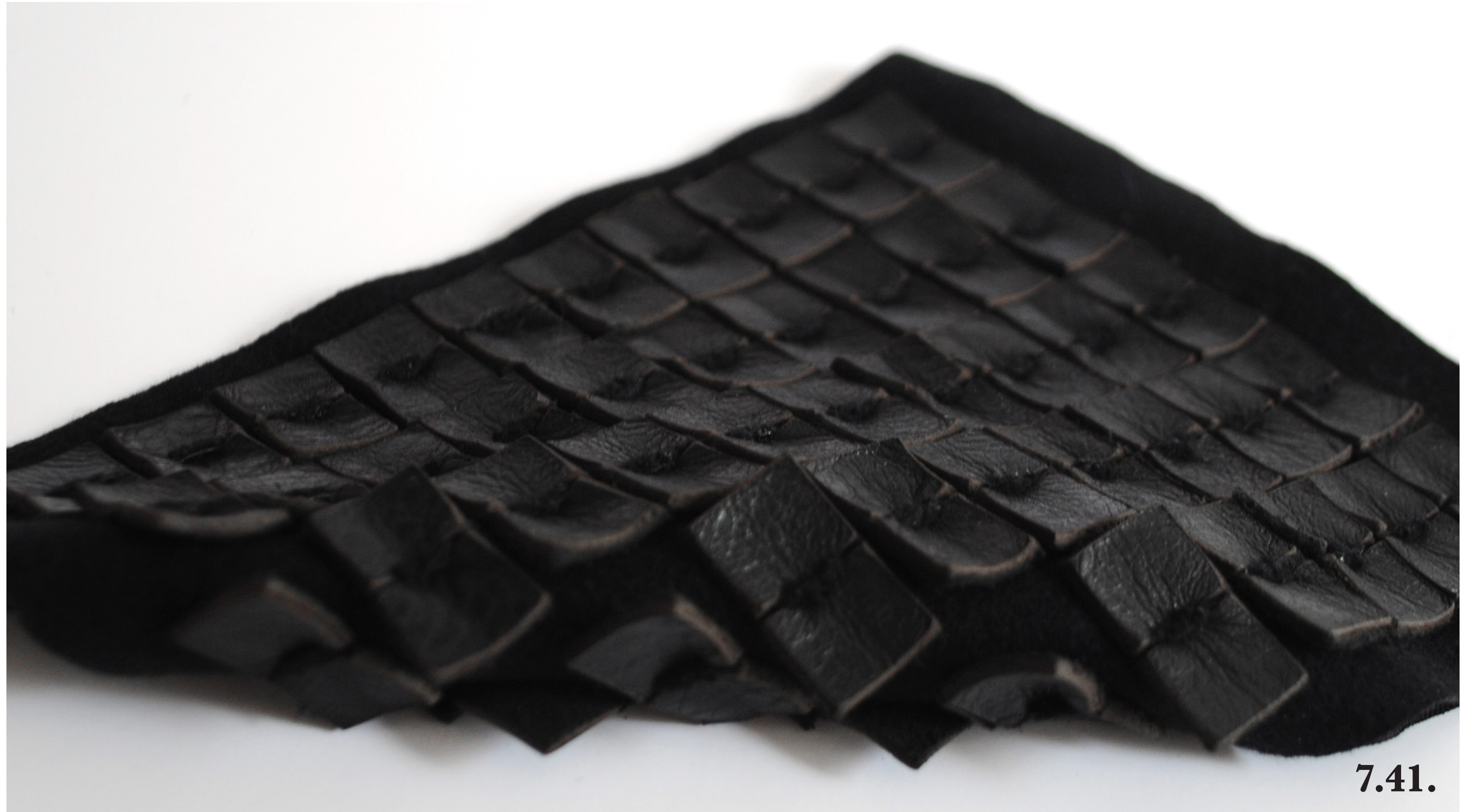
in the Service Shirt concept are lost. The focus is however intended to channel the work towards the resolution of some of the issues highlighted in the annotated portfolio and draw insights from the transfer of the TDfD approach to a new product context and brief. The brief therefore puts TDfD at the centre of the work, removing the business model aspects linked to the service that a brand might provide to focus purely on how the TDfD assembly techniques can allow for the jacket to be taken apart at the end of its use phase.

Sampling with leather

Using small pieces of leather to stand in for the biodegradable Santori goat skins, a series of samples were made to test the applicability of the TDfD techniques to this new material. In a similar way that the samples were developed in the previous iteration where placeholder materials were adapted to the use of Alcantara and recycled polyester lining (see figures 7.22. to 7.32. p.217 to 219), the leather tests highlighted the changes needed based on some of the characteristics of the combinations. This shows how in most cases the assembly techniques will need some form of adaptation to be transferred into a product system. In this way the replication of this phase for a new product brief shows the essential phases of the TDfD process.

In this instance, the Textile Lock technique was kept as one of the strongest propositions, further experimenting with the potential for these locks to become a key element of the combination using the tiling techniques shown in figure 7.41.. Leather was also associated with different materials as can be seen in figures 7.41. to 7.43.. The polyester canvas which acts as a lining against any other part of the blend is a constant in these samples also, but in some instances, wool was used as a potential insulation material.

As previously mentioned, the aim of this second version was to demonstrate the applicability of TDfD in a multi-material garment concept. This means that the different components of the jacket are made from different mono-materials which do not belong in the same recycling streams. While some more complex associations such as sandwich materials with three layers of leather, wool and polyester were explored in the sampling phase, they were eventually left aside as leading to too many new layers of complexity, and the variation that was closest to the original Service Jacket concept was taken forward.


7.41.


7.42.


7.43.

7.41. Leather, polyester and wool combination test, with rectangular locks acting as a tile effect and covering the surface of the wool as tested in some of the samples with placeholder materials.
7.42. Leather, polyester combination tests, applying the same shapes as the Alcantara sample to thick leather.
7.43. Leather, polyester and wool combination test, with diamond locks texting an alternative to the rectangles to cover the base fabric.

In this new version the Alcantara is replaced by black biodegradable goat leather sourced from an Italian tannery. To fine-tune the final prototype, a series of intermediate prototypes as shown in figures 7.44. to 7.47., were made before moving on to using the valuable leather. This phase checked the shapes and refined the aesthetic of the jacket, solving problems with each iteration. By moving through two garment shapes and then altering the assembly system, further checking whether the gathered lining effect was possible and if the lock systems functioned, the various elements for the final leather prototype were optimised. The pictures on the facing page show the shape was first tested as a simple cut and sewn mock, pinning the lining to the outer layer to test the puckered effect, and then run through the full process of laser cutting and assembly to troubleshoot any issues.

In this prototyping phase, the repartition of the locks was defined in a hands-on approach. Pinning the lining to the outer layer in the mock version with placeholder materials showed the frequency at which these needed to occur which then informed the design of a pattern. This was then laser cut with a polyester suede and lining with properties which were as close as possible to the leather and recycled polyester materials intended for the final piece. This stage highlighted any remaining unresolved issues before using the right materials.

Limitations of working with hides for garment design

While the first iteration of the service jacket was based on a zero-waste concept which took the width of the fabric roll as the measure for the length and shape of the garments, this is no longer relevant to a leather jacket. Leather is often seen as a challenging material to work with in a design for sustainability framework as, beyond the implications of agriculture, the uneven shapes lead to large amounts of cutting waste. While some approaches to leather use zero-waste strategies, such as the Shoey Shoe (thomasleech.co.uk) project using the offcuts as a composite base for other parts of the product, or 11458 (www.rca.ac.uk/students/alice-robinson) which highlights the origins of the hide and makes use of it all, this material doesn't fit the rectangular system approach of zero waste such as presented by Rissanen and McQuillan (2018). Other strategies, such as with the Elvis and Kresse (www.elvisandkresse.com) line of interior products and small leather goods, use scraps of leather to make small modular elements that assemble into larger objects. These

7.44. & 7.45. Mock prototype using cheap materials to test the bomber shape of the jacket. 7.45. shows how the constructed garment makes it possible to include the puckered effect for the lining which was developed in samples.
7.46. & 7.47. Detail and full view of an intermediate prototypes made in the laser cutter to test the assembly systems and detect any issues ahead of using the leather. The detail picture shows an unresolved finishing of the collar joining.

examples demonstrate the context for zero-waste design with leather and are used as inspiration for this work. They also show the shift in applying circular design strategies to materials that are either grown or manufactured. This transferability of the TDfD approach is essential to highlighting its role in a circular economy for textiles.

7.48. The pieces of the Split Jacket. Taking the laser bed size into account from the start meant that all the pieces for the outer layer and the lining could be cut one after the other, removing the technical challenges encountered in the Service Jacket.

The use of hides therefore generates a new context for the prototyping, with new material limitations. While the Service Jacket was difficult to process in the laser cutter due to the use of a full garment as the lining, starting from virgin materials that could be cut to the right size for the Split Jacket made the process easier. Additionally, using relatively small goat hides forces into a patch system where the jacket is made of a combination of smaller parts, therefore allowing to cut these elements one by one in the laser bed as shown in figure 7.48.. This circumvents the problems encountered with having to match and align the pattern with the polyester jacket.

7.49. The gathered lining effect made possible by the new garment shape.

Using hides also disables the possibility of designing with systematised zero-waste patterns as these are based on the use of a standard rectangular piece of cloth. While generating a new set of challenges, it also liberated the garment pattern from the T-shape that had been set in the first iteration. This meant that using the gathered effect, shown in figure 7.49. and 7.50., which was abandoned in earlier experiments was once more possible. The new shape was thus based on a conventional pattern for a bomber style jacket, also grounding the design in more commonly accepted aesthetics for this type of garment and enabling better acceptance by a potential user.

This exploration of TDfD with leather and polyester fabric scale components shows how the textile lock technique can enable assembly systems which will allow for the materials to be separated for potential recycling at the end of life. Confronting the technique to this new context has shown how the TDfD approach influences the making process, tested new garment construction techniques and yielded aesthetic and functional effects which are a direct result of the circular redesign challenge.

7.50. The gathered lining effect in the final leather and polyester garment.

7.51. Split Jacket final prototype, back.

7.52. Split Jacket final prototype, front.

7.2.2. New Recycling Story and Use Scenario

With new materials, the life cycle scenario for the garment changes to accommodate their recycling requirements. This version of the jacket is specifically designed to show how TDfD can allow materials from different cycles to be brought together and then returned to their appropriate recycling stream. This adjustment phase builds on the previous insight regarding the need for flexibility with material choices, adapting them and the TDfD techniques as the design process unfolds.

Biodegradable leather, recycling story

The leather was sourced from Santori Pellami, a leather tannery established in the Monte Urano region of Italy. The company has been striving to achieve better environmental results in this originally polluting industry while maintaining high material quality. Their biodegradable Naturella leather is the product of 7 years of research and was first presented in 2017. Rather than use a vegetable tanning process which tends to harden the leather and make it stiff, although some results with various tanners show vegetable tanned skins which are also quite supple, this leather is treated in a chromium free synthetic tanning process. Moreover, the quantities of chemicals used throughout the process have been reduced to a minimum. In order to ascertain that the Naturella leather is equivalent to standard leathers, antimicrobial and soil burial tests have been carried out. These show that the quality of the Naturella leather is in fact higher than conventionally tanned leather in the conditions set by the experiment (Elegir and Sadocco, 2019). Of particular interest to the work carried out here, the leather is certified as biodegradable. The certification (Accinelli, 2018) guarantees 75.1% and 74.3% biodegradability in industrial compost settings for the two tested samples. This is sufficient to qualify the leather as biodegradable.

In the context of a jacket designed for disassembly, biodegradable leather could return to this optimal path for recovery. Many leather products are manufactured from a combination of components such as zippers or other trims, which defeat the purpose of a material being specially engineered to biodegrade. In a TDfD product such as this one, the leather is complemented in terms of aesthetics and functional qualities by the polyester lining and the two elements come together to form a complex, desirable garment, but recovery for recycling is not impeded.

While leather is acknowledged as having high potential for remanufacturing and upcycling (Child, 2016:264), this iteration focuses exclusively on the potential of the combination to be released. It leaves extended lifecycles beyond the scope of this part of the study to focus on the recyclable nature of the components in the combination.

Recycled polyester, recycling story

Polyester is commonly used as a lining as it is a relatively cheap material that can be engineered for the lightweight and smooth features needed for this application. Multiple suppliers provide recycled polyester made from recovered plastic bottles. For the purpose of this prototype, a generic recycled polyester canvas was sourced from an Indian fabric supplier. This supplier provides a range of GRS certified recycled polyester (RPET). RPET is made by collecting, cleaning, shredding, melting and spinning post-consumer PET bottles. While this reaches beyond a strictly textile cycle, it offers a reduced impact base material which can, later in the product's life, be fed into a chemical recycling process through which it can be regenerated into a new textile. While this work focuses on the potential for recovery of recyclable and mono material resources and therefore mainly uses virgin materials which are yet uncontaminated, the use of recycled polyester shows the potential of the combination to use materials which have already been recycled in an optimal way which does not prevent their further recyclability.

The scenario suggested for this garment looks further into the future than current recycling technology. While chemical recycling is not yet available on a commercial scale (Mathews, 2015), this scenario imagines that the garment will keep the materials in circulation until the technology is fully developed. It could be imagined that several years after the product is first bought, the lining has been worn away and needs replacement. This can then be disassembled from the leather outer layer and fed into a polyester recycling system while the leather is either kept in circulation or biodegraded.

New use features

The complete hand assembly of the different layers suggests that the reversible and non-destructive assembly and disassembly could be taken into the user's hands at different points of the object's lifecycle. This could mean that the lining could be replaced if needed or that a new layer could be added between the polyester and the leather to add insulation properties when necessary. The Service Shirt concept was developed within a design researcher in residence framework which led to approaches which were specific to the brand which became the context. The Split Jacket can reach further in terms of use scenarios and appropriation of the concept by potential users. As stated earlier in this section, the use context is left beyond the scope of this prototype as it focuses on the potential for the disassembly of the combination components, however this model could support a variety of product service systems.

This could lead to expand the concept of the garment towards more modular aspects, giving a series of options for functional elements such as pockets or sleeves, or variations in the shapes of the collar, cuffs, or textile locks for decoration. This level of involvement of the user could be paired with an approach to decentralised manufacturing through local and community-based makerspaces. The Post-Couture example presented in the case studies (case 17 p.108) shows the potential of this form of assembly system for distributed manufacturing. Using this case as an inspiration takes this concept further with the integration of a circular use of resources. In this way the garment becomes the trigger to question the system in which it is embedded (Malpass, 2017), offering a vision for alternative futures.

7.3. Drawing Insights from the Jacket Redesign Iterations

This section offers a comparison between the two jacket iterations to draw insights relating to the implementation of TDfD strategies within a redesign process.

7.3.1. Comparison of the Two Jackets

Comparing the two jackets shows some of the key aspects of the TDfD redesign process for this product, either by highlighting the improvements from one version to the other, or by uncovering the common elements which are an integral part of the TDfD methodological framework. This section suggests a review over five key themes: materials, design process, production, use, and end of life. The reflection on these themes offers an understanding of the effect of TDfD on all the phases of the full lifecycle of a product.

Materials

The second iteration resolved the issue identified with the recyclability of the Alcantara in the Service Jacket. While the lining material stayed the same, moving from a polyester suede to a leather outer layer showed that the TDfD techniques are not restricted to a single material type. Using the assembly techniques with this range of materials also showed that TDfD could enable the circulation of unrecyclable materials without contaminating the recyclable components they are associated to during the use phase, as was the case in the first iteration of the jacket.

The presentation of the TDfD techniques with placeholder materials leaves them open to be applied to a wide range of materials even beyond those presented in the two jacket prototypes.

Design process

The two prototyping phases offered a shift from collaborative design to solo practice. This shift showed the pivotal role of TDfD as an enabler for a collaborative take on a multi-lifecycle garment concept. While in the Split Jacket the disassembly is purely effected to recover materials, the context of the Service Shirt project showed how TDfD could facilitate the circulation of materials between different designers in a circular design process. As described by Lomée (2016) modularity redefines the role of the designer, making products more open and forcing designers to relinquish part of their ownership when putting them to market.

The comparison of the role of TDfD between a solo and a collaborative process has demonstrated the way in which this strategy can act as a hinge between different collaborative practices.

Production

The two iterations were an opportunity to address some technical challenges in the production of the jackets. Going from the difficulty of remanufacturing full garments in the Service Jacket to adapting the process to include the TDfD techniques in the samples from the start of the product development in the Split Jacket, the prototyping highlighted the challenges of making garments for disassembly. The lesson learned from making the two jackets suggests the inclusion of the laser machine specifications from the outset of the design.

The TDfD approach tested in these prototypes means that new ways of making garments are developed. Moving away from traditional garment manufacturing techniques required a phase of testing the efficiency of these new assembly methods.

Use

Embedding the TDfD techniques within a product situates them in regard to aesthetic and functional standards, in this case, those expected from a jacket. The iterations have solved some of the unsatisfactory qualities in the Service Jacket. Nevertheless, the new assembly techniques lead to original aesthetic effects. These can be seen as added value, making the garments singular statement pieces.

With the improvements effected in the Split Jacket, the prototype shows that a garment can be made in an aesthetically pleasing and functional way while allowing for its components to be taken apart at a later stage. These qualities satisfy the aesthetic judgment of the designer as laid out in chapter 3 (see 3.2.3. p.79) and demonstrate the value of approaching a circular design challenge from a textile designer's perspective.

End of life

While the Service Jacket was part of an extended lifecycle concept, showing how TDfD could redefine end of life as remanufacturing for a new use phase, the Split jacket offers a focus on disassembly for the recovery of incompatible materials.

The comparison between these different scenarios suggests that TDfD can enable a variety of end of life scenarios depending on the materials and systems which are involved

7.3.2. TDfD in the Redesign Process

The insights from the two jacket prototyping iterations show how the stages of the methodological framework developed in this study enables the use of TDfD as a key strategy in a circular redesign process. Given the redesign approach laid out in the introduction to this work (see figure 1.8. p.26) the second jacket is identified as the outcome of the full process. This section offers a brief review of the phases which are influenced by this textile design perspective on TDfD as a circular design strategy.

Understanding the reference product to redesign

The first step in a redesign process is to understand the reference product. This work suggests an alternative to the types of material combinations which are laid out in Level 1 of the hierarchy of blends presented in chapter 5 (see figure 5.15. p.132). These in turn are used to redesign a reference product which allows for better acknowledgment of the benefits of the innovation in a specific use and end of life context.

If considering a jacket, in terms of material combinations, the main challenge resides in the association of a lining with an outer layer (Norris, 2012:47). This relates back to the hierarchy of blends presented in chapter 5, this type of assembly can even be directly associated to model 15 in the typology of blend archetypes: a stiched combination of materials a and b.

In this specific redesign exercise, the Service Jacket and the Split Jacket, the starting point was to set the brief as the association of these two layers of the garment in ways which would allow them to better be taken apart.

Using TDfD samples as redesign tools

Once the scale of the components to assemble was defined in the context of the jackets, the TDfD samples described in chapter 6 were used to support the next stage of the redesign process. As stated previously, up to now, very little evidence of the use of DfD at the textile scale could be found in literature and practice reviews. The body of work developed in this project therefore offers a new range of options to use as inspiration when setting out to apply a TDfD process in redesigning a product.

The samples were developed as a response to the identification of laminated materials as barriers to recycling. The techniques from this blend redesign were then transferred to the issue identified in the jacket reference. In the case of both jackets, the textile lock technique in combination with a dovetail assembly were chosen as the most effective way of combining the two layers.

In this way, the initial range of samples was drawn on to inspire further developments to fit the product brief. As described in this chapter, the technique was first adapted by combining aspects of different samples, and then adjusted to the Alcantara and polyester combination in a first step, and to the leather and polyester combination in the second iteration. The samples therefore offer inspiration for these new types of component association within complex textile products.

7.3.3. TDfD Innovation in Circular Systems

As demonstrated in the five categories in chapter 4 (see 4.2. p.98), DfD can enable raw material recovery but also suggest alternative and extended lifecycle scenarios. In this sense the implementation of TDfD strategies within a textile product produces characteristics which can add to its functionality, generate new and more sustainable use and end of life scenarios, and generally improve on existing products.

Innovation is described by Tonkinwise as the permanent replacement or displacement of an unsustainable product or habit by a better option. To achieve this displacement, the new object must not only have a reduced environmental impact, but also provide an improvement to the user experience (Tonkinwise, 2014:207). It can therefore be argued that the TDfD approach used in the two jacket prototypes enables this type of innovation. This section offers a short review of the ways in which they improve on existing garments and what their potential limitations may be.

New product scenarios

As argued by Walker:

> "The essential core of creative design is not concerned with investigating what already exists but with envisioning what could be. It calls not on the power of methodical examination but on the power of human imagination and open minded exploration"(Walker et al., 2017:447).

This redesign process not only suggests potential alternatives to materials combinations and complex products which currently prevent effective recycling, it also scripts new product lifecycles.

A prevalent aspect of the Service Shirt story is its presentation of a product which can travel through different use phases and be renewed without drawing on virgin resources or hindering end of life recycling. TDfD strategies have been proven relevant in enabling this type of scenarios. As presented in the comparative review of the prototypes, the openness of the modular construction makes a collaborative remanufacturing of the product possible in an extended lifecycle, or can even suggest approaches to distributed and decentralised manufacturing. The insights provided by the experimentation in this research push the boundaries of conventional garment production and use patterns.

Material recovery paths

The two jacket briefs suggest the use of different materials as the starting points of the design, this shows parallel ways in which the TDfD strategies can be used to facilitate end of life recovery.

While the premise for this research is based on the need to lift barriers posed by material combinations concerning end of life recovery and recyclability, the exploration of TDfD concepts and techniques has slightly shifted the frame around this question.

The initial brief of combining different materials while enabling their later separation has been followed in both jackets. However, the research has demonstrated that assuming clear recovery to regeneration paths would be over-simplifying the reality of recycling systems (see 2.3. p.49). The prototypes therefore stop at presenting ways in which complex products can be disassembled. The ways in which this disassembly is geared towards easing the recyclability of such garments can be honed depending on the context within which this is set. The jackets already suggest two ways in which this could potentially take place. As highlighted in the conversations with experts described in chapter 6, the materials could, for instance, be recovered in a brand-led product service system as proposed by Climatex, or be returned to adequate recyclers through a local system of collecting and recycling networks as suggested by Circular.Fashion.

The Split Jacket shows an example that follows the guidelines of Cradle to Cradle design and combines materials with different regeneration systems in the biological and the technical cycle. In a system in which all the elements are in place for the recovery and composting of bio-degradable materials on one side and the chemical regeneration of polyester on the other, the TDfD techniques make this possible despite the complexity of the product. This effectively exemplifies Gulich's expression of multi-material composite systems with detachable connections, having made the compromise between ease of recyclability and functionality more balanced.

On the other hand, the Service Jacket has expanded the concept of material circulation in a circular economy beyond the duality of the Cradle to Cradle model. Following from the RSA approach to circularity, it enables multiple circulation in larger and larger loops before the materials need to be broken down (Royal Society of Arts and Innovate UK, 2016). This suggests that TDfD can allow for different approaches to circular economies. The context of this study and the prototypes discussed here have demonstrated the different scenarios in which it can be applied.

7.4. Conclusion: TDfD in a Product Context

This chapter has demonstrated the applicability of the TDfD approach to a product brief and context. The samples presented in the previous chapter have been used as tools and inspiration to offer an alternative to a reference jacket as identified as a barrier to effective recycling.

Giving a context to the DfD strategies for textiles tested the feasibility of the techniques at the garment scale. Indeed the abstract nature of the samples, while allowing to develop models, also removes them from any confrontation to collaborative and industry-imbedded practice as well as from user considerations (Dorst, 2017:51).

TDfD in an extended circular garment system

The implementation of DfD within the Service Shirt concept gave a point of reference to conventional conceptions of how a jacket may be produced and used and to assess whether the circular design strategies provided any improvement.

In this ultra-long lifecycle concept, TDfD enables the transformation of the shirt into a jacket. This redefines disassembly beyond raw material

recovery and suggests its use as a hinge between remanufacturing phases. The modularity element and the involvement of users that this entails as described in the review of DfD case studies is well represented in this application of TDfD.

TDfD in the Split concept

The Split Jacket returns the brief to a more direct interpretation of the task set in this research. The simplification of the scenario when removed from the Mistra Future Fashion project resolves some technical and aesthetic issues from the previous prototype. In this product concept the disassembly is mainly geared towards separating materials from different recycling streams as stated at the outset of the redesign task. This shows the effect of the new assembly technique on the aesthetic and functionality of the product, demonstrating how including TDfD in the design process can produce original and pleasing effects.

The jacket redesign

The two jacket prototypes have demonstrated the potential of TDfD in offering an alternative to unrecyclable complex products. Although each of the prototypes offer a wide range of insights for the validity of TDfD as a circular design strategy, the Split Jacket will be the focus of the redesign process. The learning curve between the two prototyping phases position the Split Jacket as an appropriate response to the redesign process put forward in this research.

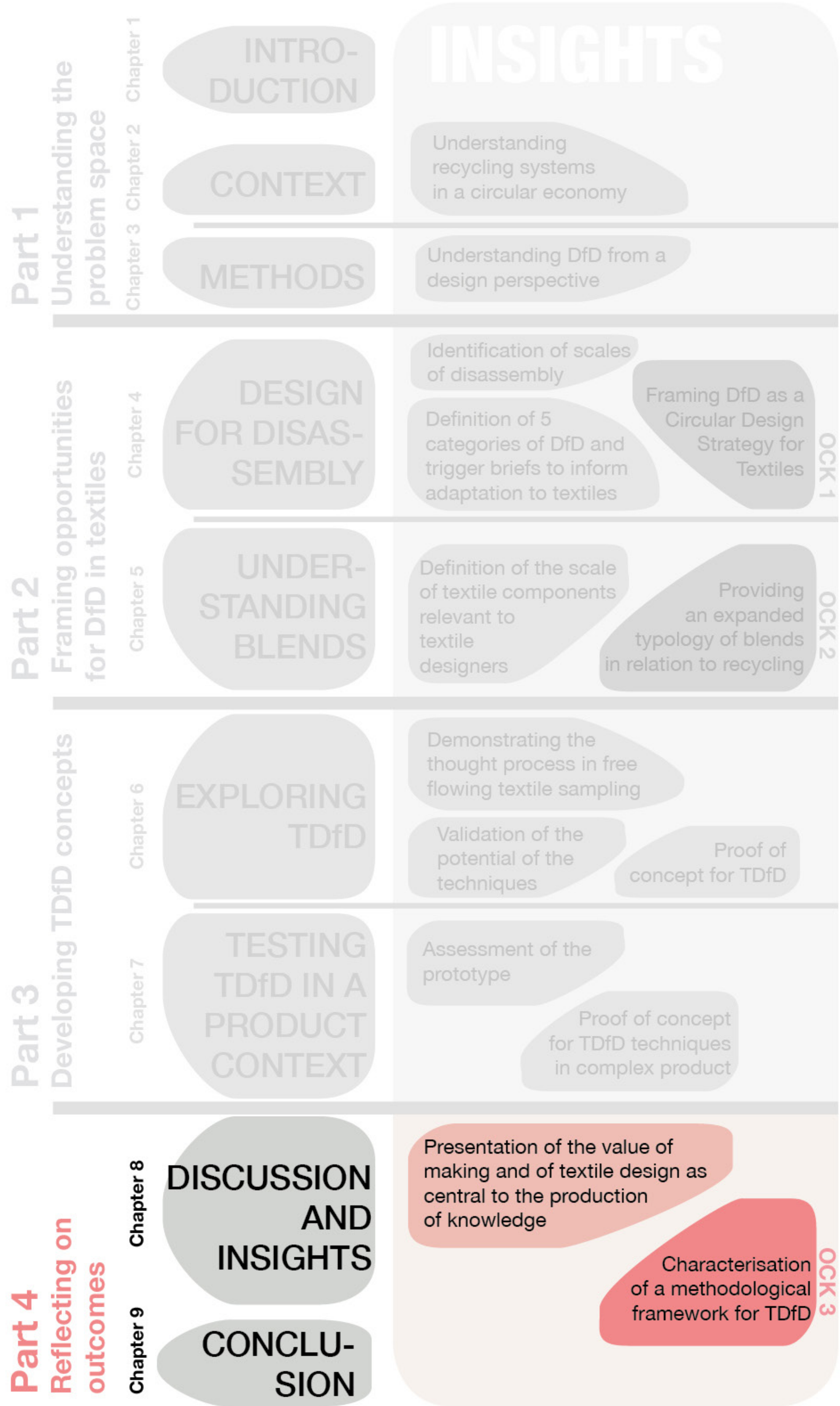
This body of design work has demonstrated how the four stages of the methodological framework are represented in practice. The reflection on the process of adapting the TDfD techniques from the samples to a full garment scale has highlighted transferable lessons for the use of this approach elsewhere. Indeed, while the TDfD samples presented in chapter 6 are a starting point for the implementation of the strategy in circular fashion contexts, a phase of adaptation to the new materials is necessary. Carrying out this translation in the two jacket iterations shows its potential for the applicability of the approach to a variety of materials and product types.

Summary of Part 3

This section has shed light on the process of designing Textiles for Disassembly in a circular economy context. Through free-flowing creative design practice, the work has also demonstrated the applicability of the DfD concepts described in previous sections to the scale of textiles.

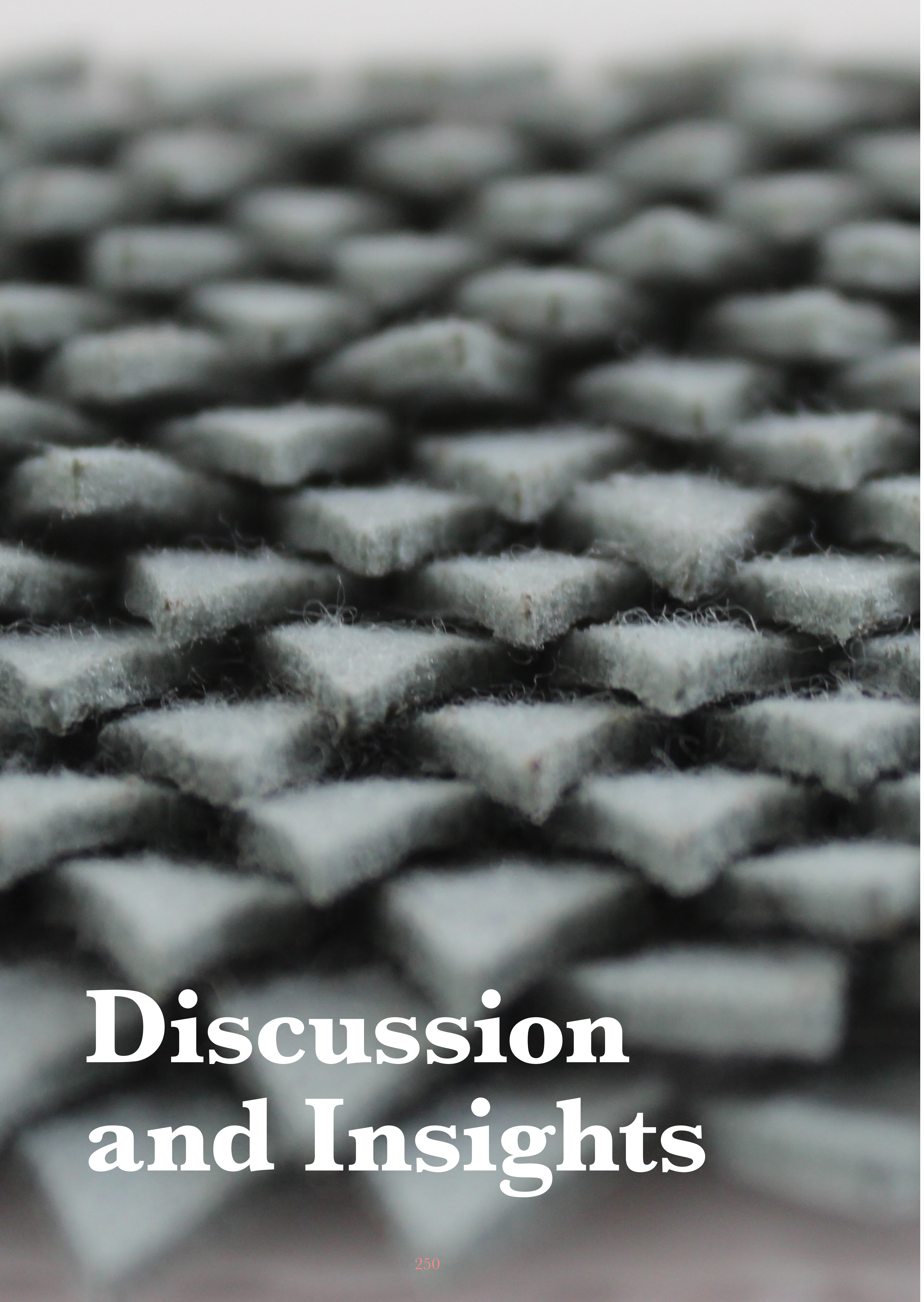
Through the exploratory practice presented here, the use of TDfD as a circular design strategy has been materialised and given proof of concept. The samples and prototypes provide the basis for further discussion on the potential and future applications of the strategy as was already initiated through a new round of interviews and the reflective annotation of the design process for the samples and Service Shirt respectively.

While the techniques in themselves have been explored in other practice in this field, the value of the work lies in the framing of the textile design process within the circular design challenge of blend recyclability and in outlining the whole process. The experimentation with these techniques in samples and in a product context demonstrates a new mindset which breaks away from the current unsustainable status quo in material combinations.



Part 4

This final part offers a reflective review of the process carried out in exploring the potential of TDfD as a circular design strategy. It highlights the key role of the textile designer's perspective through a set of methods that have provided a better understanding of the field where previously little literature was addressed to designers. This work demonstrates how conventional ways of assembling resources which prevent recycling can be challenged by taking the insights from the phases of understanding the problem into practice. As highlighted in the diagram on the opposite page, this section outlines a methodological framework for the use of creative textile design practice in addressing circularity challenges. The framework brings together the different steps of the research process which were built in an iterative and responsive way throughout this project and then articulated as a four-steps process that can be applied to future work in the field.



8. Discussion and Insights

Having developed an understanding of the challenge and tested potential solutions through practice as described in the previous chapters, this section offers a retrospective reflective review of the specifics of a textile design approach to circular economy challenges. First the prototyping process and the insights it produced are reviewed with transferability in mind. Then a methodological framework which considers the full research process and highlights the value of making in taking on circular design challenges is articulated to be transferred to future practice.

8.1. Reflection on Practice

As presented in the introduction (see figure 1.8. p.26) the final outcome for the practice is fixed in the form of a redesigned jacket, while this is a simplification of the overall process, it serves as an example of circular innovation that can be achieved through TDfD. This section offers a reflection on the redesign process and aims.

8.1.1. Redesigning a Jacket

Redesign processes are used in design for sustainability to replace problematic products and systems with positive alternatives. This is described by Bhamra et al. (2017) as an approach which is connected to incremental improvements in products which aim at reducing the overall impact or at increasing product efficiency. A redesign process takes into account the full lifecycle of the product, but most importantly "in order to successfully redesign a product, service or system, it is important to have a clear understanding of the resources required for the creation of the current design" (Bhamra et al., 2017:110). In this way, the analysis of problem blends shows the starting point for this redesign process.

The redesign process operates on two levels in this study. The core problem that is being "designed away" (Tonkinwise, 2014) is blends that combine materials that are incompatible for recycling. The work therefore offers a range of alternative combination techniques which allow for a shift towards combinations with detachable connections for the recovery and recyclability of their parts. However, these are free of any context and use placeholder materials. Therefore, the redesign process was taken to a second level to apply the new TDfD approach to a reference product which gives a context to assess improvements. The jacket brief therefore gives a setting for the benefits of TDfD in a circular system.

Starting from the end

While this thesis describes the chronological unfolding of experiments destined to generate an understanding of the potential of TDfD, the redesign process works in reverse. The thesis is laid out so as to show how the initial gap in knowledge in the field is canvassed and filled by the gradual stages of research and practice. In a redesign framework however, the starting point is an existing object.

The main pillar of the circular economy is that the design process should start from the end: with the end of life recyclability criteria of the product in mind. The framework laid out here does exactly that. By starting with recyclability constraints to design a new way of thinking of material combinations, the results of the sampling and prototyping include the requirements for ease of recycling from the outset. This has allowed for the development of textile assembly techniques which can be implemented as a way to respond to the needs of a specific product as well as the material recycling criteria.

Any future redesign processes which involve these TDfD techniques and concepts can be initiated with a reference product as a starting point. The jacket concepts presented here illustrate the journey from a complex unrecyclable product to a redesigned one which includes TDfD as a strategy to enable the recovery of its parts for upgrade or recycling with minimal compromises on functionality or aesthetics. This is but one way of interpreting the redesign brief and it can be used as an inspiration and example for other product or material types.

The redesign brief

The jacket brief offered by the Service Shirt project gave a reference point to embark on a redesign journey. As the brief originated from an elaborate research project involving several partners with different expert contributions, this gave the initial scaffolding to guide the development of a new jacket using TDfD. Although this was set with a specific background in mind and with a focus on the work of Becky Earley and polyester shirts

as a starting point, the mechanisms highlighted in this process can be applied to future practice as was demonstrated with the extension of the brief into the Split Jacket concept. Designing a jacket using TDfD technique in that instance showed how the reversible textile assembly techniques could be applied to a lifecycle extension and remanufacturing concept. In that sense, the redesign approach was taken further than Bhamra's original description and crosses into the category of systems innovation in which "designers are part of the development of new and complete sustainable systems implying new lifestyles and ways to understand production and consumption of goods and services" (Bhamra et al., 2017:115). This approach to TDfD as an enabler of bigger change in the industry is particularly relevant from a textile design point of view as the discipline has often been left aside in these broader issues. Indeed, environmental issues are mainly considered from a problem-solving perspective and, as argued by Igoe, "the question of the nature of design problems for textile designers still persists" (Igoe, 2013:100). The Mistra Future Fashion context for this prototype therefore provided a framework within which textile design methods and TDfD could prove their worth in solving recyclability issues.

The second iteration on the jacket concept went on to demonstrate the potential for a TDfD approach beyond the specifics of the original Service Shirt concept. By modifying the different variables of the jacket brief and concept, this transformation shows how future practice might take on a TDfD approach. This second iteration is taken as the final outcome of the redesign process carried out in this work. While further improvements could be implemented, the Split jacket fully demonstrates how problematic blends can be transformed into combinations with detachable connections through TDfD to enable the recovery of incompatible resources.

Taken as a whole, the stages from a reference product, here identified as a generic bomber-style jacket with a lining and an outer layer made of incompatible materials, to the Split jacket, shows the process through which to achieve an effective redesign for the disassembly and recovery for recycling of the incompatible pieces. Figure 8.1. on the next page details this shift put forward in the introduction to this thesis and shows how each phase of the work described in these pages leads to the redesign of the initial jacket.

8.1. Jacket redesign process

This retracing of the process, as with the mapping of the making throughout the work, offers a reflective representation of the stages to follow in new redesign activities which aim at increasing the recyclability of complex products through a TDfD approach.

Sustainable innovation

As put by Tonkinwise:

> “Sustainable design has, to date, been a strategy of replacing existing toxic or inefficient products with “greener” alternatives. Of course, much of the problem was that, apart from being greener, the products rarely showed more significant, comparative advantages […] consequently failed to displace existing products. Ideally, elimination by design involves a net reduction in materials intensity by virtue of one new product eliminating two or more existing products.” (Tonkinwise,2014:207)

The creative approach in this redesign process aims to address this need for proposed solutions to offer equivalent or superior functional and aesthetic qualities to the reference object. In using the designer’s tacit understanding of effective colour and texture combinations this approach to TDfD suggests solutions in which the aesthetic component is not an add-on but rather an integral part of the success of the techniques (see 3.2.3. p.79).

The particular aesthetic effects afforded by the TDfD techniques are used as added value in the redesign process. As described in chapter 6, the interpretation of existing blend types which currently create barriers to recycling yields new effects which are not an exact replica of the reference but offer original and pleasing effects. In the jackets these are used as aesthetic features, combining technical connections with 3D patterns giving the product its specific character.

Papanek signals at the potential for DfD and other design for sustainability strategies to propel design towards an era in which aesthetics are driven by environmental considerations (Papanek, 1995:235). The creative challenge of TDfD for complex garments in this practice suggests ways in which constraints can lead to desirable products. In this way the jackets offer effective sustainable innovation by showing alternatives than can successfully replace current problematic products.

8.1.2. Insights from the Redesign Process

This section offers a summary of the insights from making the two circular jacket concepts presented in chapter 7 and formulates recommendations for future practice. The focus here has been to use sampling and prototyping as drivers in both the understanding and the redesign of the problem. The value of this outline is therefore in the emphasis on the use of creative textile practice to develop solutions to circular design challenges.

Circularity beyond raw material recycling

While the starting point for this work came from the identification of blends as barriers to the recovery of raw materials for recycling at the end of their lifecycle, the research has led to understand the implications of imagining multiple cycles for material circulation. Adding this nuance to the understanding of DfD as an alternative to problematic blends describes the opportunities for the strategy in a circular economy and acts upon them.

The detailed description and classification of DfD offered in chapter 4 has highlighted different aims for the disassembly which reach beyond pure raw material recovery. This understanding has then been transferred to the exploratory practice with the set of briefs which act as creative triggers for the experimentation. Connecting the samples to the appropriate triggers in the reflective mapping phase also connected these abstract representations of TDfD techniques with wider consequences on production, use and disposal behaviours.

The Service Shirt work takes this reflection even further by including a TDfD strategy within a complex and multi-cycle system for a circular garment. In this instance, TDfD assembly techniques are used in a remanufacturing process which in turn enables future remanufacturing processes which are scripted in the transformation from shirt to jacket with the laser engraving (see figure 7.19. p.210). This prototype embodies the knowledge concerning the scale of the elements which are taken apart, it demonstrates the potential of TDfD to enable material circulation beyond the direct return to its raw material for full regeneration.

This takes the concept of TDfD beyond the original ideological

framework set in this research which is based on a dualistic Cradle to Cradle approach. This approach to the circular economy tends to receive critiques based on its over-simplification of the hugely complex field of recycling. Rather than offering a blanket solution, the study suggests a variety of approaches which are more finely tuned towards different types of materials and combinations. The outline of the process of developing TDfD solutions for blends shown in Figure 8.1. provides a foundation for a detailed approach to redesigning blends that can be adapted for different products.

A textile design approach to complex problems: redesigning the design team

Niinimäki suggests that:

> "A design-driven approach and design research methods can combine tangible prototyping with abstract knowledge-building, haptic and creative experiences with cognitive knowledge-building, emotional experiences with technical knowledge, and further bringing in commercial reality to strive for future innovations" (Niinimäki, 2018:311)

Building on this, the role of the textile designer as defined in this work takes a central place in combining the technical aspects of TDfD with the requirements for aesthetically and emotionally pleasing products. The textile designer's work usually happens before the product design phase begins, letting product, interior, and fashion designers pick from a range of samples to apply to the product development. As demonstrated in the two jacket prototypes, the TDfD concepts co-evolve with the product development to produce an effective circular concept. This puts the textile designer at the centre of the redesign process as an essential "material liaison coordinator" (Hornbuckle, 2018:1728). Borrowing this term from Hornbuckle highlights the role of the TDfD textile designer as a facilitator, enabling the use of an unrestricted range of materials in temporary combinations for a wide range of complex products.

As it was highlighted in the collaborative work on the Service Shirt project, the design of circular concepts cannot be successfully carried out in a linear process. TDfD in this context can act as a hinge element allowing for different designers to take shared ownership over multiple remanufacturing stages. These detachable connections offer an open-ended approach in the way that they enable future transformation and adaptation of the garment or product if the circumstances for use change. These changes can be in the expectations of users, or in the system surrounding the product. This means that the development of the product co-evolves with an understanding of the system in which it fits. This can for instance enable the circulation of resources until new recycling technology is made available to scale.

8.2. Reflections on the Research Process

Beyond the redesign of problematic blends and complex products, this work puts forward an overarching methodological framework for TDfD which can be expanded to research through practice which investigates circular innovation. This section reviews the main characteristics of this distinctive approach to pinpoint how the different bodies of work contributed key insights.

8.2.1. Making as a Central Factor for the Development of Insights

While the replacement of a problematic product or material is the aim, making is the main means through which this is achieved, and it is a key component of the methodological framework laid out here. Throughout the research process, from the understanding of the issue to the testing of solutions, making has been a central constituent. This section proposes a brief review of the importance of the practice and its use in retrospective analysis to draw insights. Different types of making have been used in this research process, they are presented here as either sense-making, in which a hands-on activity leads to a better understanding of existing contexts, or the making of original practice which tests the potential for new ideas.

Making as sense-making

Crafting representations of blends translates the available data in ways which allow it to be taken on by a textile practitioner. In the fast pace of the textile industry, approaches which fail “to define a goal that successfully integrates different agendas” (Andersen and Earley, 2014:6) and speak directly to designers will fail to provide effective alternatives to current unsustainable practices. This is particularly relevant when having identified designers as the main stakeholders in the creation of blends which currently create recycling barriers. The information and alternatives therefore need to be presented on the same level as the existing creative process for the production of new sustainable concepts. It is therefore crucial to extend the textile thinking process to the information concerning material recyclability.

The making of models of unrecyclable blend archetypes filled an existing gap in knowledge. Indeed, no representations of materials which account for the role of blends in limiting recyclability from a designer’s perspective had been identified in the review. This hands-on approach therefore offers a materialisation that draws on the tacit knowledge of textile designers and highlights how previously unquestioned conventional ways of assembling materials cause recyclability barriers and must therefore be urgently addressed in a redesign process.

In providing a framework for design for disassembly for textile design, this work positions itself as a hinge, a bridge to integrate TDfD on the same grounds as other assembly techniques. By being integrated to conventional textile design practice as an alternative to the currently unquestioned approach to material combinations, this can potentially enhance the agency of designers in making materials and products for ease of recovery and recycling.

Original bodies of practice and proof of concept

As highlighted in the series of case studies presented in chapter 4, DfD is currently almost unrepresented in the field of textiles. While some instances of modular fashion offer ways in which pieces of fabric can be assembled and taken apart, no extensive study of the strategy in the context of textile design had yet been carried out.

The samples and prototypes therefore offer a recontextualization of the concept of DfD within the field of textiles. This original body of practice demonstrates the practical implementation of techniques which enable temporary assembly with detachable connections. These examples not only provide evidence of the feasibility of TDfD, they also generate a new understanding of the role of textile design practice in exploring circular design challenges.

8.2.2. Mapping the State of the Art in the Field: Defining Briefs through Visualisations

In the scoping phase of the research, visualisation was used to review the field and feeds directly into the subsequent practice. By using direct visualisation, the gaps that this project had the potential to bridge were made apparent. Furthermore, the categorisation of the field showed themes that have guided the creative practice throughout this work. This section offers a discussion on the insights drawn from this transversal approach to mapping which has taken the conventional literature review exercise into an active process of sense-making.

Mapping existing practice in the field

The new convergence of approaches to the problem of blends which distinguishes this work has led to frame existing design concepts in an original way to achieve new understanding of DfD (see 4.1.2. p.92). In the first stages of the work, as described in chapter 4, selected cases of practice across disciplines were reviewed to understand the state of the art in this area. It is important to highlight here that throughout the thesis, practice, whether the author's or existing work by other designers, has been instrumental in the development of an understanding of the potential of TDfD. These cases were drawn together in an inspiration phase which nurtured the subsequent practice. This takes on some aspects of the mood board process (Cassidy, 2011) but builds on this textile thinking method by adding structure to it and making it a way of understanding the problem.

This mapping of existing practice showed parallels between disjointed references, taking on the conceptual blending (Biskjaer et al., 2018) or bisociative process (Koestler, 1989) argued as an essential element of design (see 2.2.2. p.45). Conventionally, mood boards "are tools used by designers to bring together apparently incongruent visual data to promote inspirations to develop suitable end products" (Cassidy, 2011:227). This work takes this approach further by giving the association of different cases representing complementary concepts in the field a set of categories and a hierarchy based on scale and level of user involvement in the disassembly. As a bridge between the traditional academic field review and the design fuzzy front-end mood board, this canvassing of the field showed the gaps to address. For instance, the mapping showed that

the scale of yarns and fabric in the construction of textiles themselves had not yet been addressed through DfD in the selection of cases reviewed. This therefore contributed to giving a direction for the practice to follow.

In chapter 4, the mapping of blend archetypes associated the act of making models of blend archetypes with creating a hierarchy which narrowed the scope of the study. The models of archetypal blends and the hierarchy which relates them to their recyclable mono material components has pinpointed how a textile designer's skills are most relevant where the materials assembled can be identified visually or through touch in the final product, as opposed to intimate blends which prevent such discerning. The hands-on approach to representing these blend archetypes showed a direct relation to the combinations existing in problematic blends and highlighted them as the issue to address from a specifically design-led perspective. As stated by Arnheim, representation is also a process of "working out solutions of problems" (Arnheim, 1969:129). This reflection on the visual hierarchy of blends is an essential step in defining the scope of the research in order to use the design skills available here in the most effective way to solve the issue of complex material recyclability.

It is indeed at this stage that the focus of the work was redefined from addressing blends to redesigning material combinations. This shift shows how TDfD can offer new ways of approaching the creative combinations of colour and texture in textile design. Rather than a technological fix to the issue, it suggests reconsidering the way in which resources are mixed, blended, or combined from a mindset, or design decision perspective. Moving away from a default blending which is seldom given much thought, leading to the recyclability issues described in the early chapters of this thesis, this work asks that designers be more deliberate with this creative bisociation.

The work takes a deliberate stance in responding to the concept of blending with large scale element combinations as a way to make this usually hidden issue visible and challenge the thought process which leads to the creation of unrecyclable blended materials. This builds on the strengths of the author's existing practice (see 1.1. p.19) but reaches beyond in using this deliberate extreme to better visualise the issue as well as offer graphic solution propositions to be refined in future practice.

Categorising the field

In the scoping phase, the untreated information from the practice equates to the results of a brainstorming activity, in which, as put by Jones: “the immediately valuable output is not the ideas themselves but the categories in which they are placed by classification. Identifying feasible ideas in a large random collection is not possible until the design situation has been explored in some detail” (Jones, 1970:275). Building on this, the transferable value of the practice does not come from individual case studies or models of blends, but rather from the categories which give them a broader meaning. This shows a shift from an understanding of the state of the art to the clear definition of the targets set in this work. As part of the broader redesign target of this research, this phase responds to the need to clearly understand and articulate the components of the problem before addressing them in practice.

As described in the previous section, the retrospective reflection on the practice drew insights from the intermediate knowledge embodied in the samples and prototypes (Löwgren, 2013). This has come in the form of categories which begin to pave the understanding in this new field of TDfD.

The categories of DfD (chapter 4) and of blends (chapter 5) offer a convergence point and lay the first stones for the expansion of their understanding in this field. These categories propose the framework for an expansive typology of DfD approaches, of blends in terms of recyclability, and the ways these two are combined in a circular design challenge.

Creating new briefs

In response to Igoe’s framing of design problems for textile designers as being “entirely tacit” (Igoe, 2013:95), this phase of understanding the issue has enabled the development of a problem articulation which draws directly from the textile design and making experience. Using the framing of the issue as a form of mood-boarding has yielded briefs, or creative triggers, from the association of converging concepts.

These creative triggers originated from a combination of the information collected in the initial expert interviews and the insights and categories drawn from the case studies’ analysis and mapping. The additional

information relating to scale and blend challenges have refined them and they correlate to each of the categories drawn from the review of existing DfD case studies.

The briefs presented in chapter 4 thus acted as triggers for the creative process. This is important to highlight as the research has proposed itself as a way of offering a solution to blend recyclability issues that do not limit the creative process in ways which were identified in engineering, problem-solving approaches, or in some instances of mono-materiality. The triggers, which are the product of a bisociative process themselves, are essentially conceptual blending tools for TDfD (Biskjaer et al., 2018).

The process of offering single word briefs is typical of the creative textile design process whether in education or in industry. Studd connects the brief to the articulation of a “thematic design word” which triggers a brainstorming process to develop a large variety of ideas (Studd, 2002:44). In this way, translating the DfD categories to thematic words enables their interpretation in a variety of ways in textile practice. This use of design approaches to understand the issue offers a way in which the solutions can be fitted within existing creative processes in the most seamless way. The briefs offer a framework for the exploration of TDfD. Their interpretability is key to generating satisfying creative processes in the sampling of detachable material combinations. These concepts have fed into this research as it is represented in the tracking of the thought process in the mapping of samples (see figure 6.52. p.181), they are however left open to be interpreted differently for the use of DfD concepts beyond the framework of this project.

8.2.3. Mapping Exploratory Practice

As described in revious sections, the practice has been carried out in a free-flowing way with little restriction in the moment of making for optimal creative processes drawing on the tacit knowledge of textile thinking. To draw insights from this practice, it is retrospectively reviewed in a series of visualisations.

Mapping textile thinking

While the exploratory samples which test the potential of TDfD techniques were made in a free-flowing process, they were subsequently used to extract meaning through mapping. This retrospective analysis of the creative process embodied in the series of samples aims to draw insights for the transferability of this practice framework.

As highlighted throughout the work, the craft-led, free flowing practice of the textile designer is central to the development of TDfD concepts. The samples and the prototypes represent an exploratory type of practice in which the end result is not known at the start of the making. This level of uncertainty is embraced in the process, and the later reflection reaps the benefits from this exploration.

This type of practice is tightly connected to tacit knowledge which resists articulation and the description of the process. In the words of Harrison:

> "Suppose such a practical agent [the craftsperson] is interrupted and asked why it is that he does what he does, why he uses his tools in that particular way. Then, he may pause and explain, but then he is searching for words, not attending his actions with tools and wood, and because the direction of his attention is different his actions and his thoughts in what he does are different: he is then teaching, explaining, instructing, not carpentering." (Harrison, 1978:45)

In the textile design process described in these pages, the continuity of the sampling and thinking process that fuels it was kept by limiting, at first, the documentation of the process and letting it unfold with the materials and processes as actants. Using the term in Jane Bennett's way an actant "is an entity that modifies another entity in a trial, something whose competence is deduced from its performance" (Bennett, 2010:viii). Textile designers are accustomed to letting themselves be guided by the materials (Igoe, 2013; Marr and Hoyes, 2016; Philpott, 2011), and an effort is made in this work to draw transferable insights without stifling the creativity of the process. Very limited recording of the process as it unfolds was made, but this was replaced by subsequent stages of reflection on action (Schön, 1983).

An in-depth retrospective reflection on the unfolding of the experimentation was proposed and used to draw meaning from the series of samples. This approach is inherited from the annotated portfolio (Gaver and Bowers, 2012; Löwgren, 2013; Sauerwein et al., 2018) or after action review (Morrison and Meliza, 1999) methods. As it was presented in the

retrospective analysis of the prototype making phase, this combination of approaches makes apparent intermediate levels of knowledge which are held within the object or sample.

The samples produced in the exploratory making phase represent a variety of ways of combining different materials in ways which will allow them to be taken apart. The making process flowed from a generate-and-test (Rowe, 1987) approach in which each sample gave a slightly adjusted direction for the next one to improve the results. Retracing the chronological steps from the first sample made the design journey visible in a mapping of the practice across laser cutting, felting and weaving samples. In line with textile design research approaches (Earley and Hornbuckle, 2017; Igoe, 2013; Marr and Hoyes, 2016), the documentation of this making phase was a way of materialising the journey into unexplored techniques and recording the failures as much as the successes.

This approach offers a valuable proposition for the textile designer's approach to creating new knowledge. Following the intuition that comes with a tacit understanding of materials, the reflective phase categorises the outcomes, and generates abstract meaning from the samples and prototypes so that these findings can be transferred to other practices.

Textile thinking as problem solving

The outcomes of these exploratory practice phases, whether samples or prototypes, are used as tools to understand the process which was carried out in this work in exploring solutions for blends through DfD. This can enable a better transferability of the insights and provide a framework for the replication of this type of approach to new circularity problems.

Textile design is normally seen as separated from problem-solving approaches, and as put by Igoe, designers often consider "solving problems for themselves" (Igoe, 2013:93), responding to a self-set goal for the aesthetics of the final textile. However, this research has highlighted the role of textile design in solving external problems. The connections with the field of engineering or more conventional industrial design takes on technical issues have translated this approach to problems to the field of creative textile design, embedding some of the considerations from problem-solving perspectives into the practice of this research itself. The mapping reflected on here is instrumental in showing the workflow in addressing the issue of blends through textile design practice.

The reflective review of this iterative process identified four assembly techniques that adapt DfD to the practice of textile design. These took the form of temporary assembly methods which can be produced using textiles techniques such as weaving, felting or laser cutting and hand assembly of materials as demonstrated in chapter 4. The use of annotated portfolio and after-action review methods also provided an understanding of the opportunities and challenges in taking these assembly techniques to the scale of a garment prototype.

Elaine Igoe asks:

> "Tacit knowledge is embodied in the designed outcomes of textile design and exhibited in the textile designer's approach to design thinking and the behaviours and activities they undertake within their design process. Can a textiles orientated approach to design be correlated with a more concrete methodology within the broader remit of design research?" (Igoe, 2010:6)

In response to this, the recording of the processes undertaken in this research show how textile designers may approach complex issues and redesign problems without relinquishing the specificity of the discipline and its ability to bring forth materials and products which are "addictive, emotive and pleasurable" (Igoe, 2010:6). The samples and prototypes clear a path for the use of TDfD in this context and can act as inspiration or creative triggers for future practice. But more importantly, the reflection on practice which is proposed here articulates the different stages and the value of the making as a strong method for delivering insights for circular design challenges. The stages of this redesign and exploratory process are laid bare in this thesis and offer a concrete example for textile design as a problem-solving process.

8.3. Overarching Methodological Framework

The previous section reviewed and reflected on the key aspects of the research with a focus on making and visualisation. Based on these insights concerning the methodological approach, an overarching structure which represents the key stages of the work in a way which allows them to be transferred to other practices is proposed here. This is put forward as one of the contributions to knowledge of this thesis.

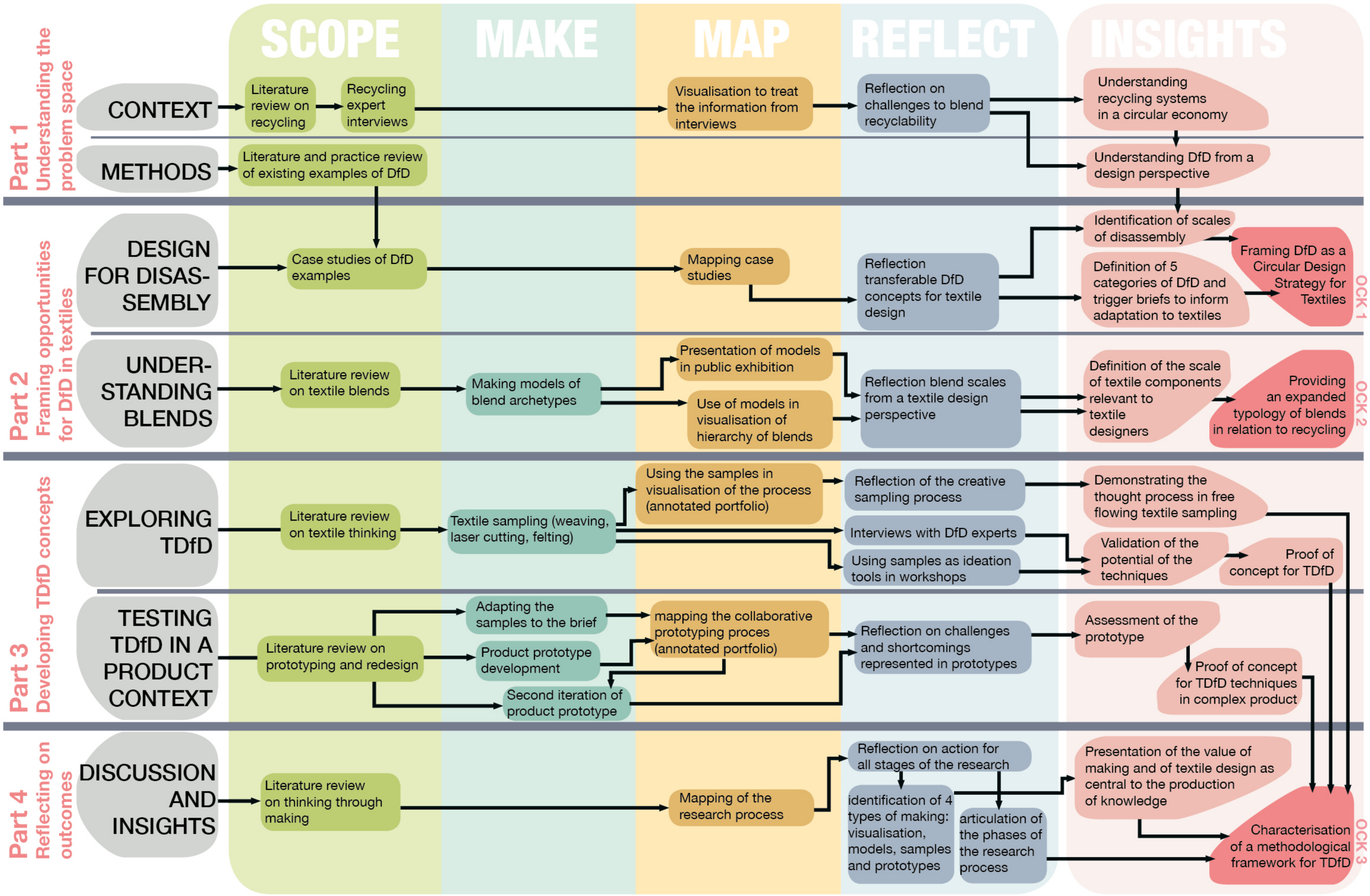
8.3.1. Four Phases to Insights

As presented in chapter 3, each action in the research process can be allocated to one of four phases: scope, make, map, and reflect. The reflection narrated in this chapter has highlighted how these phases and the actions they include lead to key insights throughout the work, the diagram presented in figure 8.2. draws these together visually to provide an overarching framework for the research. Expanding the breakdown of insights by chapter presented in figure 1.9. (p.28) and inserting the methods presentation from figure 3.1. (p.67) demonstrates the flow through the series of research processes which led to insights for TDfD. The diagram shown here goes on to demonstrate how insights themselves converge as contributions to knowledge.

Moving forward from the chronology of methods diagram, this representation of the process breaks the scoping phase down into the sections that have directly influenced subsequent practice. Similarly, the various events in terms of making, mapping and reflecting on outcomes are presented in terms of how they fed into each other to produce the insights rather than strictly chronologically.

The bricolage of methods is thus retrospectively collated into a guiding structure. As described in chapter 3 (see 3.1.2. p.64), the choice of methods was made in an iterative and responsive way rather than following a set protocol. This map of methods draws out the logical steps for the research: from a set of disjointed actions, a flow towards insights can be interpreted. This diagram also contributes to highlighting how each body of work as presented in individual chapters, whether the understanding of blends, textile sampling, prototyping or methods framework building, all move through the same four phases.

As shown in figure 8.2. the initial scoping phase includes actions such as conventional literature reviews but also some of the alternative approaches to information gathering used in the project such as interviews or case studies. The making phase considers the work produced in three bodies of practice: the making of blend models, textile sampling, and garment prototyping. The mapping phase encompasses the different ways in which intermediate knowledge embedded within the making outcomes or the case studies was classified and analysed to understand categories



8.2. Methodological framework diagram

or processes. The reflection phase considers the information made apparent in the mapping and relates it to the issues addressed in this work, considering subjects such as the potential of TDfD to overcome blend recyclability barriers, or the value of making in the innovation process for instance. These reflective methods then converge the understanding of the full process into specific insights which crystalise the new knowledge produced in this work.

While the second phase is clearly labelled as the making stage and contains actions such as the production of samples or prototypes, it must be pointed out that, as described in previous sections (see 8.2.1. p.258), the importance of making permeates every step of the work. This is particularly relevant when associating the scoping phase to an initial inspiration gathering in a conventional textile or fashion design process. Similarly, the mapping is itself a form of crafting of visualisations. This emphasis on the role of making as a key component throughout the framework is one of the ways in which it is made particularly relevant to material designers in approaching complex issues.

8.3.2. A Model for Future Research

The full detail of how each action fits within the framework serves to demonstrate how it emerged from the entire research process as laid out in this thesis, the transferability of the approach lies in the simple injunction to follow the set of four stages outlined here. The abstraction afforded by the representation of specific methods within the four stages means that it can be translated to other work by assembling a new set of actions in a bricolage approach within this overarching structure.

The value of such a framework is also in the way that practice is put at the centre of the work, as a hinge between an understanding of the field and the development of solutions to a circularity challenge. As demonstrated throughout the thesis, textile design perspectives have been under-used in problem solving contexts. This model and the demonstration of how creative textile design practice has permeated all the phases of the work thus provides a precedent for textile designers to address new challenges in a circular economy context.

This thesis provides a structure within which the understanding associated with recyclability challenges, textile structures, materials experimentation and garment construction, to name but a few of the pools of tacit knowledge from which such a process draws, come together. They can be combined and converge to practical and innovative solutions to a given problem filling a gap in the field of circular design.

9. Conclusions

9.1. Summary of the Research

This thesis set out to explore how DfD could be used in the context of creative textile design to offer ways of combining materials from different recycling streams so that they could be taken apart and recovered as recyclable mono materials. The underlying motivation for this was to suggest alternatives to the current status quo in materials combinations which contributes to the difficulty in recovering and recycling materials in a circular way. These barriers, despite being an inherent design flaw, had not yet been addressed from a textile designer's perspective. The work therefore aimed at understanding the potential of TDfD in redesigning material combinations for circularity.

9.1.1. Achieving Aims and Objectives

As presented in the introduction (see 1.2. p.27), the initial plan for the research was structured along two main aims and associated objectives, which were achieved and fulfilled through a series of practice experiments. Table 9.1. offers a summary of how each of these aims was achieved through the completion of the list of objectives.

The research succeeded in showing the applicability of existing DfD concepts to a variety of textile techniques such as weaving, laser cutting, felting and a combination of these. It demonstrated that rather than being a limitative constraint, designing with end of life in mind could be a powerful creative impulse. The practice and subsequent analysis have proved that using resources without creating any permanent connections between incompatible materials within the framework of a circular economy can lead to the creation of attractive and functional materials and products.

The aims and objectives laid out at the beginning of the study as a structure to gradually understand and fill the gap in knowledge have also influenced the research process. Indeed, these match the phases of exploration, testing and reflection which have been identified as characteristic of a creative textile perspective in approaching complex issues and translated into the four stages of the methodological framework put forward in this work.

Aim 1: Understand the current state and potential for DfD in designing textiles for recyclability	
Objectives	Achievements
Create a visual map of the typology of existing blends and their characteristics	To gage the redesign task ahead, a design-led understanding of blends was achieved through the expansion on Gulich's work in creating a hierarchy of materials for recycling. This is shown in the mapping of existing blends in Chapter Five.
Understand the barriers to recyclability created by blends	As a complement to a traditional literature review, the series of expert interviews gave first-hand experience of the barriers caused by blends in existing recycling systems. This led to identify two types of materials which were commonly a hindrance to the recovery of resources: laminated and stretchy textiles.
Identify the ways in which DfD can influence product end-of-life and recycling	In the literature and practice review in Chapter Four, the range of approaches to DfD strategies in various fields of design were laid out. This led to create a typology of five categories of DfD, leading to design briefs for creative textile design practice.
This set of objectives have been successfully reached and led to achieving Aim 1, providing a design-led understanding of recycling systems and situating existing DfD approaches within this framework. This positioned the next stages of the research towards enabling ease of recycling in redesigned material blends through DfD. Moreover, a set of design briefs were articulated to fuel the following stages of creative textile design practice.	
Aim 2: Design textiles with detachable connections and draw insights for the use of TDfD in circular economies	
Objectives	Achievements
Carry out textile design practice exploring TDfD	As described in Chapter Six, a series of samples were made as part of a body of textile design practice, using creative textile design practice as a way of eliciting original outcomes.
Identify the opportunities for textile practice to propose models for TDfD	From the analysis and mapping of the samples developed through practice, four TDFD assembly techniques were identified. These are a non-exhaustive repertoire of techniques that can be expanded on in future practice.
Apply the TDfD concepts to a set product context	In Chapter Seven the insights for TDfD developed in earlier phases were applied to a circular garment concept in two iterations of a jacket prototype. This highlighted the challenges and opportunities of applying the TDfD strategies at this scale.
Draw insights from the challenges of designing for disassembly and the opportunities for the product life cycle	In a phase of reflection on action the two iterations of the jacket prototype were compared to draw a series of guidelines in the form of questions which will guide the application of DfD to future product development.
Aim 2 has been achieved through creative textile design practice. In addition to this, a broader and more holistic understanding of the role of textile design practice in developing circular economy solutions has been articulated from the analysis of the research process.	

Table 9.1. Acheiving aims and objectives.

9.1.2. Summary of the Research Process

The project took the form of a redesign challenge. The task that was set was to provide an alternative to blends which currently act as barriers to the effective recovery and recycling of materials and products in a circular economy. This suggests that the solutions must provide equivalent or superior qualities to replace problematic blends with TDfD alternatives (Tonkinwise, 2014:207).

Design processes often start with a phase of redefining the issue (Brown and Katz, 2009; Cross, 2011), this project builds on this with a phase of scoping of the existing context and issues to better define what challenges the project was set to undertake. Through mapping, DfD was articulated in a way which was appropriate to the type of research and the skills available in this context. Furthermore, the problem of blends was analysed to better understand its relation to current recyclability barriers. Combining the insights from these two angles from which the problem was assessed, the brief was redefined as offering alternatives to material combinations in which the elements can be individually identified in the final material or product. This provided a narrower framing of the issue which excludes intimate fibre blends or chemical approaches to DfD for instance.

Based on this redefined design brief, the inspiration and creative triggers from the review phases were carried through into practice aimed at exploring the feasibility of detachable connection between different materials in samples and products. Four different types of assembly techniques which allow for the future separation of components were characterised with two of these being combined and further adapted to specific materials and applications in the two jacket iterations.

The redesign structure ends at this point with the jackets showing an alternative to current complex outer garments which cannot be recycled. The journey through the phases of understanding the issue and redesigning the material combinations and the products in which they are applied was laid out to demonstrate the validity of TDfD to respond to the challenge of blends.

The next phase of the research adds on to the redesign process with a reflective review of the entire process in order to articulate the contributions of a textile design approach to circular design and formulate it as a transferable methodological framework. This has articulated the specificities of a textile designer approach in moving through four stages of scoping, making, mapping and reflecting to achieve insights for TDfD. This framework has highlighted the importance of making throughout the work and provides a structure to support exploratory research which draws on tacit knowledge and designerly ways of knowing. Reflection on the practice research process laid out here draws some transferable insights which can be applied to the development of further circular design solutions to current issues.

9.2. Contributions to Knowledge

The research set out to fill an existing gap in knowledge, the three main contributions detailed here offer new insights that structure the development of TDfD but also demonstrate the ability of the approach used in this study to reach further into the field of circular design. The first two contributions offer a new analysis of the field adding to existing knowledge either by reframing it in the context of TDfD or by adding nuance to the understanding allowed by previous work in this area. The third contribution builds on the previous two as well as it originates from the analysis of original practice to offer a methodological framework for TDfD.

9.2.1. Framing DfD as a Circular Design Strategy for Textiles

The visualisation of the selection of case studies presented in chapter 4 has articulated DfD as a design strategy so that it can be applied to future practice in a circular economy. This constitutes one of the main pillars of the research as it has identified the specifics of DfD and translated them to the scale of textiles. It has also demonstrated where the current gaps in the application of the strategy lay, in order to best orient the subsequent research.

Previously to this study, DfD had mainly been understood as an industrial product design or engineering approach to optimising the recovery of components, most noticeably for electronic and electrical products. The

work presented here has argued for the need to translate this strategy to the responsible use of textile resources in ways which enable their recovery from combinations at the end of life.

The research has successfully added granularity to the understanding of DfD and framed it as a circular design strategy. This design perspective has yielded five categories which provide an outline for the inquiry into TDfD. This approach which expands the understanding of DfD beyond raw material recovery is useful in the way it harnesses existing design approaches in the context of designing for recyclability and makes them available as circular design strategies for textiles. The translation into simple design briefs, or creative triggers, enables the implementation of these approaches into textile design practice.

9.2.2. Providing an Expanded Typology of Blends in Relation to Recycling

As a second contribution, this work provides a description of the variety of blends which currently hinder recyclability in order to operate a shift towards a type of textile that is easier to recycle. Building on Gulich's classification, the research adds nuance to the understanding of the most problematic category to enable a shift towards the category of multi materials combination systems with detachable connections to offer an optimal compromise between ease of recyclability and functionality.

This is useful to textile designers looking for ways in which to design for ease of recycling in a circular economy as it demonstrates how the different categories relate to the reality of making textiles. By visualising and analysing the variety of blend types in the original problem category in relation to recyclability, the specifics of some of these types can be better understood to be redesigned into materials with better recyclability properties.

This acknowledges the role of designers in changing the ways in which materials are combined in a circular economy, translating the existing analysis from engineering into information which invites design-led action and empowers individual designers as agents for change in design for sustainability.

9.2.3. Characterisation of a Methodological Framework for TDfD

The reflective phase of the research produced an overarching methodological framework which is inherently tied to research through textile design practice and demonstrates its value in solving complex problems. This description of a process which normally relies on tacit knowledge and is articulated only with difficulty highlights the mechanics inherent to textile thinking in the problem space of circular design challenges.

The research demonstrates the phases in the design process that lead to the development of solutions to recyclability challenges in textiles. By retrospectively retracing the process to achieve insights regarding DfD and blends, the framework demonstrates the validity of a design perspective to explore alternatives to unsustainable practice.

Beyond the remit of this project an understanding of the structure of the workflow, through a combination of scoping the field, making samples and prototypes, mapping various processes and sets of information to highlight intermediate knowledge and reflecting on this analysis, shows a transferable methodological approach to overcoming barriers to a circular economy through practice.

9.3. Future Research Opportunities

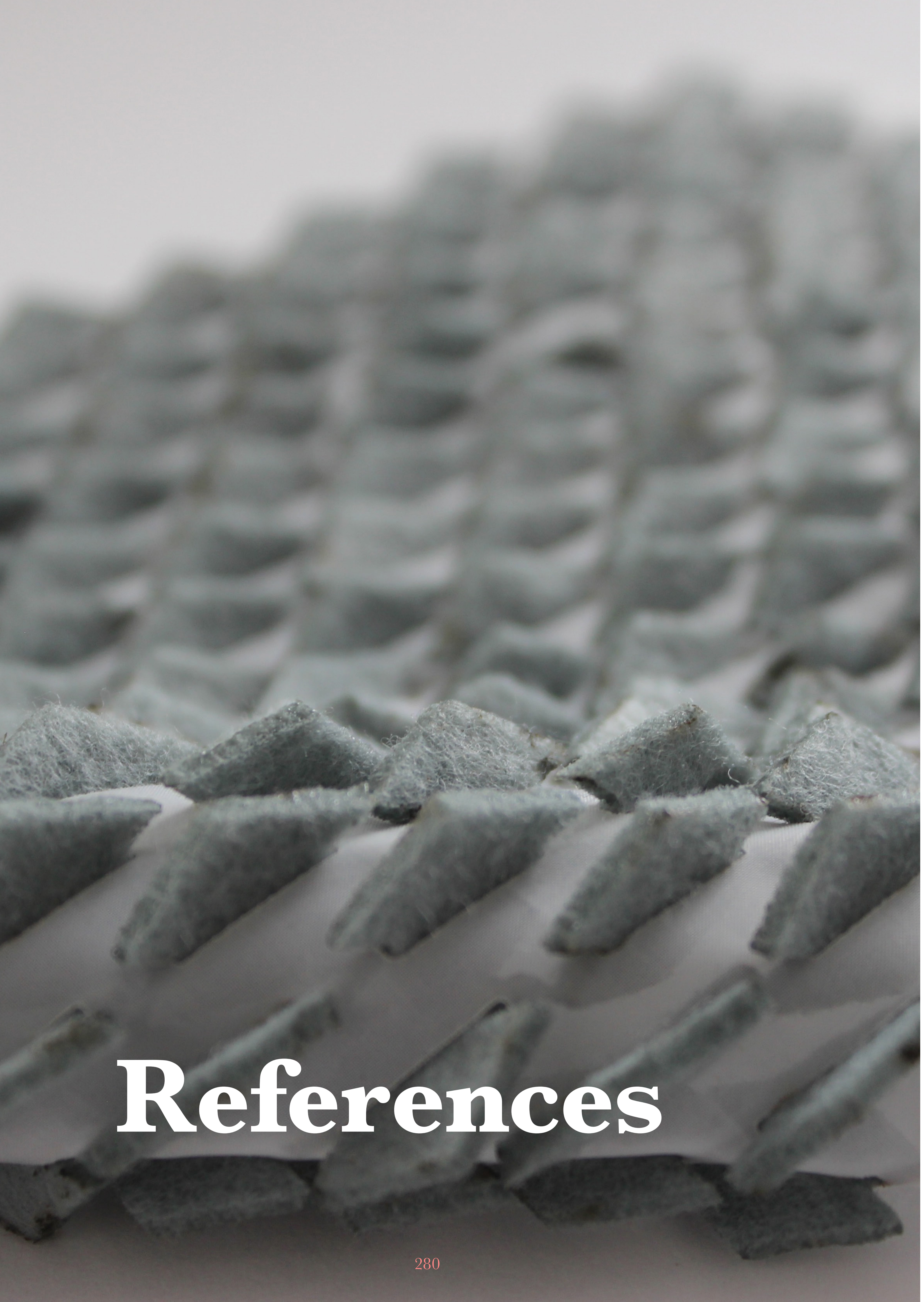
The abstract nature of the examples of TDfD presented in this study offer a broad range of future opportunities for application and adaptation to various fields. At each stage of the practice, different techniques or categories of approaches were articulated, and within the timeframe of this research, not all of them could be addressed. This therefore leaves a wide range of strategies that can be further explored.

Firstly, while the samples and prototypes presented here show combinations of two resources, the number of elements combined could be expanded. In the study of blends the different archetypes were codified and represented as the combination of two incompatible resources for more clarity. The reality of blends is however more complex and instances of three or more fibres being combined are common (Maldini

et al., 2017; van Duijn, 2019). This could be taken further into the making of TDfD materials and products which combine more than two elements in a redesign process, using a reference product or blend with multiple incompatible components. A brief exploration of this approach was initiated when experimenting with wool, and a few sandwich materials with insulating middle layers were made. However, this was not taken into the product prototyping to maintain manageable boundaries for the study.

In a similar way, the potential of TDfD could be tested further with the development of other types of products than a jacket. The service shirt work came from a serendipitous opportunity, however other paths that were left aside at that point of the research could be taken up at a later date in collaboration with the experts with whom these ideas were initially discussed. Even in the same product scenario, new opportunities could emerge. The review of the Service Shirt work as a local system involving designers and various prototyping facilities led to imagine how circular design networks could be developed with products, people and places (Real et al., 2018). The materials involved in these products could be adapted and connected to a variety of recycling systems as the flexibility of the framework in the jacket iterations has demonstrated. In addition, the examples that were not developed fully into the jacket prototype such as the woven samples or various assembly techniques with laser cutting and felting, can be used in a new brief in future practice.

The prototyping of TDfD into a circular fashion system initiated a reflection on the potential of this approach to influence user behaviour. In this context the focus was specifically on the evolution from one product lifecycle to the next through transformation effected by different designers. The use of DfD has been shown to enable modularity enacted by the user in various product contexts, this could lead to interesting functionality in garments or other products which put disassembly at the centre of the user experience, questioning themes of trend and material durability. New developments around material narration with dissociated lifespans and with modular materials in a community maker space environment could take on the poetic potential of TDfD, opening a wide range of possibilities for the further development of TDfD for a circular economy.



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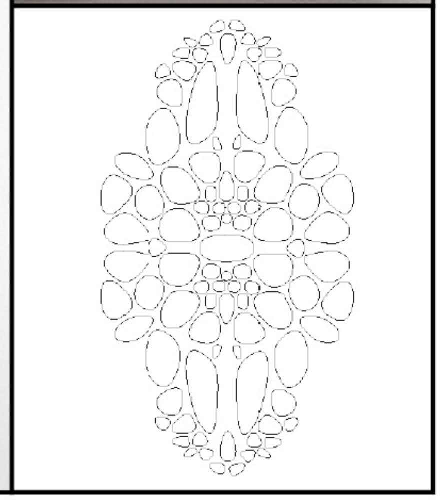
11. Appendices

11.1. Sample Cards

sample number: 1	sample name: organic bobbles	
materials: translucent thick plastic sheet - polyester stuffing - cotton/poly jersey		date: 18/04/17
disassembly: mechanical		size: 13cm x 23cm
technique: ☐ felting ☐ weaving ☒ laser cutting ☒ other: stitching		
process: laser cutting the plastic, making by hand of the bobbles, cutting different sizes of circles according to the sizes of holes and stitching around a ball of stuffing		
material description: inspired by the bone chair (ref) in which the structure of the chair is also the grid into which the cushion elements are fitted, this material (hard to call it textile) is an attempt at taking the concept to a smaller scale, potentially as a step towards a further, much smaller and more textile-y scale the modularity taken from the inspirational chair could allow to update the material throughout its useful life, the squishy cushions create the pattern which could be designed freely		
future improvements: could make the bobbles in a 3D printed geodesic structure with flexible thread different patterns/densities could be tested		

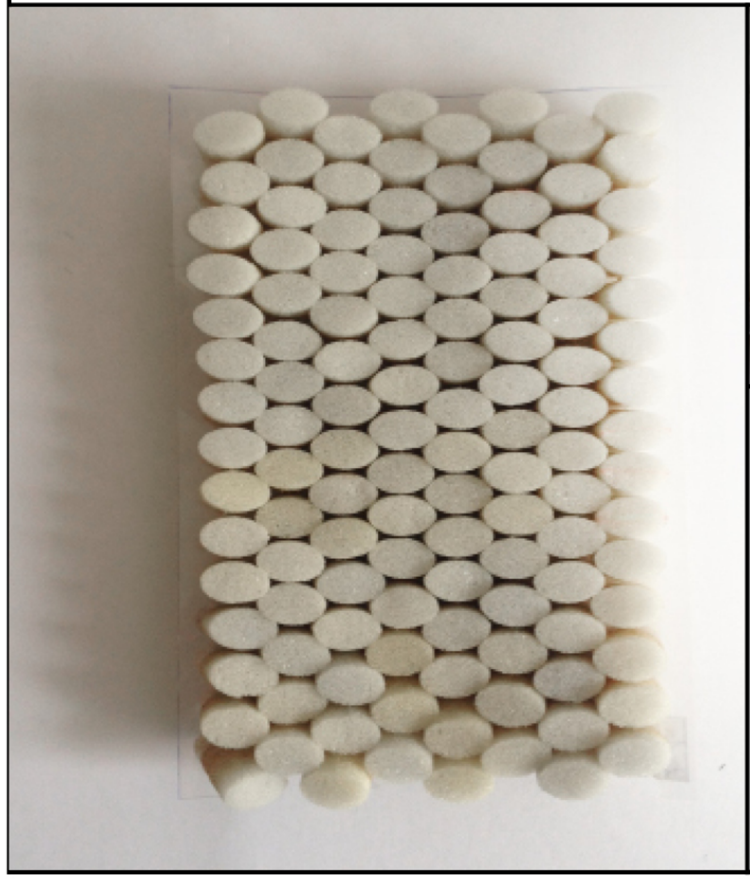


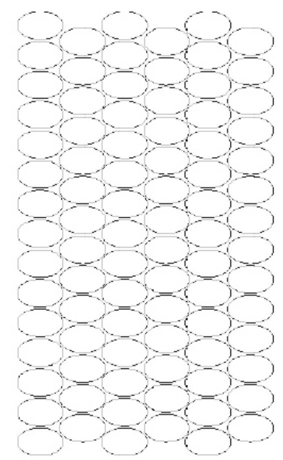
sample number: 2	sample name: oval foam	
materials: translucent thick plastic sheet - high density upholstery foam		date: 18/04/17
disassembly: mechanical		size: 15cm x 20cm
technique: ☐ felting ☐ weaving ☒ laser cutting ☐ other		

process: laser cutting the elements and assembling, to get through the entire thickness of the foam, the focus of the laser must be made mid way through the material

material description: inspired by the bone chair (ref) in which the structure of the chair is also the grid into which the cushion elements are fitted, this material (hard to call it textile) is an attempt at taking the concept to a smaller scale, potentially as a step towards a further, much smaller and more textile-y scale the modularity taken from the inspirational chair could allow to update the material throughout its useful life, the squishy cushions create the pattern which could be designed freely, the foam is slighly compressed as it enters the plastic sheet, which holds it in place

future improvements: the foam doesn't cut very well (melts and stinks), it could be replaced by another type of foam that reacts better to the laser cutting, or by 3D printed shapes with flexible thread, the pattern can be modified to test different ways of covering or uncovering the base sheet



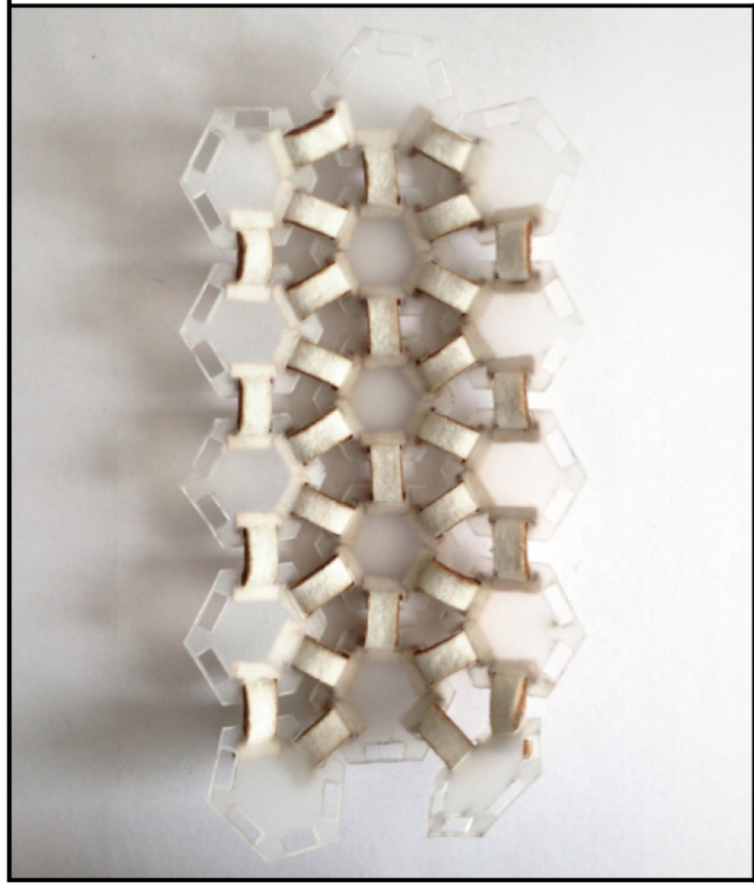


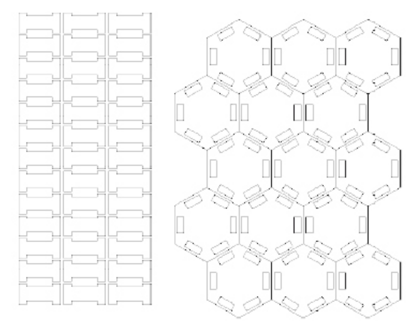
sample number: 3	sample name: hexagone structure	
materials: translucent thick plastic sheet from paperchase - wool felt		date: 18/04/17
disassembly: mechanical		size: 12cm x 24cm
technique: ☐ felting ☐ weaving ☒ laser cutting ☐ other		

process: laser cutting and assembling by hand

material description: inserting all the felt elements in the same direction makes the whole structure fold in on itself and become a little elastic, the contrast between plastic translucent and dense wool is also interesting, the structure can be assembled and disassembled many times (modular)

future improvements: test different materials, combine different materials in the hexagones, make the structure bigger to see what happens to the folding-n effect, test different thicknesses and sizes of the felt links





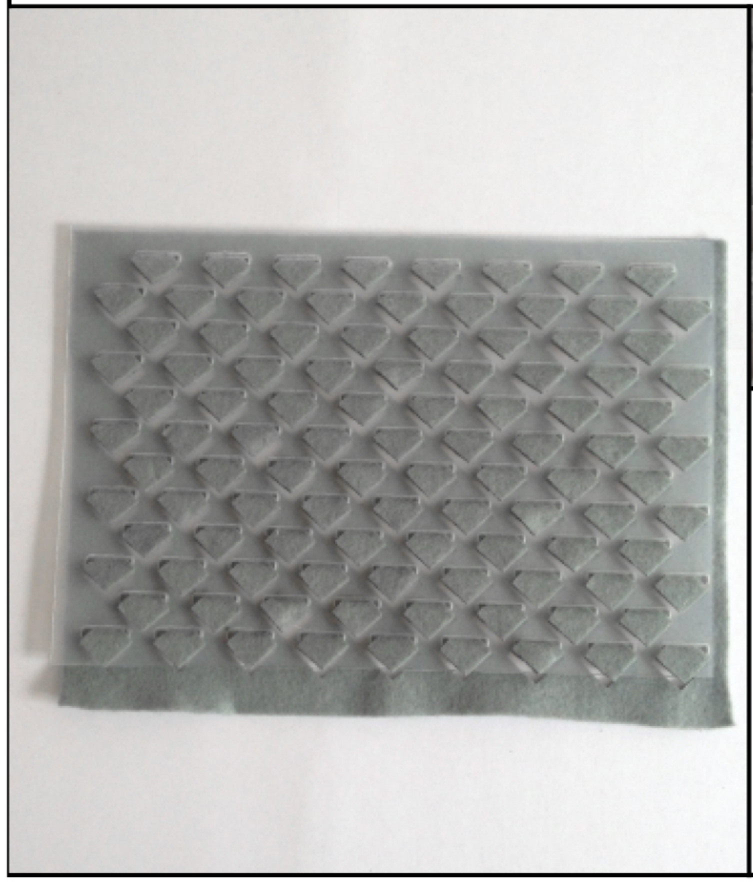
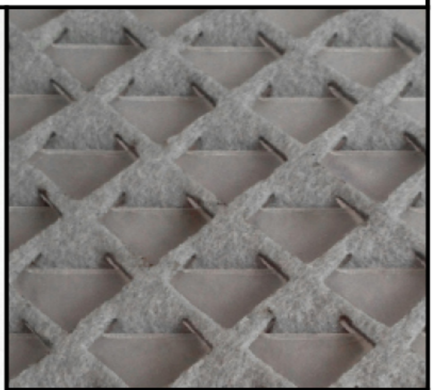
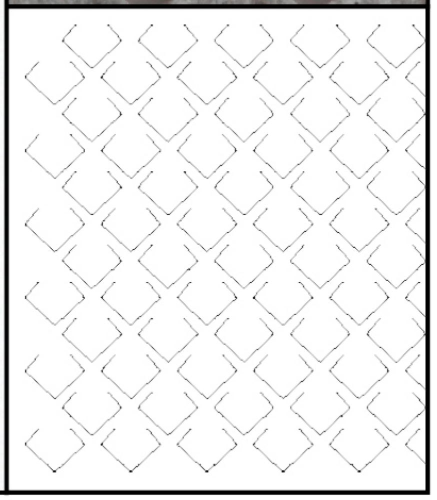
sample number: 4	sample name: diamond inserts
materials: polyester felt - translucent thick plastic sheet from paperchase	date: 18/04/17
disassembly: mechanical	size: 22cm x 16cm

technique: ☐ felting ☐ weaving ☒ laser cutting ☐ other

process: laser cutting and assembling by hand

material description: the thickness of the materials makes the felt diamonds stand up a little and creates a spiky effect as well as letting the transparency of the plastic appear in some parts, the contrast of materials is also interesting

future improvements: it could be intersting to use the same system with a material that reacts in response to sunlight, this could allow for a type of ‘reponsive blinds’ effect as the light would be let through more or less
the size and shape of the diamonds could also be played with to test different levels of transparency of the outcome

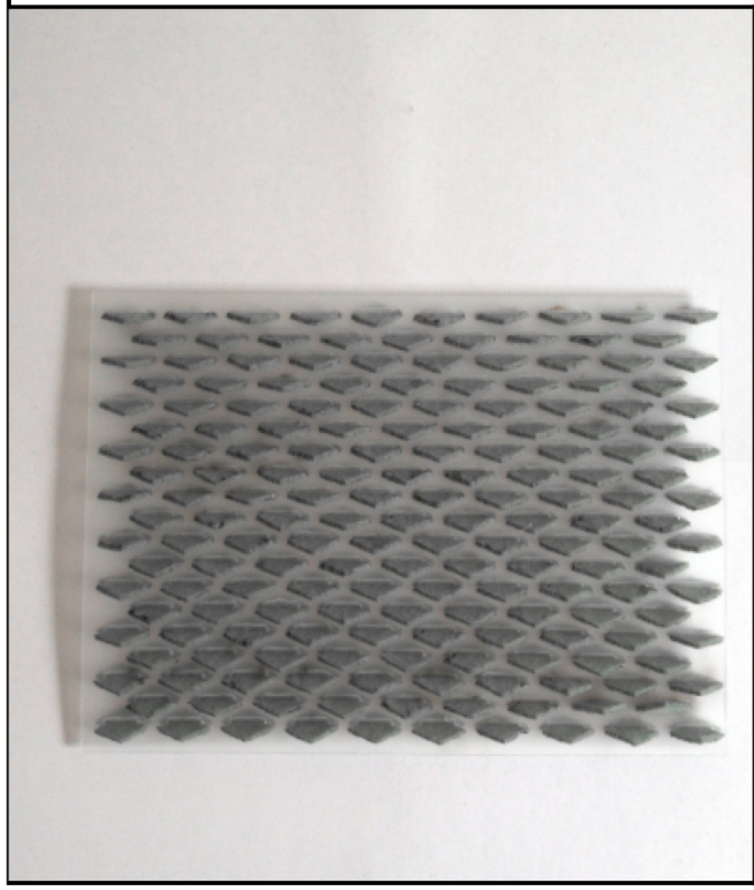
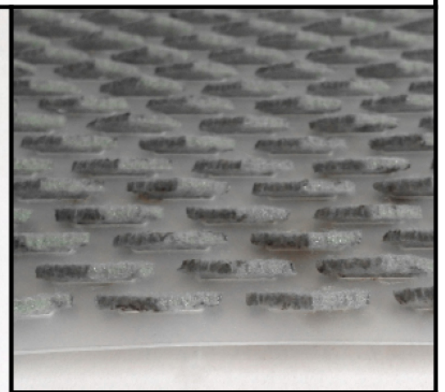
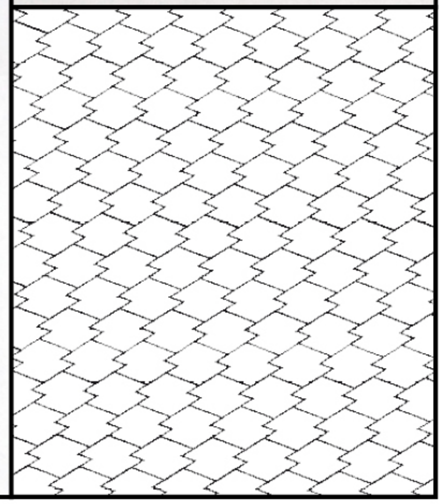
sample number: 5	sample name: sapin stiff
materials: polyester felt - translucent thick plastic sheet from paperchase	date: 18/04/17
disassembly: mechanical	size: 20cm x 15cm

technique: ☐ felting ☐ weaving ☒ laser cutting ☐ other

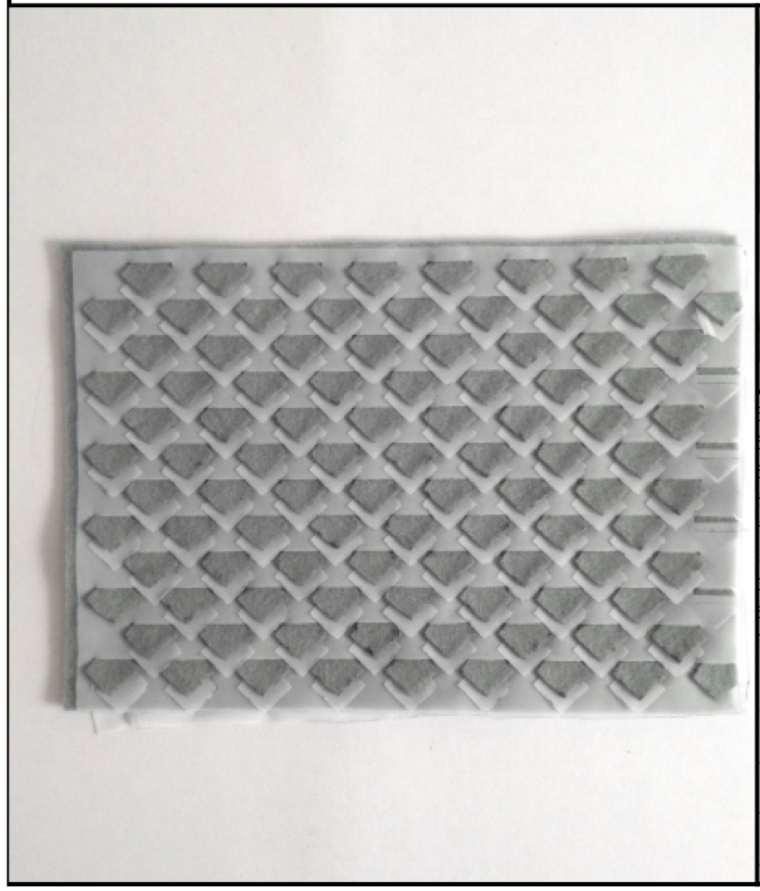
process: laser cutting and assembling by hand

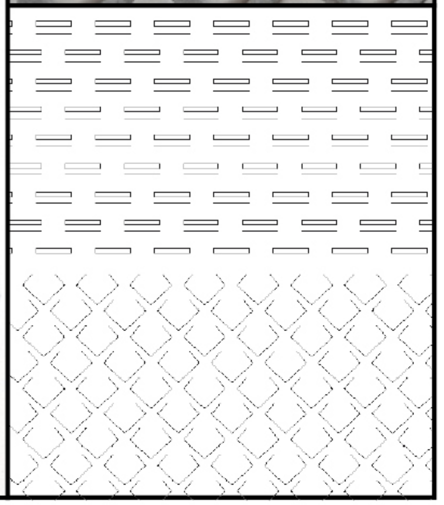
material description: each invidual module can be moved seperately, giving the material a more ‘moving’ or supple effect than most other samples, this could allow to replace the spikes for updates or customisation

future improvements: test different materials and sizes of spikes to enhance functionality of the material (black out to light, thickness...)
look for a way to make it easier to remove the felt elements than one by one by hand, maybe a type of net connecting them?

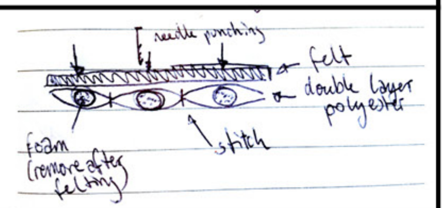




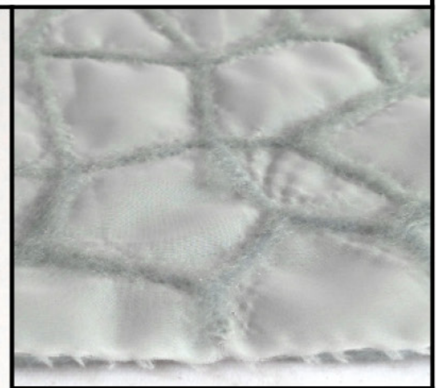
sample number: 6	sample name: double diamond insert
materials: polyester felt - polyester canvas (for silk screen printing)	date: 18/04/17
disassembly: mechanical	size: 21cm x 15cm
technique: ☐ felting ☐ weaving ☒ laser cutting ☐ other	
process: lasr cutting and assembly by hand	
material description: based on the previous sample (diaond insert) this looks at a way of ‘sandwiching’ the felt between two layers of poly canvas, this creates a latice or grid effect and a supple material with an interesting patern and texture	
future improvements: test different disposition of slits and dfferent width of the grid brances to see if possible to completely cover the felt	





sample number: 7	sample name: tessalation felting
materials: polyester felt - polyester canvas (for silk screen printing)	date: ~20/04/17
disassembly: mechanical	size: 21cm x 12cm
technique: ☒ felting ☐ weaving ☐ laser cutting ☐ other	
process: needle punching by hand along pre-traced lines at the back of sample	
material description: the dense smooth polyester canvas covers the rougher felt, the connection that can be pulled apart with sufficient leverage (get hold of a corner) create the pattern with their fuzzy lines could replace some types of laminating for waterproof or windproof performances	
future improvements: test with properly waterproof upper layer, test if the fuzzy lines are a problem for waterproofness test not making the lines apparent (see sketch)	





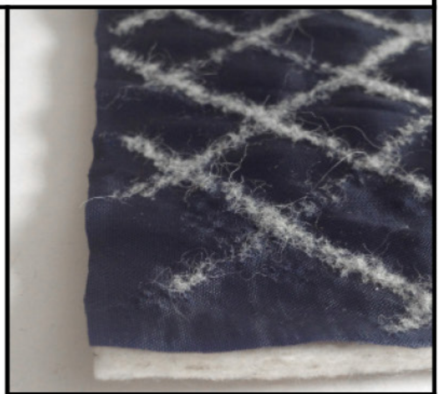
sample number: 8	sample name: checked felting
materials: wool felt - polyester lining canvas	date: ~20/04/17
disassembly: mechanical	size: 22cm x 14cm

technique: ☒ felting ☐ weaving ☐ laser cutting ☐ other

process: needle punching by hand along lines traced at the back of the sample

material description: the thick and dense wool felt does not penetrate and bond as well as the polyester felt, but the characteristic of the felt is intersting to use with a smooth polyester

future improvements: test different materials, thicknesses and fibre lenghts in th felt, test different patterns (see sample 7)



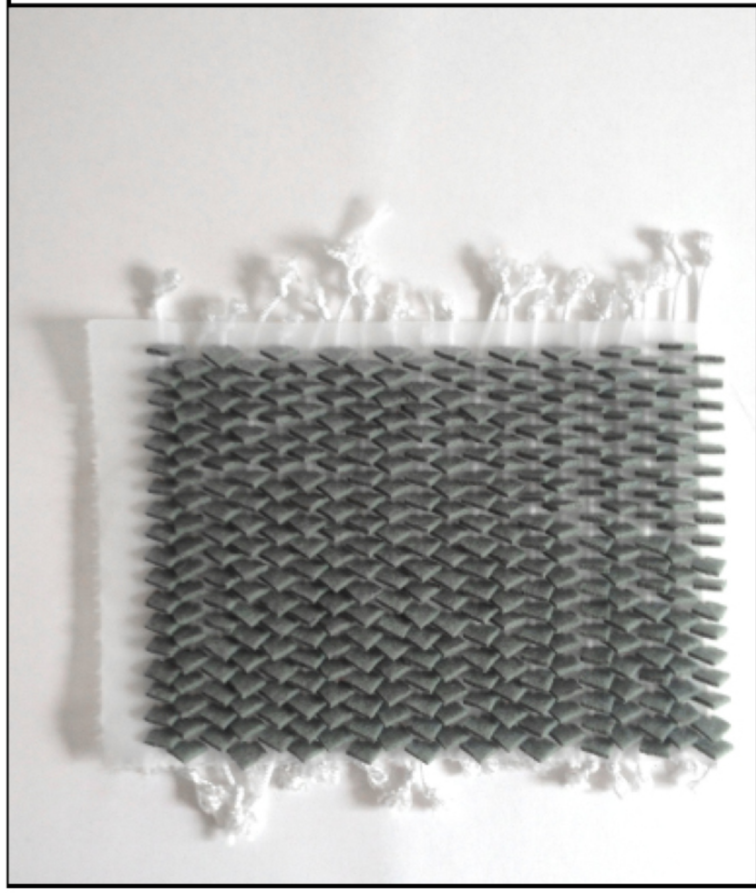
sample number: 9	sample name: square lock
materials: polyester felt - polyester canvas-polyester cord (drisse pré-étirée 3mm)	date: 04/07/17
disassembly: mechanical	size: 22cm x 15cm

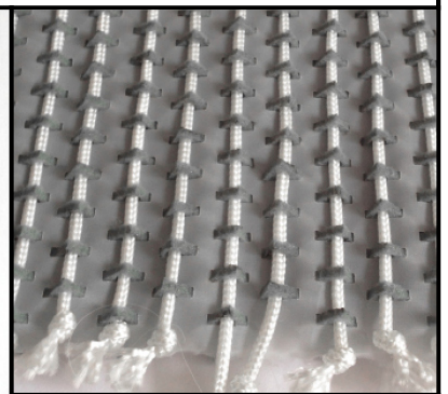
technique: ☐ felting ☐ weaving ☒ laser cutting ☒ other: threading

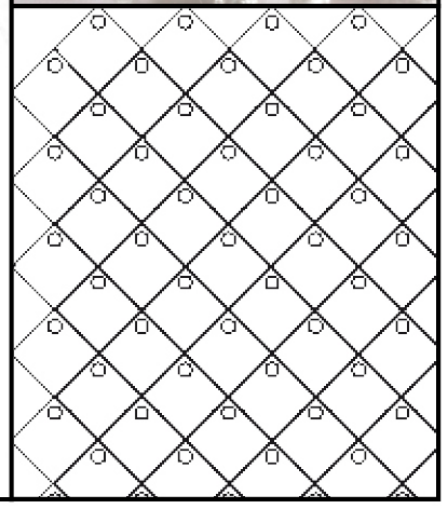
process: laser cutting and assembling (threading) by hand

material description: the assembly system makes the squares stand almost perpendicular to the canvas surface, creating a very ‘spiky’ effect, the elemnts are all cut independently, making the material very flowing, the contrast in materials at the back (shiny rope, translucent mat canvas, extra mat felt) create an interresting visual effect

future improvements: test ways of making assembly/disassembly easier, find ways of making it possible to use as part of a cut-and-sewn garment, not with the thread running through the whole back of the material try different shapes of elements







sample number: 10	sample name: oval lock

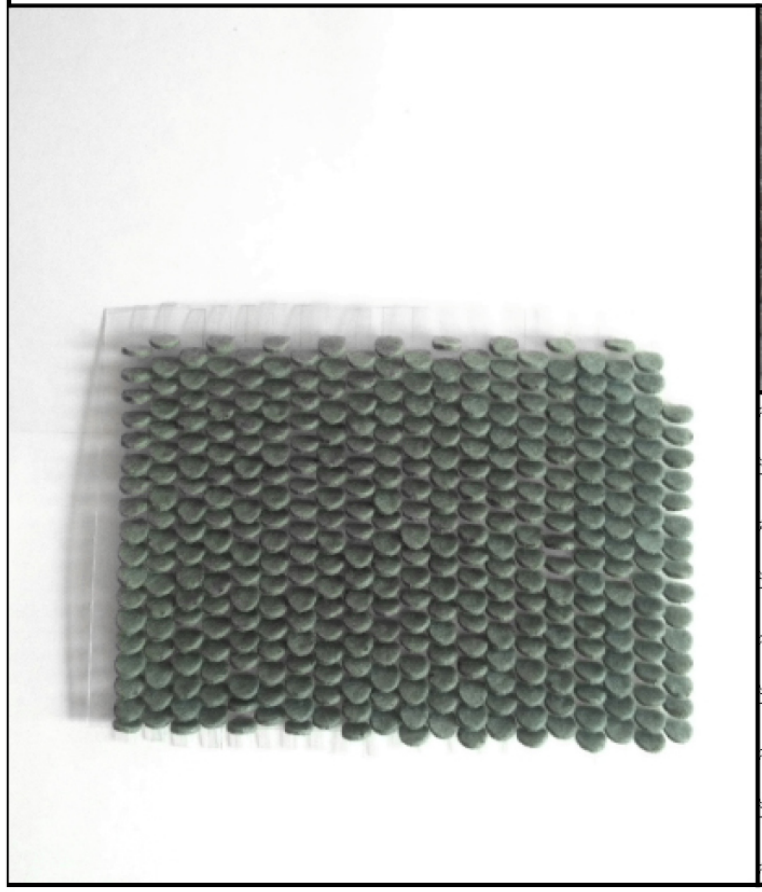
materials: clear thin plastic sheet from paperchase - polyester felt	date: 04/07/17
disassembly: mechanical	size: 21cm x 15cm

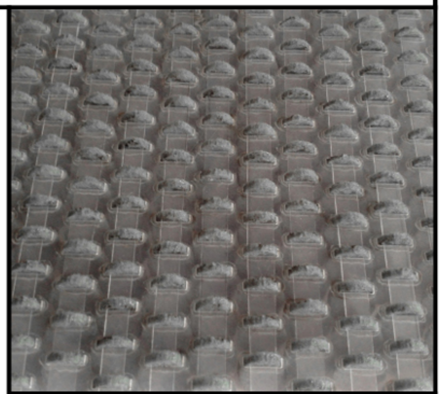
technique: ☐ felting ☐ weaving ☒ laser cutting ☒ other: threading

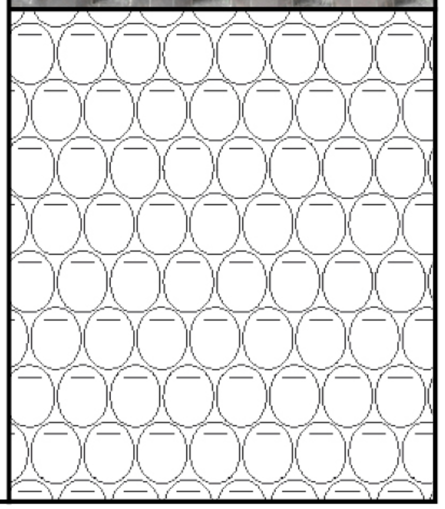
process: laser cutting and assembling (threading) by hand

material description: the assembly system places the ovals almost perpendicular to the plastic surface, this also makes the position rather firm, the only thing that can be influenced in handling the material is the direction of the tips, creates a smooth scaly effect

future improvements: test ways of making it possible to be part of a cut-and-sewn garment, find ways to block the strips non-permanently







sample number: 11	sample name: sapin supple

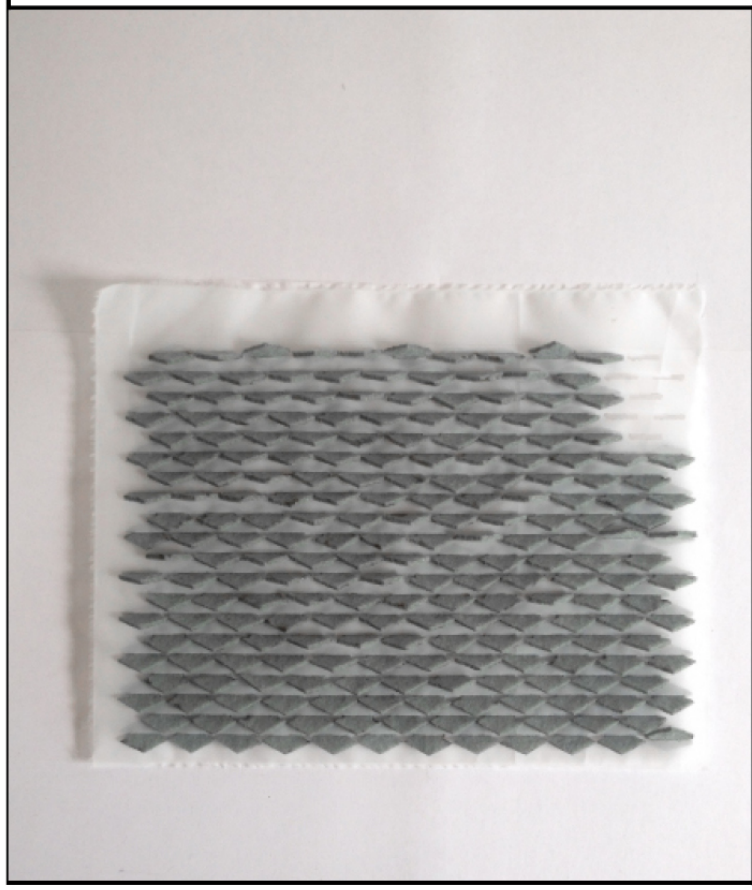
materials: polyester felt - polyester canvas (for silk screen printing)	date: 04/07/17
disassembly: mechanical	size: 22cm x 17cm

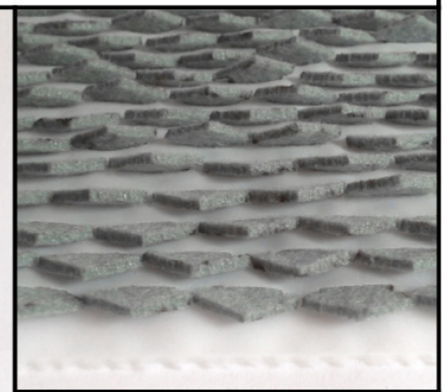
technique: ☐ felting ☐ weaving ☒ laser cutting ☐ other

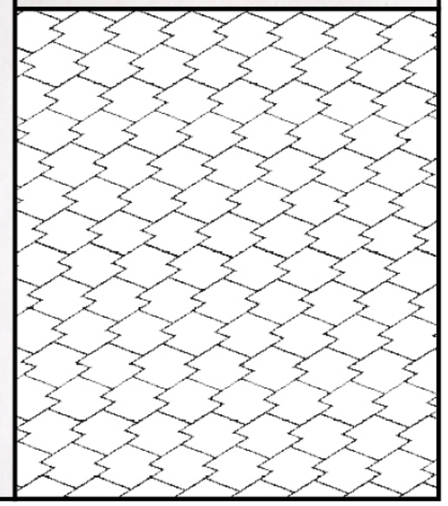
process: laser cutting and assembling by hand

material description: addaptation from sample 5, the alignement of the felt elements gives a very specific fluidity to the material, creating rigid lines along the fabric, the elements move around (from side to side) disrupting the geometry of the pattern

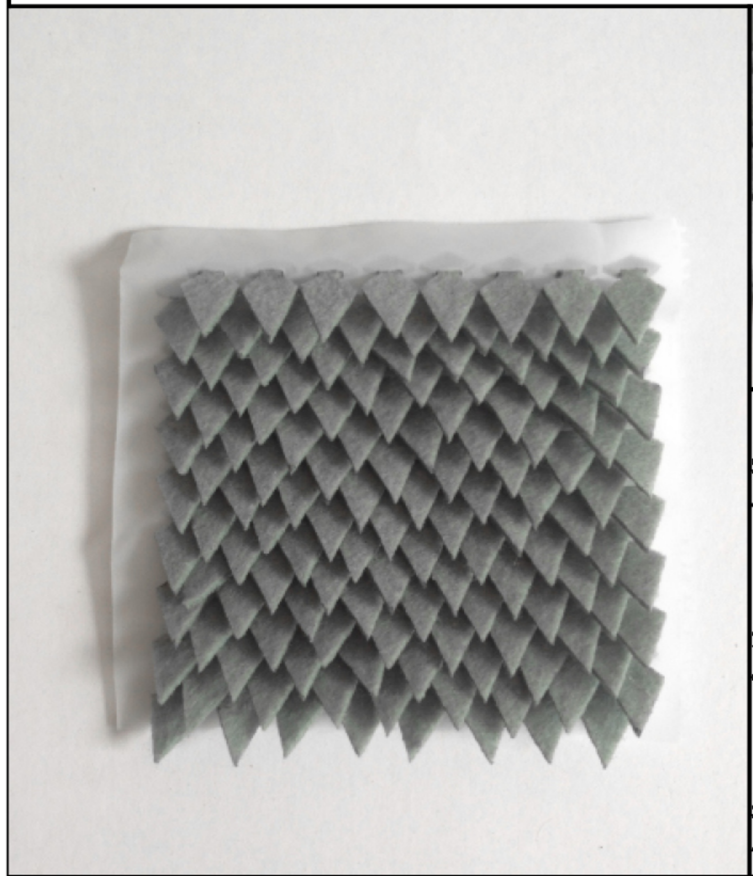
future improvements: test different patterns, different densities to see effect on ‘main du tissu’, test diffe-rent matterials and shapes for felt elements

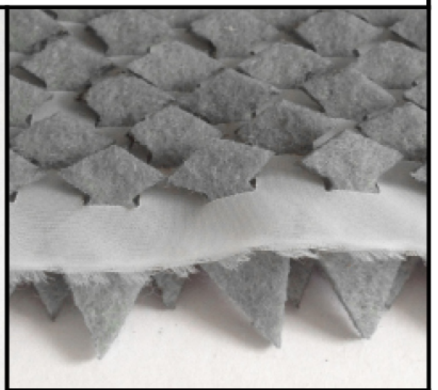


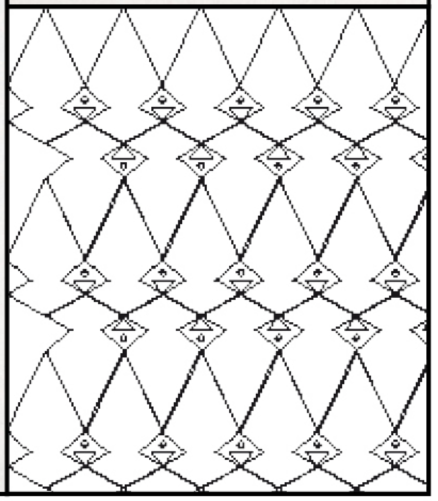




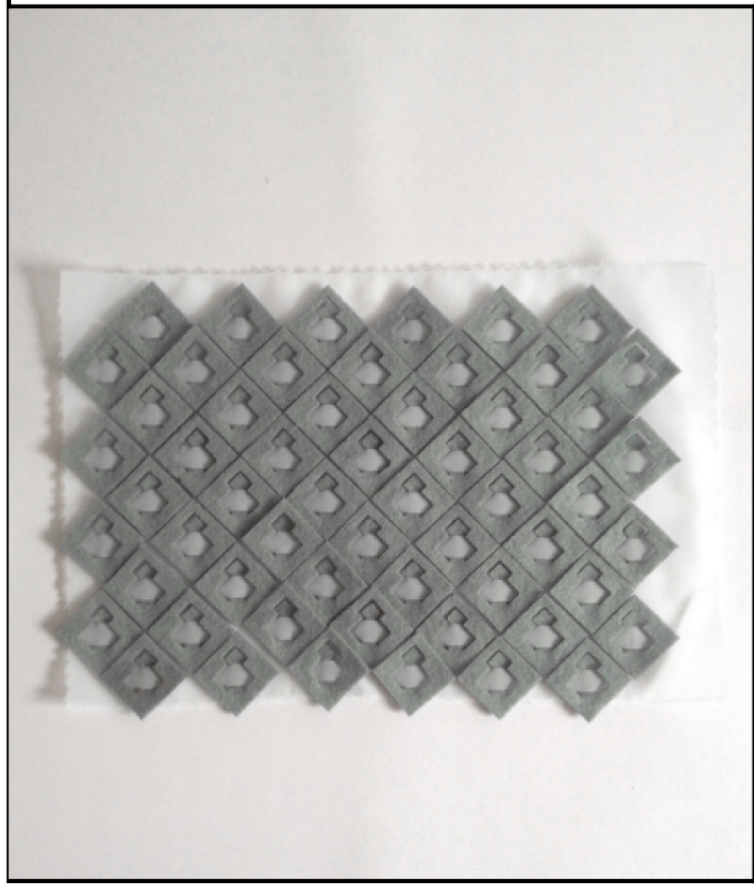
sample number: 12	sample name: sapin long supple
materials: polyester felt - polyester canvas (for silk screen printing)	date: 18/07/17
disassembly: mechanical	size: 11cm x 10cm
technique: ☐ felting ☐ weaving ☒ laser cutting ☐ other	
process: laser cutting and assembly by hand	
material description: evolution on sample 11 and 5, the felt elements are assymetric crrating different effects on back and front, the lenght of the front bits give a lot of ‘pull’, the overal scaly effect is poetic and interesting	
future improvements: test larger surface for flow and feel, test non-triangular shapes	

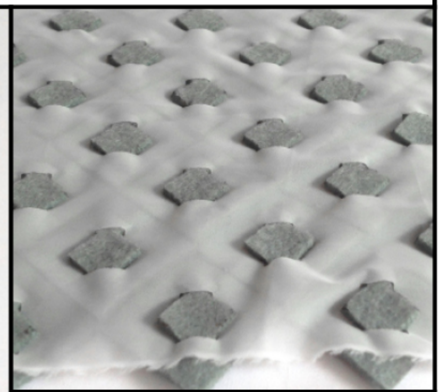


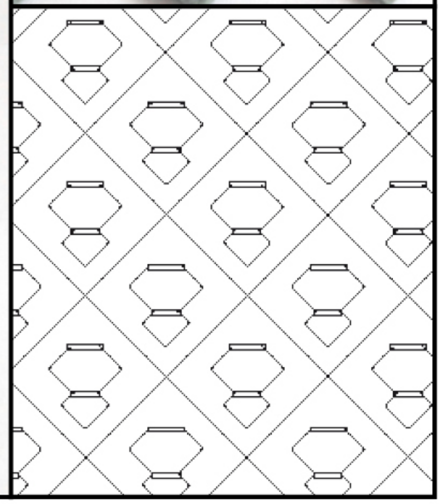




sample number: 13	sample name: diamond patch
materials: polyester felt - polyester canvas (for silk screen printing)	date: 25/07/17
disassembly: mechanical	size: 23cm x 16cm
technique: ☐ felting ☐ weaving ☒ laser cutting ☐ other	
process: laser cutting and assembly (doube fastnening) by hand	
material description: the felt covers the surface entirely, blocking the transparency, but since the elements are individual, some of the flowiness of the fabrc remains	
future improvements: test patterns with variations of scale and zones with no patches, imagne in a garment for covering/uncovering parts of a body	







sample number: 14 | sample name: waves

materials: polyester felt - thin and flowy polyester canvas | date: 25/07/17

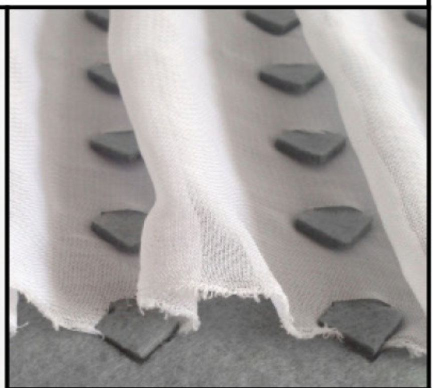
disassembly: mechanical | size: 24cm x 18cm

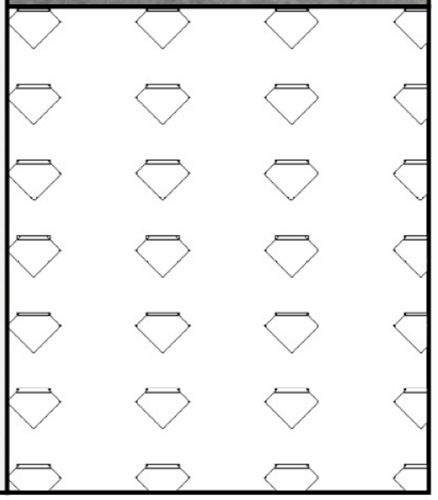
technique: ☐ felting ☐ weaving ☒ laser cutting ☐ other

process: laser cutting and assembly (caution, need to delete some lines in the slit file)

material description: the loose fastening of the very flowy fabric with the stiffer felt creates a wavy aspect

future improvements: test different materials to avoid the 'limp' effect of the flowy polyester, see what can be the benefits of having two non-parallel layers (insulation, put something between them...)





sample number: 15 | sample name: flowy diamond patch

materials: polyester canvas (for silk screen printing) - flowy polyester canvas | date: 25/07/17

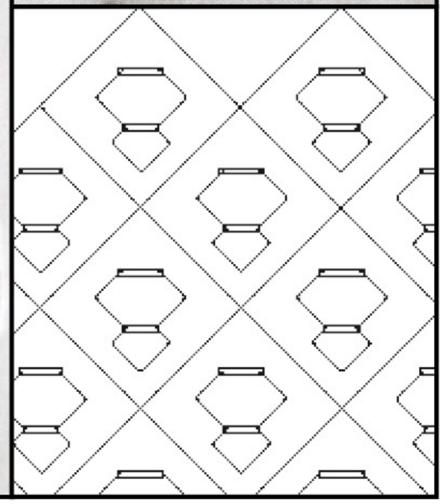
disassembly: mechanical | size: 24cm x 17cm

technique: ☐ felting ☐ weaving ☒ laser cutting ☐ other

process: laser cutting and assembling (doube fastnening) by hand

material description: based on sample 13, this attempts at a different effect, less stiff and more transparent, but the polyester burns and the whole looks rough

future improvements: try stiffer materials just dense poly canvas maybe, a bit of a failure really...



sample number: 16 | sample name: laced elastic

materials: cotton thread (blue) - elastic thread | date: 04/09/17

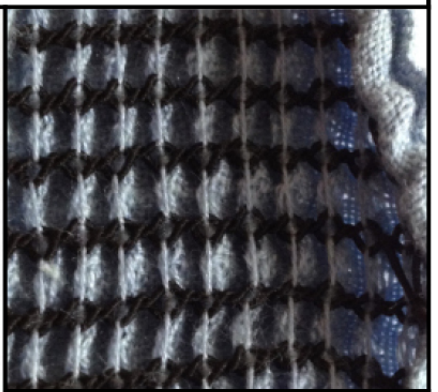
disassembly: chemical | size: 5,5cm x 13cm

technique: ☐ felting ☒ weaving ☐ laser cutting ☐ other

process: plain weave and insert one weft of elastic thread on the 9th pick, next 9th pick, lace the elastic thread under the previous elastic thread between each lifted warp thread, then weave a straight elatic thread, then plain weave, repeat

material description: the use of elastic thread as an added weft is meant to give the material a stretch feel wich would usually be achieved through a small proportion of elastomere fibres intimately mixed in with the rest of the material composition, for the elastic to be removable, it has to be separate and incoporated into the weave, this creates a smocked effect, in this case the high density of elastic gives the material a form of rigidity also

future improvements: the interlacing was meant to bring a vertical stretch also, didn't really work, see how that can be fixed, also test ways of making the process less manualy intensive



24 cardres montage suivi

1

cotton
elastic thread
hand interlacing

not disolvable

sample number: 17 | sample name: straight elastic

materials: cotton thread (blue) - elastic thread | date: 04/09/17

disassembly: chemical | size: 6cm x 13cm

technique: ☐ felting ☒ weaving ☐ laser cutting ☐ other

process: plain weave, insert elastic thread on 9th pick

material description: a faster version of sample 16, no attempt at vertical elasticity, the elastic pull creates ridges or folds, the lastic moves about a little, getting stuck at different levels of stretch

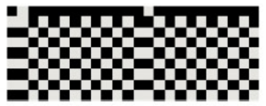
future improvements: augment the number of lifted warp threads to avoid to much folding and fixing the elastic more within the fabric, find way to gett two-ways elasticity, use elastic thread in warp

24 cardres montage suivi

2

cotton
elastic thread

disolvable



sample number: 18	sample name: nylon honeycomb

materials: cotton thread (blue) - acrylic hand knitting yarn - nylon thread	date: 04/09/17
disassembly: chemical	size: 14,5cm x 8cm

technique: ☐ felting ☒ weaving ☐ laser cutting ☐ other

process: odd pick numbers weave acrylic, even pick numbers weave nylon

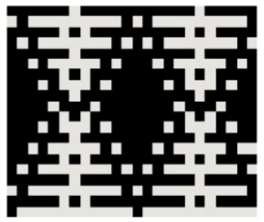
material description: double layers with a punctual connection that can be dissolved in special circumstances (at the end-of-life more likely)
shows a possibility for a protective layer (made of nylon but could be kevlar or other) that is included into the weave as a thread, the honeycomb structure is used to emphasize the difference between a hard, outside-facing layer and the soft, insulating skin-facing layer

future improvements: make sure that the two layers are truly independent when redundant thread is dissolved, it seems there might be a mistake in the draft here, try replacing pick 11 with a thinner thread than the acrylic to make the nylon surface more smooth, test other ‘protective’ threads instead of nylon

24 cardres montage suivi
3

cotton
acrylic knitting yarn
nilon thread

not disolvable



sample number: 19	sample name: honeycomb strips

materials: cotton thread (blue) - polyester canvas strips	date: 08/09/17
disassembly: chemical	size: 13cm x 13cm

technique: ☐ felting ☒ weaving ☐ laser cutting ☐ other

process: sublimation dye the polyester (180°C), cut into 4mm strips, weave honeycomb ad insert strips on 6th pick

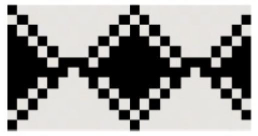
material description: a «protective» layer is included in the construction of the textile, rather than being an added element as part of a finishing process, covering the base with another fabric or a coating, the layer of polyester is woven into the structure of the cotton base in a way that allows it to be released through chemical action, so at the end-of-life facility most likely, one side is flat whie the other has a deep honeycomb structure

future improvements: test replacing the polyester with a truly waterproof material, test to see if the gaps beteen the strips are a problem, look for a way to make the weaving faster than when using individual strips

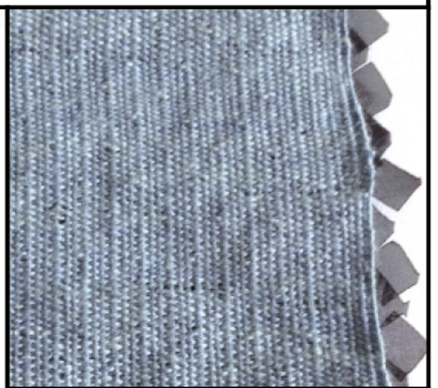
24 cardres montage suivi
4

cotton
printed polyester screen strips

not disolvable



sample number: 20	sample name: diamond scales
materials: cotton thread (blue) - polyester canvas	date: 07/09/17
disassembly: chemical	size: 13cm x 13cm
technique: ☐ felting ☒ weaving ☒ laser cutting ☐ other	
process: sublimation dye the polyester (180°C), laser cut the strips, plain weave (see draft), insert strips on 11th pick	
material description: the ribbon of scales completely covers the woven base, with a small over-lap that gives it a crispy feel, the diamonds are also a little constrained in the weave, making them go bumpy and creating an interesting scale effect	
future improvements: use the transparency of the polyester to show a pattern in the base, test more water-proof materials, test different shapes of ribbon, look for a way to make weaving process faster, not needing to insert each strip invidually and place diamonds by hand	

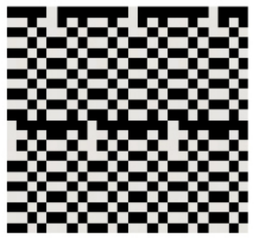


24 cardres montage suivi

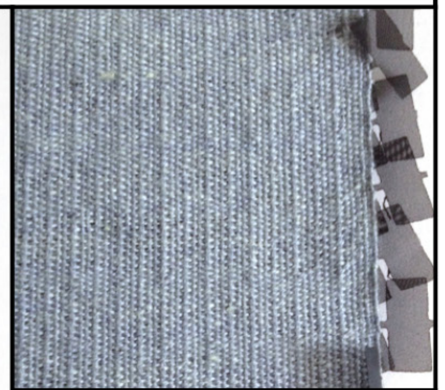
5

cotton
printed polyester screen laser
cut strips, lozange

not disolvable



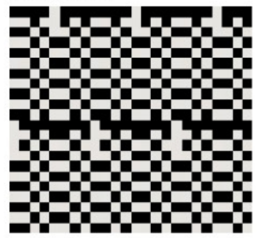
sample number: 21	sample name: small rectangle scales
materials: cotton thread (blue) - polyester canvas	date: 07/09/17
disassembly: chemical	size: 13cm x 13,5cm
technique: ☐ felting ☒ weaving ☒ laser cutting ☐ other	
process: sublimation dye the polyester (180°C), laser cut the strips, plain weave (see draft), insert strips on 11th pick, then skip next lift, insert again on 11th	
material description: less crips and tight than the diamond scales, but interesting visual effect with the overlap, the scales lift a little when manipulated, letting the base appear in flshes	
future improvements: test different shapes and materials for polyester ribbon, improve weavability	



24 cardres montage suivi

6

cotton
printed polyester screen laser
cut strips, rectangle
skip alternate lift
not disolvable



sample number: 22 | sample name: big rectangle scales

materials: cotton thread (blue) - polyester canvas | date: 08/09/17

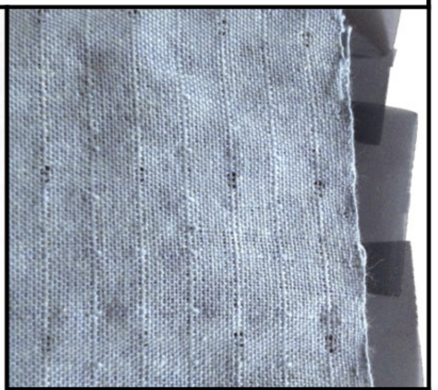
disassembly: chemical | size: 13cm x 13,5cm

technique: ☐ felting ☒ weaving ☒ laser cutting ☐ other

process: sublimation dye the polyester (180°C), laser cut the strips, plain weave (see draft), insert strips on 11th pick, skip next 11th pick and intermediates

material description: not really interested in the material’s quality, mainly just a faster, blown-up version to test disolving and make video

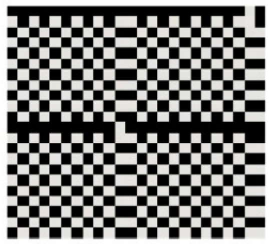
future improvements: do video and see



24 cardres montage suivi

7

cotton
printed polyester screen laser cut strips, rectangle big
skip alternate lift
disolvable



sample number: 23 | sample name: tube layer

materials: cotton thread (blue) - polyester canvas | date: 08/09/17

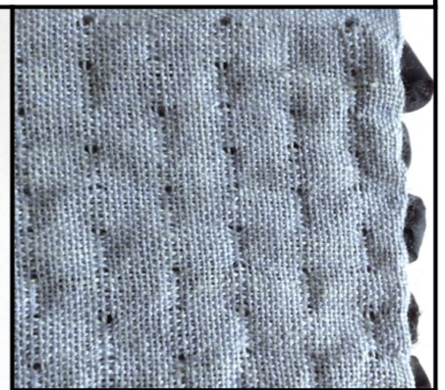
disassembly: chemical | size: 13cm x 11,5cm

technique: ☐ felting ☒ weaving ☐ laser cutting ☒ other: stitch

process: sublimation dye the polyester (180°C), sew tubes, plain weave (see draft), insert tubes on 11th pick

material description: the empty tubes create a cushiony effect, potentially heat insulating, gives idea of protection or high-tech material

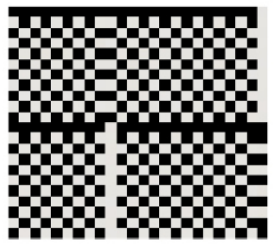
future improvements: find way to make tubes without creasing them or making them twist around the stich, test different spacings of the attaching threads



24 cardres montage suivi

8

cotton
printed polyester screen hand sewn tubes
skip alternate lift
not disolvable



sample number: 24	sample name: double elastic
materials: cotton thread (blue) - elastic thread	date: 08/09/17
disassembly: chemical	size: 9cm x 13cm

technique: ☐ felting ☐ weaving ☐ laser cutting ☐ other

process: cotton thread (blue) - elastic thread

material description: same weave as sample 17 but adding in vertical elastic, lacing it under and around lifted warp threads at the same time as weaving in weft elastic

future improvements: control the stretch is elastics to make vertical and horizontal more equal, include vertical elastic in warp

24 cardres montage suivi

9

cotton
elastic thread, in weft and parallel to warp

not disolvable

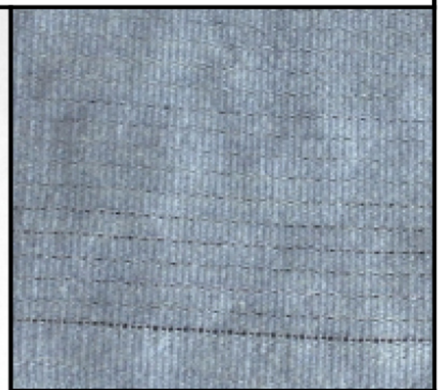
sample number: 25	sample name: two-sided
materials: cotton thread (blue) - cotton thread (black)	date: 12/09/17
disassembly: chemical	size: 13,5cm x 14cm

technique: ☐ felting ☒ weaving ☐ laser cutting ☐ other

process: plain weaving, blue thread on odd picks, black on even picks

material description: this is more of a technical proof of feasibility sample, it does not display any particular aesthetic or technical properties, apart from the fact that in can be dissolved and separated into two independant textiles that do not come apart after the dissolution of the linking thread, the double layer does mke it nicely thick however

future improvements: find a way to avoid the lines at the intersection between the two layers, or ake it into a pattern, test interlacing vertically also to have an equivalent of a 'tissu poche' and eventually stuff materials between the two layers



24 cardres montage suivi

10

cotton
black cotton
skip one interlock

disolvable

sample number: 26 | sample name: cord reinforcement

materials: cotton thread (blue) - polyester 3mm cord | date: 12/09/17

disassembly: chemical | size: 12cm x 9cm

technique: ☐ felting ☒ weaving ☐ laser cutting ☐ other

process: plain weave and insert one weft of cord thread on the 9th pick, skip next 9th pick, then next, lace the cord thread under the previous elastic thread between each lifted warp thread, then weave a straight cord thread, then plain weave, repeat

material description: the strenght of the cord pulls the material in, creating a semi-rigid structure that the fabric is attached to, also a little stretchy because of the pulled in effect

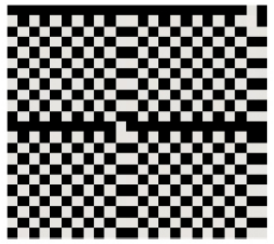
future improvements: find other weaves that can create the structure without interlacing and the pulling effect, test other thread than cord

24 cardres montage suivi

11

cotton
rope
skip intermediate lift

not disolvable



sample number: 27 | sample name: metal reinforcement

materials: cotton thread (blue) - silver metal thread | date: 12/09/17

disassembly: chemical | size: 13cm x 13cm

technique: ☐ felting ☒ weaving ☐ laser cutting ☐ other

process: plain weave, insert metal thread on 9th pick

material description: the metal makes the fabric maleable and it can stay in any given shape, this only works horizontally, no metal structure vertically

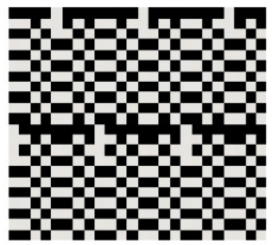
future improvements: include metal in warp threads, test different densities of metal thread, sizes of metal thread

24 cardres montage suivi

12

cotton
metal thread

not disolvable



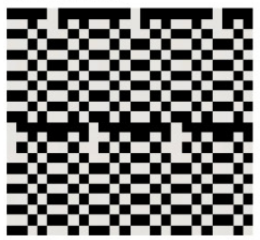
sample number: 28	sample name:	
materials: cotton thread (blue) - elastic thread		date: 12/09/17
disassembly: chemical		size: 11,5cm x 8cm
technique: ☐ felting ☒ weaving ☐ laser cutting ☐ other		
process: tick elastic threads under lifted warp thread and then zig-zag up when they lift again		
material description: the elastic has a strong vertical pull and a weaker horizontal one, the pull creases the fabric up in an interesting smocked effect		
future improvements: test wider apart horizontal connections to increase horizontal stretchiness		

24 cardres montage suivi

13

cotton
elastic parrallel to warp
skip alternate lift

not disolvable



11.2. Interview transcripts

11.2.1. Interviews with Textile Recycling Experts

These notes are taken from the transcriptions of the interviews carried out with seven experts in the field of textile recycling in May and June 2017. The information from these interviews fed into a better understanding of the challenges of recycling blended materials in a circular economy.

Interview #1

Date : 10-05-17

Interviewee: Mel Knudsen

Company: Worn Again

Expertise: Input feedstock research in the cellulosic/polyester separation for recycling developed by Worn Again. Data collection from ~ one tonne of used garments at LMB garment sorting facilities.

Information extracted from the interview

The input fabric must have minimal contamination by fibres that are neither cellulosic or polyester

“polyester and cotton or other cellulosic fibres would be ideal feedstock, with like a minimum of 80% of those fibres for the process to be commercially viable.”

Most textiles are blends

“our last big sorting trial gave around 8% pure polyester, and I think 85% was worn again grade, so that’s to say either, pure polyester, or pure cotton, or pure cellulose or a mix of all of them.”

The dissolution process happens in two stages, first the polyester is dissolved and filtered off, then the cellulosic (after shredding).

“When we only take out the polyester of a cotton/polyester piece of material, depending on how it’s woven or knitted, you’re left with a sort of thinner fabric, so it maintains some of the structure of the original textile, it’s just minus the polyester.”

Interview #2

Date : 18-05-17

Interviewee: Helene Smits

Company: Stating the Obvious / Recover

Expertise: Ambassador for mechanically recycled fibres by recover. Acceptance of the fibres by the industry.

Information extracted from the interview

Virgin quality is not achievable with mechanical recycling, but the result can sometimes be as good as 'bad quality' virgin fibres.

"you do see a fibre loss, because the fibre length of the mechanically recycled fibres is shorter than virgin fibres. The difference can actually be not that big if you're talking about not so good quality cotton, the fibres are not so long either"

Chemical and mechanical are complementary in a circular system

"yes, chemical has better potential than mechanical to have that holy grail circularity, well even though you are exchanging cotton for lyocell, which is something different so, yeah, that's something to consider. But you're also adding chemicals and you have to re-dye because you're stripping the materials. For as with mechanical, you're not adding any water, you're not adding any chemicals, you're using what's already in there. But yes, you're degrading the fibre a little bit. So what is circular what isn't circular, this technology has a little less of that and a little more of that, which is interesting to consider and I think that's why I would always argue for keeping both in a circular system."

To ensure consistent quality of the output yarn, Recover needs 80% cotton in the input feedstock

"so we can't get every offcut, it needs to be 100% cotton or 80% and above let's say"

"We can even deal with more contamination, the issue is that to ensure the quality of the standard products that we make, this is the qualities that we need"

The market needs to accept lower technical qualities as a trade-off for high environmental quality

"we should be realistic and say, this is a super superior product in regards to sustainability, you cannot expect the same properties as from a virgin resource."

Recycling processes need to be made more efficient

"all of these steps in between having the material collected, and having it suitable for recycling, is a very important step, and since it's such a marginal business, it' has to be super cheap. So it has to be automated somehow."

"Well if you're thinking about being able to twist buttons off from jeans, or like mud jeans have been doing, printing the label, not having a leather label, these kinds of things are interesting, and it will definitely... If you for example have to prepare that for recycling you're able to recycle a lot more of it than with regular jeans, which is great. In essence I think that the better solution would be to have a machine, that for everything that has buttons and zippers, it's able to take it off automatically by having this pre-step before recycling. These machines already exist but then they already destroy the fabric to a certain extent that you cannot recover really long fibres from it anymore."

Input needs to be standardised globally

"think of the solution that would work for a big variety of things because, yeah ok great if three brands do that, if you look at the practicality of how it really works, the collection and sorting and recycling, there's just bulk from everywhere coming into this facility and yeah ok one t-shirt is designed for disassembly. Ok? How will they deal with it?"

Biodegradability is not a priority

"Basically what's the point of putting all this effort of making it biodegradable with the idea of the nutrients going back into the soil, when the nutrients taken out of the soil

came out of the soil somewhere completely different in the world? We're all going to plant our cotton garments in the ground, really?"

Some fibres pose specific problems for recyclability

"you've probably heard about chemical that maybe certain contaminations are more problematic than others so there's maybe something that can have an objective recommendation on what to combine and what not to combine. With mechanical it's the same, yeah elastane is an issue, we can handle some of it but really only small amounts. Acrylics and some things like that are sometimes problematic because they're a very thick fibre, so when you then want to create another thin yarn it can be an issue, there really are some elements of that that are things to consider when you're designing or when you're deciding what goes into products or material blends."

Interview #3

Date : 18-05-17

Interviewee: Issac Nichelson

Company: Recover

Expertise: Ambassador for mechanically recycled fibres by recover.

Information extracted from the interview

Mechanical recycling allows for colour (dyestuff) conservation

"Starting with the 100% cotton input and levering the dye-steps that are already in those fabrics so as not to dye the cotton, we're just blending it in order to get about 90% of the way there in colour matching. And then that's topped off with carrier fibre."

Mechanically recycled fibres can be recycled again through the same process.

"So currently we are recycling, the recover fabrics that are produced, in programs that we call Infinito, Recover Infinito. And that is just now taking off and the trials that have been done are coming back through the years and it's actually totally feasible to get multiple life cycles out of the recover fabrics"

Recycling relies on external sorting

"So the sorting is happening at origin, when the fabrics are cut they're stacked generally by colour, so if there is planning, which there has been now for many decades in some cases with these suppliers who are part of the Recover system"

Mechanical recycling (by Recover) uses only 100% cotton waste

"Yeah well generally we're really only purchasing 100% cotton cutting waste with pre-consumer and post-consumer programs that we have been doing."

It's also possible to mechanically recycling high content blends (but to lower quality outcome)

"But we have very recently with the Dutch military done a trial where we recycle 65% poly, 35% cotton camouflage wovens from their uniforms and this was made into yarns that will go into fleece and polos but the primary use of it was to go into disaster relief blankets for refugees."

New processes are starting to be developed to include problematic blends and materials

"I think you are referencing a document that was about the circular systems recycling which is synthetics focused. So that is a mechanical synthetic recycling system, now with a new line added to it, that now it includes the recycling of spandex blends. That is what we call a chemi-mechanical or semi-chemical process so it's a low chemical application way of recycling textiles."

Added from notes from memory

"The semi-chemical process is more than allowing to deal with "contaminants" as these are defined as parts of 2 or 3% in the mix, but rather it can deal with real blends that have up to 25% of other, non-recyclable fibres."

Interview #4

Date : 13-06-17

Interviewee: Anita De Wit

Company: Recover

Expertise: Entrepreneur in the use of mechanically recycled fibres from blended post-consumer waste materials for fashion and interior fabrics

Information extracted from the interview

Mechanical recycling might be problematic as it maintains the presence of hazardous chemicals in the fibres

"And then the next thing people would say is: even if you could, you shouldn't do it because you don't know what's in the material."

It is possible to make mechanically recycled yarn and fabric from 100% post-consumer, mixed fibre materials, however the quality levels are lower than virgin fibres

"in 2014 we had 20 kilos of 100% recycled yarn only made by recycled textile waste"

"I mean it's still fragile of course but we were able to make knitwear from it and also to make a 100% woven fabric from it with both warp and weft."

For production, the mechanically recycled fibres need to be supplemented with a carrier

Like I said, in the knitting and weaving in the experiment, people really had to lower the speed. You can ask them that for and experiment, if people are interested in the story, everyone will do it, but you need to make, let's say, we did the production for 150 or 400 scarfs, then you can't ask them to do it on a very low speed. So we knew that for the first step, we had to decrease the percentage to find a new balance. In meetings with the general director of recover, we made the decision to go for 70% and combine the yarn with 30% recycled PET.

To achieve spinning with 100% post-consumer recycled material, the levels of quality control need to be lowered, the standards and expectations cannot be the same as for virgin fibres

"The interesting thing was that he made quite a—how do you say— discussions and, let's say, small fights with professors to fine tune the machines to do things differently, a little bit, and just differently by removing some of the controls on the machines. I mean normally yarn is being checked on the quality and because of the 100% [recycled] textile fibres, there were a lot of inequalities. Normally they want to have an equal yarn and there are a lot of checks on this. But he experimented with removing these controls and it show that the spinning machines could continue while otherwise, they would just stop every second because there are a lot of inequalities at the time."

In general, the machines need different settings to accommodate the recycled yarn (slower speed of knitting/weaving)

"It was an industrial loom, but for both the knitting and weaving, it would mean they have to lower their speed. Of course with this 100% new fibre material, the people working with that, they needed to be very enthusiastic to do the experiment because it takes more time, and when they started, they had to do it a couple of times over and over."

"I think that if you look at the current production, then it's almost up to normal, but at the time… The hand knitting machine it was quite ok, I mean she wasn't lowering here speed, but the industrial knitting machine, yeah, it would be kind of a wild guess, I think it was substantially lowered."

Adaptability and technical creativity are important to achieve results

"With weaving we saw that the first person who started with it, he wasn't that creative, maybe, with it, and the yarn was breaking over and over, every second and then we had a shift and then another person started trying it and he was more, yeah, I'm not sure if he was more enthusiastic, but he was more creative with the yarn and managing the speed of product he managed to create"

Use of recycled materials gives an 'accidental' melange effect that is otherwise difficult to achieve

"And the interesting thing to see at the time was that the designers who were quite sceptical at the beginning they started to really see the potential of the material and the melange effect, that's how they call it now, is seen now as the main added value of this kind of producing. Because normally they say, you need to make a lot of effort the create the melange effect which makes the fabric way more living instead of the flat dyed material."

Wool is seen as a high potential fibre for mechanical recycling

"Our technical expertise at the time was coming from Texperium, a Dutch innovation platform, and they advised us at the time to use the longer fibres from wool, because the idea at the time was to look for a yarn with as high as possible percentage of recycled product. And he had the pragmatic idea that the longer fibres from the wool could be an advantage.

LF: Did you find that was the case?

ADW: Yes in the way that with the students we first started by not sorting any kind of material, by just sorting by colour and saying: it doesn't matter what it is. And the results were way worse if you would do it like that. So in the second phase we did a kind of rough shift in kind of material, we just selected materials with a small percentage of wool, 20% wool, and the results were way better. So our overall conclusion is that it is important to make a separation based on material kind. And we don't use any wool for the time being, but I still see that you need to look into the different material types."

Sorting by label is too time consuming, the sorting is done relying on the expertise of sorters, sorting by feel

"So we don't use any labels at all, and it takes too much time to look for a label So in the sorting fabrics, there is a lot of expertise, experienced ladies who just feel the material. It starts by mostly, if you just have the normal cotton t-shirt of course by just looking at it you will see that it's mostly cotton. The second step would be to feel it, in sorting centres, there kind of training, but it's kind of hard to actually train it, but there are ladies who are very good at this. In the future it will be interesting to use a kind of automatic sorting machine for this."

Tweaking existing spinning machines can be an important step towards scaling up post-consumer waste fibre to fibre recycling

"And of course looking into technical things, it would be good to dive into the way the materials are shredded, and how the main material is spun, to see what is the difference if you use recycled fibres. Because all the machines have been made for virgin materials, and it's not like it would be a different machine, but it would be interesting to know if you could make the quality better if you have a different kind of fine-tuning, something like that, additional research should be done in this field I think. "

Material cascades can allow to maintain materials within the loop

"In my belief, if we look at the Reblend yarn in response to your aims, in the beginning our yarn does not have an endless loop, but if look at the new possibilities, if you would recycle it chemically… The mechanical recycling with our yarn can be done two or three times maybe and then if you would only use the same material, then the quality would be lower. In my belief the next step then would be to use it for chemical recycling, and then you would have a new material again."

"I think what surprised me along the way is that there isn't so much knowledge about the possibilities, and everyone is in a way looking at mono-materials, which I understand, and of course it is in a way better and easier to use mono-materials, but there is the fact that we also like to wear blends, there is a huge difference so it's kind of an illusion to think that there won't be blends anymore. For me it would be interesting to have a kind of overview of what the difference would be looking to materials, different material combinations. For us we did not do any research about that for now because we are basically very pragmatic and we roughly sort by colour and the kind of material, but it would be interesting to have further research, more detailed in the different kinds of combinations and to see if there is a difference in the quality of recycled yarn. "

Interview #5

Date : 14-06-17

Interviewee: Helena Wedin

Company: Trash2Cash / RISe

Expertise: molecular composition of materials, textile regeneration and sorting for better quality inputs in the recycling system

Information extracted from the interview

Variety and complexity of blends is an issue

LF: So what would you say some of these challenges are?

HW: That there are so many, many blends and that there are so many blends in low volumes and that there are very few materials today that could be going to recycling streams.

End of life should be thought in cascades

HW: Yeah I know—if you design for the recycling streams we have today, of course it would be better to design for using the garment for a long time—I think the reuse is the top.

LF: Design for reuse is the top, of course to maintain value…

HW: Of course but then if you also think of the next step also, and you have a route to textile recycling then it's better to have textile to textile recycling than down-cycling.

Sorting is one of the main issues for recyclability

HW: Yeah and how to purify, how to get higher quality in those streams and also how to increase the production of those streams, and that's why we're looking at automated sorting, because, if it's something automated then it could be faster, and also it needs to be high quality output from it otherwise you sort to down-cycling processes. Yeah you can have automated sorting, for low quality streams, with this low quality or high reach fractions, but you won't get these pure streams. That's what we have looked at in Trash-2Cash, just to see what is the potential of the quality we can get out of automated sorting if we can get these pure streams. Because in chemical recycling, you need pure streams, at least in the beginning, if we are going to start with post-consumer garments, so we want 100% and guarantee for everything else, but it's impossible.

Complexity in materials slows down and complexifies the recycling process

All these are contamination you need to remove, because when you're working with chemical recycling, it's quite an expensive process so the quality of the fibre, you need to have as good as virgin I believe because otherwise you can't compete with the other virgin fibres and that's why you need to have so many pre-treatment steps to purify your stream, and if you have a very contaminated stream, feedstock input, then you need to have more processes to clean it, and it could cost. And that's why the dream is to have as pure as possible.

In chemical recycling, even low levels of contamination are a problem

When you are working with regeneration for example if you have polyester, I have learned, that you could have traces for example cellulose traces or just very very small content of metal it can destroy the polymerisation or destroy the quality of the regeneration process. […] And maybe some are better now, we will see but still they need to be quite pure, they cannot tolerate 80% or 90% they need to be closer to 97 or, yeah— that is my feeling, I don't know if worn again can take 95%

Errors contaminate the input in a very problematic way

I'm thinking that they sort— for example if you want to sort polyester or if you want to sort cotton or if you want to sort a cotton polyester blend, you always have, the challenges are that if you have automated [processes] then you have a challenge with multilayer you cannot see all the layers, detect. Or if you have some errors, you cannot detect, how to say this, if you have so many different kinds of blends they will be contaminating, just by errors in the other streams that you are sorting out— how to say this…

Automation of sorting processes can allow to bring costs down, and bring systems back to Europe

Yeah I believe in automated because then you can also have it in Europe and you don't have to have it in Asia.

Structures in textiles hide the real content of the material from the lense of the sorter

So we got the cotton and cotton/elastane garments but we also got contamination from polyester fibres because with some woven techniques you will have cotton on one side and polyester on the other side so it's a blend but you only see, in like the twill structure, if you have that twill structure woven technique, we saw that we only have cotton on one side and polyester on the other side. Because threads are like that, yarns are like that, then we got contamination of polyester in the cotton and we got the same with polyamide in these woven techniques. Then we could also have errors because of the speed and that could be whatever error. So we have the multilayer error, we have the speed error, we have different woven and knitting techniques or blends that will be contamination because if you only see the cotton then it goes to cotton but it should be sorted as a blend, but it's not. You only see the cotton on the surface. And there are so many blends that have— if you go in blends and take in 3D and you start from the surface the outer layer and then you go down through the fabric and then you end up on the other side, if you measure the blend content from the surface through, it will be different. If you divide a fabric in different layers, can you think of that? In the thickness direction, you will have different blend contents at different points. Because you have this technique. And then I started to realise, if you have a spectroscopic technique you are just detecting the surface you are penetrating just a part of it, there are different content it's so complex. So then it's sorted by this content it's not the real content but it's the content it's analysing, yeah wow… But what struck me was that all this contamination if you have the cotton stream and then you've got all the contamination from the other fibres, if you have many many different kinds of blends, we get more contamination I believe.

The input needs to be standardised

HW: If you have many low volume blends like more than 3 components and—for me it's also a loss of— it would be good to have just mono-materials and a few blends that are good, and you know that those blends can be recycled because if you have many low volume blends then it's just, you cannot do anything with them and they will just contaminate the good feedstock, because of some errors due to multilayers, due to how they are structured in knitting… So that's my message I guess, only design for blends that could be recycled and avoid designing these blends that could contaminate other streams.

Spectroscopic sorting can be questioned as the best option

HW: It could be several points on the garments and I guess it takes like an average or something. But if you have an RFID technology then you have a tag and then you know the content, it could also be an automated sorting solution. I'm not saying that the spectroscopic is a better one, it's just that that's the one that is most developed and used in other recycling sectors, yeah since it's the most developed it could be good to test it on textiles first but I believe that tagging also will come and help.

Complex garments are a problem

Maybe it doesn't exactly need to be equal in all points but more, closer to that at least, because I've also seen some yarns, if you have a striped, one yarn with polyester and

the next yarn with cotton and then the next with cotton/polyester blend, so you mix, so it means the fabric is not equal. SO if you just analyse the cotton part then you get cotton, if you analyse the stripe that is cotton blend, then you have a blend [laugh]. I have so many examples of garments that we have seen, and were like can we do like this, and like this? There is also that knitted structures are more homogenous on the inside and outside than woven, I thing that wovens are more tightly bond and then they are different

Small proportions of valuable and recyclable materials such as wool in blends are a waste

HW: Yeah because if you already have a current good way to recycle cashmere or other kinds of wool 100% why are you putting them in small content in so many garments?

It is also important to maintain diversity in textiles

HW: What I like is that you said in the beginning that it's important to keep the diversity in the materials.

LF: It's actually the opposite from what you were saying.

HW: Yeah but I still, if there is a need for something there will also be, you create a need to make a recycling method also, because there is a need for this type of blend, it's not only— you need both I think. Then you decide, is this possible, by combining this and the polymers and I think a material recycler can say if it's possible already by seeing it. And then you can meet to develop also, new processes.

HW: Yeah but of course it would be good to have less diversity in colours and finishings and—so you know what you have more, because now it's a mix of, could it be 25 thousand colour dies or could it be, you don't know. And the finishing, there are so many developments in the finishing techniques, and if you have post-consumer garments then you have everything from all parts, so minimising maybe, but not restrict, I don't know yeah.

Designer have a bridge role in recyclability

HW: I kind of like what we have done in Trash2Cash because from a researcher perspective you give some guidelines but I don't have to give the whole, like thinking in the whole perspective. Like the designer has the project leader role in thinking of parts of the process, by collecting the expertise in the productions and in the sorting, and for the consumers also… Because researchers, we usually like one niche thing so we are becoming experts in that and we will have to contribute with that, but it will be great I think if the designer can take the lead in all steps of the circle, like keeping the network working.

Technology needs to evolve in chemical recycling

HW: I guess I wish that chemical recycling pilots are asking for post-consumer garments, that they can tolerate combination and develop the process so much that they know what kind of contamination they can take and what they can't take so it can help the development of the sorting. Because I think there will always be contamination, you cannot avoid that, but it will be good to know what each process— that the processes are so developed that they know what they can or can't take. And that will set a limit also for the designer, that they will say: ok we can design for this also. Yah because if there is no need— mechanical recycling has been there for a long time and it has not been developed, it's like, the chemical recycling is needed so much to take the next step, and to create this need, If there is no end need, yeah… I would like to see chemical recycling production soon.

Interview #6

Date : 22-06-17

Interviewee: Lucie Ackerman

Company: Valvan/ Fibre Sort

Expertise: Engineering for the Fibre Sort machine, near infrared sorting for post-consumer garments

Information extracted from the interview

The machine only scans the surface of the garment

The scanner takes a near infrared spectrum of the textile. So this is a surface scan. So basically, the part of the textile that falls on top of the lens is the part that is going to be illuminated and the part which is going to be recognised. There is some absorbance so you can see a little bit into it but not a lot. For example, if there is a dye on the textile you will still see the cotton for example that is underneath, but you won't see very far really into the fibre into the core of the fibre.

Compositions are recognised following common materials categories

Going in to fibre composition, what we can recognise now is the pure fibres, so cotton, polyester, viscose, acrylic, wool or nylon I think are the main ones. And then cotton/polyester blends, we make a distinction between cotton polyester blends where the majority of the fibre is cotton, cotton/polyester blends where it's more or less 50/50 it could be 55/45 or sometimes even 40/60%, and then cotton/polyester blends where the majority is polyester. We have other blends, for example acrylic/wool which comes in 70% acrylic, 30% wool or something along those lines, that's a category. Or we have wool/nylon which is usually 70% wool 30% nylon more or less, we have 50% cotton 50% acrylic. Basically, these are the types that we have been working on to get good recognition because we recognise that these are common blends.

Colour sorting is an add on

And then when it's mechanical recycling they sometimes want to have information on the colour because obviously white cotton is very easy to recycle because you don't have to bleach it anymore etc. versus black cotton if it's mixed in with all the rest it needs to be bleached. But there are some players that actually want the black cotton or red cotton or whatever because then they don't colour it anymore, they just use the colour that is already there. Hmmm, I think that's the gist of it.

The sorting needs to be upstream from the recyclers

So I don't see it as being a machine to sell to the recyclers, because they should have a stream where they know what the content is, they won't have a recycling process for every single possible blend. So I see it between the recyclers and the sorters or maybe at an extra step, I don't know.

Pure mono-materials are better for sorting

Well the pure fibres are more easily recognised, so pure cotton, pure polyester, pure whatever, those are very easy to recognise, that's not a problem. Except with very low percentages of elastane for example, that's an issue that we are working on.

The relevance of structure when detecting small proportions of contaminating materials in an single fibre textile has not been studied yet

LF: And do you know, I mean have you found a difference in the capacity of recognition between to fabrics that have the same percentage of elastane, have you been able to pinpoint the types of textile in which the same percentage of elastane is more visible than in another?

LA: No but that's a really interesting point of view actually, that's something that we should look into [laugh], but we haven't, not yet no. But it's a good point.

A solution for knit/weave recognition is being developed

Yeah, so we are also doing some research into, like you said, finding out whether a piece of textile has been woven or has been knitted. For chemical recycling I don't think it makes that much of a difference, but for mechanical recycling obviously it does, knitted fibres are far more easy to pull apart than the woven.

Fabric finishes block the near infrared reading

Well we noticed that very new materials—actually when we started, we tried to build a data base with pieces of textiles that we got directly from manufacturers because then we were sure what the content was. But we couldn't do it, because there were still too many finishes and coatings etc., etc. on the clothing so they were blocking the spectrum, whereas if the textiles has been washed a few times then the fibre itself becomes more visible. So that's an issue of course but on the other hand it's not that big an issue because most of these clothes have been worn a few times.

The humans taking part in the first stages of the sorting process can weed out the garments that would not be properly recognised

So there would always be a pre-sorting to get out the re-wearables, and at that point, that person who is doing the pre-sorting needs to know that that thing with a lining is not suitable for the fibre sort or maybe it goes to a different stream where they take it apart first and then they send the different pieces to the fibre sort, that could be a way to work with that as well.

Zippers and other hard elements are still a problem for recycling

"And then another limitation, it's not necessarily a limitation of the fibre sort, but a big limitation in the industry is that we can automatically find out what the fibre content is but after that there has to be a way to automatically remove the fibres from the rest because you have zippers and buttons etc. and those are a big problem for most of the recycling processes, and are a pain to remove."

"I'm talking about buttons and zippers and etc., quite often that's done by people with a distance to the labour market, where employers get subsidies or it's cheaper to employ them for some reason or it's done in India or whatever, where people are just basically cutting it out. But that's not really efficient."

Innovations need to become standard to be effective

you've heard probably about this microwavable fibre where when you microwave it, it falls apart, these are all very interesting ideas but of course it's going to have to be something that is taken on globally. Because otherwise how do you know when, once it gets collected because it's been thrown away, which one can be put in a microwave and which one can't. Those are bigger industry issues

Blends with more than two components are a major issue

LF: Yeah, and for example, what does the machine not recognise, what are the things that you put through and it just doesn't work with the machine?

LA: If it's blends of more than two materials.

LF: Yeah that's interesting because it's something that comes up a lot when people talk about the problems in recycling blends: if there are more than two materials, it just becomes mayhem.

LA: Yeah, I think it's difficult to sort but it's also difficult to recycle, so it's difficult for everybody.

Threads in garments are a problem

Well that and then the threads that are being used to sew things together are usually somethings else. For me it's not a problem because the machine just won't see it, but it is an issue for the recyclers afterwards sometimes

There needs to be a change in mind-sets, more honesty in the industry

And I think in general, honesty, honesty in the industry. You've seen the exhibition at the London design museum, the labels are just so often plain wrong. I know there's talk about using QR to give all of the information, you just kind of do an easy scan and you know what's in it and where it's been made etc., etc., or even RFID tags. I know Mistra Fashion has done a report on that or is doing a report on that, on whether that would not be a better way to sort materials for recycling instead of NIR which has its limitations due to being a surface scan. I'm all for it, I mean in an ideal world we don't need a fibre sort. Even though that would mean that we can't sell any [laugh]. But it's not going to work until the industry cleans up and the big players start to be honest about what they're producing and where they're producing it and what materials they are using

The technology assumes that garments are the same composition all over

LA: Yes, so we are going of the premise that 90% of the clothes are going to be the same one the sleeve or on the back or whatever. And I know the more 'designy' items, or what to call them, will have more different parts of the item of clothing but I think that's a very low percentage to be honest.

Interview #7

Date : 15-06-17

Interviewee: Traci Kinden

Company: Circle economy/Fibre Sort

Expertise: Networking for solution for textiles in the circular economy, secand hand garment industry (design background)

Information extracted from the interview

Chemical recycling is getting closer to blend recycling

Well you have something working in your favour in the sense that recycling technologies are getting better, the ones that are in development, or course not quite commercialised, the chemical recycling technologies are— there is at least ones that is saying that it can recycle blends and I have a high degree of confidence in Worn Again saying they have the ability to do blends. I've also been told by a few others that there are a few processes out there that are either commercialised or in the process of commercialisation that are addressing, you know, polymers or polyester blends with a majority or 80% of polyester, which is actually quite good. And then I've hear of another, again this is all anecdotal but I've heard of another that is actually kind of able to recycle everything under the sun, but yeah, I never hold my breath with those.

Main categories of common blends have recycling solutions

So anyway, I would say in terms of blends, I think I've told you this before, but in terms of blends, if you stick with let's say wool/acrylic, which I actually hate saying, because gross—acrylic, but, wool/acrylic blends with a high percentage of wool, wool/nylon blends with a high percentage of wool will have recycling markets today, they can be mechanically recycled and quite frequently are. If you stick with poly/cotton blend, also probably likely that if there is not a commercialised recycling technology today there will be in the short term.

Complex blends are an issue

The things that gets tricky is once you start putting in really complex blends, like three fibre blends or high percentages of spandex, pretty much any spandex in general but that one is hard to get away from so… You know high percentages of spandex or things that have for example, viscose and nylon and acrylic and cotton. I mean come on! It's just not feasible to recycle that. So instead of mono-materials, you are right, I thing that window is opening up a little bit, but a really big issue: spandex is still a big issue.

Minority fibres in blends are a problem

I think really the big one is the complexity of the blends so adding a lot of minority fibres or low value fibres, so even though wool/acrylics—acrylics do have a market, a resale market and recycling world, interestingly enough and yeah, it's just, acrylic is not—if you blend it with wool, if you blend it with a few things, but if you start blending it with rayon or viscose sort of stuff then it's— and acrylic and spandex, then you've officially blown it.

Garments are sorted according to re-use categories

the way the second hand garment industry works is they resell based on end use. So if you have a bucket full of winter jackets, the chances if that going to Africa are quite slim. That sort of thing. Even if you look at jeans versus slacks, if you look at footwear, women's heels versus more conservative women's shoes, they all have a different market, which is quite interesting. So there is that aspect, that is actually how sorters sort today, they sort for the most part, based on where they can resell the re-wearable fractions. So that's how the system is set up.

Garment wear/use categories are an indication as to the fibre/finish content

"So if you are going snowboarding you are probably not going to wear your bathing suit, well maybe, but probably not a great plan right? Not if it's really cold and windy. So, things like DWR coating or fire retardant and all of these sorts of additives and things that get more complicated tend, not always, but they tend to fit into specific categories"

"If you have, yeah, multiple fibres blended into things lie you typically find in women's fashion stuff. That's where that comment came from. If you specifically think about outerwear and the barriers to recycling, that it's not a mono-material because you might have some sort of blend in the shell or nylon blended on the shell, or polyester fill or a down fill and a polyester lining, oh and by the way, it's waterproof. So that makes it really difficult to do anything with. And outerwear typically is going to have more of those types of barriers because, especially if you think about a shell, a fill and a lining. Whereas lifestyle sort of stuff or sportswear sort of stuff, in sportswear you might have a higher percentage of spandex, but you're going to have a lot polyester and poly/cotton blends, and it's going to be pretty consistent"

"but a smart sorter will be able to say, 'oh that's sportswear, that's polyester' or 'oh that's denim, that's cotton'."

Problems, and solutions, are different for all types of garments

if you're talking to designer and you want to give them really practical advice or if you want to write something that's really practical for design and the industry then think about it in terms of product categories, instead of trying to put everything into an overarching, do this, this, this and don't do this, this and this. You'll get a couple of those, and you can absolutely say, minimise your use of spandex, minimise your use of multi-fibre blends. But you've got to do something very different for each type of garment or each type of product category.

Automation is important

You can detect fibre types much more accurately than a hand-sort and much more consistently. It [the fibre sort] decreases the amount of manual labour required. So it increases the accuracy and decreases the amount of labour required to sort for recycling feedstocks. That's the biggest deal.

Automated sorting could be either at the sorting or recycling end

The first is with the collector-sorter, that seems a little bit obvious, they are already dealing with waste materials, and if they want to create a broader range of recycling grades, they can buy this equipment and do that. The other place that it would belong is on the recycling side so at a technical, at a place where the recycling technology actually exist. Those facilities can either function as a recycling grader, meaning they could bring in all the junk. They could sort it out by fibre type, take what they need and sell the rest. Or, they could use the fibre sort as a quality control for their own inputs. So if they are buying materials from a sorter that does not have automated sorting or high precision fibre detection, then a recycling facility could have a Fibre Sort on the front end of their process to make sure that everything going in to their process is exactly as it should be.

There is a need for harmonisation of efforts and research

A lot of the stuff in the circular system of textiles is disconnected right now. There is a lot of work happening in pockets that overlap. The gaps, let's call them, are just starting to be addressed.

The infrastructure for a circular economy needs to be created

So if you build an infrastructure that can take used garments, and transform them into an input for any recycling process, then the questions come down to: how much does it cost, how much does it cost to create the feedstock and if it's a compatible input, you know, then what's the yield on it going to be. If it's not a compatible input then what is the recycling technology you have to—but, for me, the pressing thing is, you have to actually create the infrastructure for those garments, or even the post industrial waste, to go from where it's sitting and rotting and being wasted to a place where it has value. In order to do that the auto-sortation thing is important on the post-consumer side, but standardisation of the language, understanding of the system and input materials for these feedstock grades, those things together are very very important.

Need for standardisation and transparency

And then on top of that is a system that will move the materials from point A to point B in a transparent way. So, you have to create some standardisation, some common understanding and standardisation. You have to connect the supply and the demand in terms of specs and expectations, and then you connect the entire system, or you have to collect the supply and demand just in terms of buying and selling and logistics.

Need for standardisation

If you can get the materials right or at least improve the materials in a lot of ways: decreasing the spandex, decreasing the complexity of blends and focusing on majority fibres, then you find the materials side and the design side to be more effective in a circular system.

Biodegradability is not a priority

But I think we also have to be smart about prioritising the work, so for example I think that biodegradable materials are really important, but I think biodegradability is one of the lowest priorities in sustainable materials.

Solutions to problems in industry need to be developed in parallel

You know we talk about slowing down consumption and all these things, so that I think is super super important. But at the same time, you are not going to slow down consumption quickly, so because we are far enough along in creating a system that can recycle, maybe not perfectly, but we're actually down the road quite a way in building the system and even the infrastructure and the technology, there is a lot there that is very close, you know. So in my mind it makes sense to put the energy, the majority, not all of it, the majority of the energy to the things that are close, because innovation and true systemic change is accomplished step by little step, and as long as you keep going and you have something that's viable, the market will pick it up, the market will drive it, it will.

11.2.2. Interviews with Circular Design Experts

These three interviews were carried out in June and July 2018 to get feedback on the potential of the TDfD techniques demonstrated in the samples to respond to circular economy challenges.

Ina Budde – Circular Fashion

04/06/18

[presentation of a selection of samples by LF]

LF: … So that's it for the samples. So would you be able to tell me about how you approach design for disassembly in your work, and having seen the way that I have done it, maybe relate it to that?

IB: Yeah, first of all I think your samples are fantastic, because they look also visually really nice.

So maybe I can show my screen here and we can have a look at our circular design software, it has different components. So on the one hand we have materials, like a library, and on the other we have circular design guidelines, I can go in more detail with you. And then the third part is more like product life cycle management software where companies can create their product and add materials onto those products and upload their drawings, and then check if all the different materials fit together. Or if they design for disassembly they can 'create a new assembly'. So this is one assembly, so it needs to fill the requirements of one specific recycler. And they can also add a second assembly, so let's say, now it's a trousers, but it would be a hoody for a jacket, so I add this and I can put new parts and select new materials for this specific one. And then each assembly is checked separately. So let's say, the hoody is made from recyclable polyester, but the main of the coat is from biodegradable fabric, but they are put together with buttons. So it would not be necessary that they go together in one cycle but they can separately go to their respective cycles.

LF: Ok, so do you have a way of describing how the assembly works, is that something that's taken into account with the tool?

IB: How the disassemblies work? Yes this is something I wanted to go deeper into, to understand what are the different functions of the tool. So here for example is one piece of the jacket were we have designed for modularity. So it consists of this lining, which is totally separate, or actually with buttons attached to the main material, but also here with threads kind of in a modular way so that the two parts can be taken apart. So it's more like design for disassembly on the product level, in this case not really on a textile level. We also have other examples, here with the lining of the jacket which can function as a jacket itself. It kind of plays together with the patterns, it's how this design fits together. Another example where it is more on the material level is this one where we use the climatex one, but also we use a soluble thread as a sewing thread. So the lining is actually a cradle to cradle biodegradable one, so you would need to disassemble both. The sewing thread is soluble in a similar way to the climatex fabric, so if you would disassemble the climatex fabric, you would also disassemble the thread.

LF: So in the same process?

IB: Yes

LF: So just to go into more detail into that case: you submit the jacket to certain conditions, like heat I suppose, and the thread disintegrates and releases the different components. Then what happens?

IB: It would probably be the last step before recycling. Of course it could be recovered and then used again in another way, but I think that when we look at an industrial process, it would not make sense, it would be too much effort to collect all the different pieces and dry them again and use them as fabric again. So I don't really see it industrially applied to reuse the fabric parts, I would see it more as a pre-stage for sorting in a materials specific way. For regenerating it.

LF: So regenerating the fibre or like maybe biodegrading if the material is biodegradable. So we are thinking maybe mechanical recycling on one side, and biodegrading on the other?

IB: Yes

LF: Ok, is there anything else that you were on your way to showing me?

IB: I hadn't thought about it, but hearing you speak, here are some other examples, like here it's more of a mono-material approach, where we work with closure techniques that are more mono-material. We have a closure technique that is designed to disassemble. Same goes for shoes, or inspired from trousers that can be disassembled. As you see it's much more on a component kind of product level. But I think the connection possibilities that you have created with the laser, I really see it in products that have, that work with fabric sandwiches, that work with multilayers and functional parts, like a back-pack or things like that. I could really imagine that if you have paddings and things like that.

LF: That's interesting, because my approach is rather removed from the product approach, that's not really my background, so I tend to be more focused on the material itself, accessories isn't really something that enters my mind-space that much, so it's really interesting. So how would DfD be much more useful in accessories for example?

IB: So on the one hand I see it that when you're designing parts for more solidity or warmth, or any other type of function, that you should be, in a potential other situation, able to remove, kind of to store the backpack in a much much smaller, suitcase, or to put it away. Or if you have products that are trans-seasonal, you remove it again. I think that could be a great multi-functional add-on.

LF: Yeah that sounds really interesting. And in the way that you've approached it in your products, how do you… So I'm always looking at design for disassembly as an alternative to mono-materials, is that something you've looked at, trying to consider how is this better than just having a mono-material which in a sense could be more simple for recycling streams and more simple for design processes. So for example with the coat or any other products, how is that something that you have envisaged?

IB: I think it is always a decision that we take in regards to how the product's used. Then we decide what facilities are better or what function we actually need, so maybe the closure isn't for mono-materiality, it will not really work well for this kind of charges also. And we don't want to compromise the function. I think we always decide on what is the functionality to fulfil and how we can make it with disassembled parts or mono-materials. And also in terms of how complex the garment in general is. Does it look really easy or simple, is it a really easy piece or is it something that can work with a more complex look. Often actually we use disassembly when we want several functions. Often it applies that you can add function with a disassembled part, or other shapes, etc…

LF: So for example in the case of the coat–I feel like it's your most designed for disassembly product, would you be able to tell me a little bit about which materials you used and why, and how the functionality works within the assembled vs disassembled version?

IB: The coat consists of this main material, which is a very durable workwear material, I think it's an organic cotton, but a quite thick one, I think it's very densely woven material, and when water gets on to it, it kind of swells, it gets even denser so it kind of doesn't allow the water to enter, so it's not waterproof but water-resistant. But it's not really soft so we wanted to have like a polyester, like a lining that is softer, more warming and with a little bit of filling, so we chose this specific polyester lining that is much softer. But you can use the parka without the filling, without the lining, and you can also just use the lining if you don't need the waterproofness of the upper part. All the parts work on their own, and also the length etc can be changed.

LF: So with this relationship of the two materials, the outer and the lining, how did you decide that it was really necessary to use polyester, because I suppose you could have used some kind of tencel or something to keep it, not mono, but compatible materials, is that something that you considered?

IB: Yeah I think in that case, the first choice is biodegradable and recyclable, at that time the polyester had more functions still and I think the filling material wasn't very promising in the biocycle material at that time, it can also be a price decision sometimes of course. So I think there are different decisions behind it sometimes yes.

LF: So just to get some insights on how you work, how does your design process work? Who are the designers? How do you go about creating a new product? I suppose you have different sorts of expertise that come into play, with more technical versus more creative people, would you like to talk about that a little bit?

IB: So in our team we have 4 people who are involved in our workshops, because we always work for a specific brand. We sometimes do new idea developing or idea generation internally, to come up with more solutions, but often it is basically within a workshop for a brand. Then we have one person who is more on a design for cyclability point of view, so that's me and […], that's two people, then we have one that is very deep in design for longevity, and adaptability, like more a long lasting approach etc, and then we have more like circular retail models, he's not a designer at all, and he has no background in creating the product, it's more about the business models, when we do a workshop we are sometimes two people or maybe three, depending on what the content or the solution should look like. Mostly in the beginning we analyse the brand's DNA, so what's the aesthetic, what's the product we want to work with, we kind of make collection mappings and decide on the type of products that we want to change. Sometimes it's frontrunners or very easy products, it's very different approaches. How they look today, sometimes we have tear-down workshops where they tear down everything and look like here we have a lining… Usually the attendees, they normally know what kind of parts there are in this product, but it's an eye-opening task to pull it apart and really see what's in there. And then we often see, ok, what is our circular challenge now, so what do we want to exchange or what do we want to solve, and then formulate the design briefing and then we have some rapid prototyping and brainstorming sessions in between and sometimes we make little mock-ups.

We always have fabric but also paper there on the table, so we can come up with some new ideas. Often it is after that I show some examples of what we did before, and often it is a very good way to come up with ideas on, yeah, existing solutions, but then more framed to the brand DNA. Sometimes they want to play with a specific aesthetic or embellishment, and then we can use this wanting to use this embellishment, this can be a very important part in the disassembly strategy, we try to use those things. That's mainly how we work.

LF: So the products that you just showed me on your website and the things that I have seen in your presentation, are those things that have been developed in these kinds of workshop-collaborations with brands or are they your own products.

IB: I think these are mainly from my own developments, the ones that are up there. Let me see, since I worked around this topic for like 4/5 years now, so there is one big collection of 15 pieces or so that we developed all in this mind-set, so we have a lot of features of this collection, and this was a collaboration with a brand but without a workshop so it was rather my… developing those solutions. So then there are also some others that we co-developed in these workshops, and some of my colleagues as well.

LF: Are you allowed to say which brands you've been working with, or is that non-disclosure?

IB: Sure, one was Jan n June, [typing]… (jan n june, myrka studio)

So these two that I just sent you here we are allowed to speak about, then we also did workshops, a bit more established, we didn't actually develop with all of them a product, but we developed a bouquet of solutions, or like a toolbox, or things that they can take hold of and work with, that is also typical.

LF: So once you have started developing the concept and decided how you were going to make the product more circular, how do you integrate the material aspect? Do you work with the suppliers that the brand already has, or do you bring in your own suppliers?

IB: On the one hand we have our own network of suppliers, where we do a little show and tell during the workshops, to show what is already out there and what could be used. A lot of them are able to develop new things, let's say the aesthetic or the type of fabric is interesting but maybe in another colour or whatever. We can do that. But we can also do tests with existing materials from the brand. So sometimes they have carry-over products, they use a specific material and they want to know like ok, we want to slightly change this, like maybe, change the sewing thread and we want to know if this material is recyclable, and then we have a network of recyclers that we work with, we can send the materials to testing, or gather the material's data sheets and get more information on what's actually in there to apply the test.

LF: That's really interesting, so how do you assess if a material is recyclable or not? What are the parameters that the recyclers need to know about?

IB: If It's very different. The colours are of course important, the finishing, all the chemical treatments, these are all parameters that we need to check.

LF: Ok so just make sure that there are no toxic components that would carry over or make sure that the colours match what the recycler already has I suppose?

IB: It's not only about hazardous chemicals, it's also about chemicals that disturb the recycling process. So there are some things that they just can't handle, or they don't want to handle, and that's what we need to find out.

LF: So is this something that varies very much from one recycler to the other, or is there some kind of set standard for European recycling?

IB: It's quite different, it differs.

LF: And we are talking about mechanical recycling here right?

IB: No it's about chemical.

LF: Ok so polyester recycling? Cellulose regeneration?

IB: Both

LF: Ok, so staying on this topic of circularity for materials, in sustainable consulting for fashion and textiles, there is this idea of this kind of menu of different materials with their corresponding recycling strategies, and it's just extremely difficult information to have. So how do you approach that? It sounds like you have developed a local network that you can rely on, would you like to tell me a little bit more about that?

IB: Yeah our network is European wide. We started with one recycler per material group, to set up some good process, like get the requirements get the testing etc. And then we broadened it to others that we know that have more product types. For us it's a tactical approach, because standards can tell a lot, like this is cradle to cradle, this is GOTS, but no one really says, with this recycler you can actually recycle it. And if not a guarantee that someone would actually take it back. So that's our process, we practically look at who would take this back and regenerate it, to which process it fits the best. And thereby we create a database of supply and demand, what materials are out there, and what is the demand of recyclers, and make a matchmaking.

LF: Ok, so is that information that's available in your circular fashion system tool

IB: Actually we don't have such detailed information on the surface to see, it's not so necessary. The materials have all the information to which cycle they apply, and this is what a designer needs to know, so they don't need to know let's say, we did this test with 100 information and then it needs to go to this or that recycler. It's more about, you can combine this material, it's this cycle, and then that material is that cycle. So that's the outcome of the test.

LF: And then you are putting it in the hands of the user…

IB: Yes exactly, so after the first step of generating this product and creating the circularity check, the product website is created, and customers can see on one hand how sustainably the garment was made, what are the materials that are in there, where it was produced, but also, where do I need to return it so it actually ends up at the right recycler.

LF: And that information comes through the tag, it's wonderful how so much complexity and information fits into your tool. On a more general approach, it'd be really interesting if you had some thoughts about how this knowledge that you have, of materials and circular economy systems, how that actually steers your creative approach as a designer yourself, if that's something that you have articulated before, how it's important to how you design in this constraint focused

approach…

IB: What I really like about it is that it gives you like a framework which has a higher meaning, you're contributing to something. Of course it could be understood as a limitation, you can't do this, you can't do that, but actually it supports you or it pulls you to find new solutions like laser engraving or other things, like you know to kind of dig deeper into other solutions which become much more beautiful. When I look around and I see an exhibition that is just temporary and you see a lot of things nailed or glued together, for me this loses all aesthetic, I don't like it anymore, it's not beautiful anymore. If I see products that have the ability, where each component can be kept at the highest value that they have and they must not be destroyed to become something new. This is real beauty. And the aesthetic has just shifted a little bit around so that this becomes more important. It's a lot of fun to play in this framework and to use it as a power for creativity to find some solutions there.

How is it for you?

33:13[stopped because the conversation runs into a more general catch up, and I explain my project in to more detail.]

François-Xavier Ferarri, Anthony Boule, Florent Chalot, Ophélie Gatine – Coopérative Mu

11/06/18

FX : Il a deux très gros biais, le premiére c'est que l'économie circulaire, il y a une très grosse imagerie de 'on peut faire ça à l'infini' et tout va bien. Ce qui est completement faux, puisque pour faire proprement il faut de l'énergie renouvelable, et pour faire de l'énergie renouvelable il faut des métaux, rares et pas rares, et ça c'est de ressources qui s'éteignent, et tu peux pas y écoper. Si ça t'intéresse tu peux regarder 'économie circulaire et métaux', c'est Biwix, un chercheur français qui a écrit dessus. Il y a quand même un imaginaire ou on peut faire ça ad vitam qui est faux c'est comme le soleil, a un moment il s'éteindra, c'est l'entropie, la deuxième loi de thermo-dynamique. Et la deuxième idée c'est qu'on continue à consommer enf ait : changez rien, vous pouvez continuer à consommer. C'est nous qui allons prendre en charge le truc avec des produits qui vont être assimilables bio, ou techno-assimilables, ce qui est qu'une partie du problème, c'est à dire que les produits éco c'est bien mais il faut changer les manières de consommer. Il y a toute une idéologie derrière qui peut être, alors quand tu parles à des gens qui savent très bien la bible du truc, mais il y a plein de gens qui la connaissent pas.

LF : Ouais c'est des questions qui se posent, et dans le cadre de la thèse il faut pouvoir poser ses limites, et la clairement les questions ethiques autour de l'économie circulaire…

FX : c'est plus que de l 'étique, c'est que ça fonctionne pas, c'est le deuxième point l'étique, c'est que ça pousse pas à changer les comportements, et même d'un point de vue environnemental, c'est pas une réalité, c'est pas forcément meilleur pour l'environnement, c'est une jolie image, mais c'est juste une image

FC : Et il mettent beaucoup l'accent sur le produit positif…

FX : ouais à impact positif, qui régénère. La ils ont fait le truc rénette qui va dépolluer les océans, ouais peut-être mais tu vas consommer combien de pétrole avant pour faire ton machin ou combien de kilowatts de nucléaire ? Il y a pas de produit positif, tout est source d'impact. Ce qui n'a pas d'impact c'est ce qui n'existe pas et ce qui a un impact positif c'est du mensonge ou de al méconnaissance de la deuxième loi de thermodynamique. Et à date personne l'a remise en question, peut-être qu'un jour on pourra créer de l'énergie ex-nihilo, mais à date ça existe pas.

LF : et du coup ça vous l'approchez comment ?...

FX : bah moi je le dis dans les cours, après ce que je dis aussi c'est que le lien éco-conception/économie circulaire, pour nous c'est la même chose. Après chacun prêche pour sa paroisse, ce qui est intéressant, c'est que je suis allé parler à des gars, des vrais anciens de l'éco-conception, un gars qui a monté le cireg, qui est le fondateur du cireg, et je lui ai dis : c'est quand même du gros foutage de gueule l'économie circulaire, par rapport à l'éco-conception il y a rien de nouveau. Il ouais c'est vrai, mais il y a quand même un truc c'est que l'économie circulaire tu peux l'entendre dans la bouche d'un ministre, t'auras du mal à entendre éco-conception. Et c'est pas faux, si c'est une manière de faire passer la pillule, pourquoi pas ? En connaissant les limites du système. C'est une marionnette. Ce qui est intéressant c'est qui agite la marionnette et pourquoi. Mais faut pas prendre la marionnette pour un truc vrai.

LF : Du coup ce à quoi je m'attaque c'est les textiles mélangées…

FC : les fibres en mélange ?

LF : non c'est tout les textiles mélangés, et un de mes premiers boulot ça a été de les définir, et à quel niveau ça arrive [explaining the translating and mapping]

FX : Forcement c'est des questions qui vont te déranger, c'est comme ça qu'on prendrait le sujet : c'est l'intérêt environnemental du truc. Est-ce que tu mets pas 10 fois plus d'élasthanne que sur un textile normal, versus ce que ça va pourrir dans le flux, il ya peut-être une quantité d'elastanne qui change pas trop ton flux de matières recyclées.

FC : le gros problème de l'élastanne, t'as surement croisé ça c'est que c'est difficile à déchiqueter par les machines donc faudra l'enlever en amont.

FX : pour le coup ça ça marche, c'est le point positif de ça. Après il faut connaître le pendant, parce que ça va contraindre ton design : la en fait il faut que j'arrive à le diviser par deux pour que ça soit rentable d'un point de vue environnemental, formelement tu fera autrement.

FX : après il y a cette notion que le design for disassembly c'est bien, mais comment tu fais pour récupérer, il y a tout le process derrière, comment tu fais pour le récupérer pour en faire une chemise… qu'est ce que tu peux réparer, qu'est-ce que tu peux pas réparer, c'est bien mais si derrière c'est pas utilisé… c'est l'exemple du tétrapack, c'est pas forcément le bon exemple, il va passer dans les filières à recycler, mais dans 90% de cas il va être broyé et va servir d'isolant. T'as vraiment ce truc global et systémique de te dire si ça finit en isolant métisse, les trucs du relais, c'est un peu de la bouse. Comme t'as ta technosphère, aujourd'hui t'as pas deux personnes qui recyclent de la même manière, il faut la solution du designer, la c'est même avant le designer, le fournisseur textile, le comportement du designer, l'utilisateur qui va le mettre dans le bon endroit pour le recycler, la technicité pour le recycler et changer la culture de ce truc là… et pareil, se dire quelle est la durabilité du truc recyclé, la c'est du coton, c'est du coton recyclé, tu va dépenser de l'énergie… si t'arrive a le filer et au mieux t'arrive à trouver un truc de collecte pour séparer ton polyester de ton coton , il y a aussi une question que le coton une fois recyclé il faut qu'il fasse une toile qui tienne la route, si c'est une toile qui va faire un truc qui est complètement jetable parce que les fibres sont trop courtes et que ton fil tient pas, là tout l'interet environnemental devient presque merdique parce que t'auras dépensé énormément d'energie pour faire un truc recyclé qui va avoir une durée de vie de zéro, tu vas en faire des produits qui sont inutiles parce que la matière a pas la fonctionnalité pour faire des trucs utils…

FC : on commence à faire des projets avec des trucs textiles et on commence à croiser les sources et ça a l'air d'être vraiment le cas : l'enjeu environnemental sur les textiles est énormément lié à la consommation d'énergie sur le filage et le tissage, limite plus que la fibre, la matière. Après ça dépend de ton scénario de lavage, mais en tous cas jusqu'à la sortie de, jusqu'au magasin, donc il y a peut-être une piste, si t'arrive à avoir des trucs ou tu récupères un fil et pas une fibre qu'il faut refiler, la t'auras un intérêt environnemental…

FX : carrément c'est ce que je me suis dis quand tu as expliqué ton truc, tu pourrais avoir chaine trame et puis il y en a une qui se dissous et tu peux récupérer tout un fil, au moins tu sais que ton fil sera un peu moins costaud, mais tu vire une étape

FX : il y a un autre truc aussi qui m'y fait penser : il y a aussi tout un mouvement de location de vêtements, tell me en Belgique, il font de la location de trucs pour enfants et ça marche plutot bien, ton enfant il grandit et tu fais que de la loc, et là il y a un vrai enjeu parce que c'est des gens qui sont capables de re-capter leur produit, qui peuvent développer des technos en amont et en aval, c'est intéressant parce que il y a cette approche hyper compliquée de à qui tu vas donner ça, comment tu le récupère, comment tu le recycle… parce que le but c'est de créer de la valeur ajoutée, c'est pas juste de désassembler pour en faire un truc ou tu perds de la valeur ça a pas de sens

FX (en référence aux échantillons laser) : là la fonction, enfin c'est quand même plus esthétique…

FC : enfin t'as aussi un truc de réparation, tu taches ta chemise et en fait c'est juste un tric que t'enlève

LF : du coup sur ce truc modulaire l'idée c'était de réfléchir à de la réparation, du désassemblage, réassemblage, re-désassemblage…

FX : ça je pense que c'est un vrai truc intéressant c'est de faciliter le désassemblage pour augmenter la durée de vie, et pas juste pour le recyclage, et la c'est un vrai truc

FC : surtout si tu peux viser des zones d'usure, ou qi sont exposées

FX : des zones qui se décolorent, ou qui se colorent…

LF : un des trucs sur lequel ils travaillent à CCD c'est le fast and slow, d'un coté c'est du produit sur 50 ans, de l'autre c'est de l'ultra fast, de la robe papier…

FX : c'est un vrai problème de fond, la vrai éco-conception c'est garder tes fringues 10 piges

FX : ou alors t'as des matières à faible impact qui dure longtemps…

AB : la question de la matière à faible impact elle est difficile, parce que même si tu regardes, la robe papier, à partir ou c'est à usage unique, le matériau a beaucoup d'impact

FX : moi en tant que designer responsable d'un produit je le ferais pas, je préfère travailler sur un truc ou on va faire du lavage collectif ou utiliser l'eau des toits pour laver, que de faire un truc ou tu dis aux gens : vas y consomme, consomme. Ça peut pas marcher.

AB : je suis d'accord avec FX, t'évites les biais cognitifs de 'en fait l'environnement c'est pas compliqué' si tu commences à proposer une solution jetable tu biaises le message de fond qui est : il faut faire attention. Après c'est effectivement calculable, si tu vas sur des matières plutôt recyclées déjà, même des matières up-cylées, donc qui n'ont aucun avenir, et t'arrives à les recycler dans du jetable, en gagnant sur la phase d'utilisation je pense qu'en ACV t'arrives à démontrer un intérêt, mais tu restes quand même dans ce truc ou si pour 100 vêtements vendus comme ça, il y a une personne qui comprend pas, et qui se dit ah c'est bon l'industrie textile a répondu au problème environnemental, donc je peux y aller, t'as tout perdu

FX : c'est ce truc là que je trouve un important : le coté esthétique c'est cool, mais tu vas créer de la complexité, que tu vas décomplexifier en désassemblant,

mais juste pour de l'esthétique, après tu peux dire oui… moi je me dis, je créé de la complexité pour l'esthétique si ça a une fonction, c'est pour ça que la réparation tout de suite ça créé une fonction, je vais réduire un truc, je créé de la complexité mais j'augmente la durée de vie

LF : après il faut que la fonction elle match un truc qui existe déjà

FX : après sans évaluer le goretex versus ça, il y a un sens autre que juste esthétique

AB : après juste faire un vêtement hiver/été, t'as une trame été, tu l'enlèves…

FX : c'est clair, en plus tu fais des petites écailles pour créer des bulles d'air

AB : la durée de vie elle a pas vraiment de sens, c'est de la durée d'usage, t'as un t-shirt été qui dure 50 ans et un t-shirt été/hiver qui dure 25 ans, c'est pareil

FX : après dans ton choix de matières aussi, tu parlais de cuir et tout, il y a un énorme enjeu, c'est hyper compliqué, les matières écologiques en fonction du produit et donc de la fonction… typiquement, une chaussure en cuir que tu vas garder deux ans parce que c'est fait un peu à l'arrache, en chine etc, ça sera toujours moins bien qu'une chaussure en polyester qui va même durer qu'un an, qui est presque jetable. Parc contre une chaussure en cuir qui va durer 15 ans, ça commence à devenir intéressant. On bosse aussi sur de la chaussure nous.

LF : et ça du coup tu l'évalues comment ?

FC : la durée de vie de la chaussure ?

LF : oui parce que ça reste quand même hyper subjectif

FX : après tu peux aussi concevoir ton truc pour qu'il dure plus de temps, tu connais tes pièces d'usure

FC : la meilleur démarche plutot que de se dire comment est-ce que je quantifie la durée de vie d'une chaussure c'est ce que nous on avait fait sur ce projet c'est d'aller demander à des cordonniers : c'est quoi les pièces d'usure, qu'est-ce qui fait que quelqu'un se débarrasse de ses pompes, et du coup de travailler dessus en termes de design, même sans être capable de quantifier ce qu'on peut apporter de plus…

FX : on sait qu'on s'attaque à un problème et que potentiellement, après limite il faudrait le quantifier à posteriori en demandant aux gens combien de temps ils gardent leurs pompes.

AB : quoi qu'il en soit ça restera toujours in-quantifiable, parce qu'il y a pas que la problématique technique, mais tu peux quand même cadrer le truc et agir sur ce qui semble…

FX : ça c'est une notion qui est super intéressante aussi, c'est durée de vie/durée de vie technique, durée d'usage, et durée fashion, c'est trois trucs qui sont très différents. Sur le smartphone, t'as durée de vie technique c'est 5 ans, durée de renouvellement c'est 2/3 ans et ça pourrait même aller plus vite, la les deux se mélangent, marketing et technique, ils se débrouillent à faire en sorte que la technique merde quand ils font un nouveau lancement, t'as une obsolescence programmée technique avant, et t'as une obsolescence liée au marché parce qu'in te bourre le mou pour avoir le dernier truc

FX : c'est ce que tu disais tout à l'heure, il faut une référence. L'éco-conception c'est pas une ligne avec bien/pas bien, recyclé/recyclable. A un moment il faut prendre la photo pour savoir ou est-ce que tu dois aller, et puis t'y vas et tu reprends la photo, est-ce que j'ai été dans le bon sens ? c'est quoi la direction pour après ? si tu pars pas de références, c'est effectivement compliqué, mais après tu peux dire : mon premier truc c'est ça, peut-être que c'est pire que celui d'avant d'un point de vue environnemental… même réflexif, c'est moyen de se dire je pose un truc et je sais pas si c'est pire que le truc d'avant mais bon je pose ça et c'est ça mon début de mesure, ma référence… mais c'est comme ça qu'on choisit.

FC : typiquement sur du produit textile on va avoir du mal hors de toute considération technique ou de prix a conseiller un type de fibre plutôt qu'une autre, parce que vraiment à part quelques mauvais élèves, ils ont tous leurs avantages et leurs inconvénients. Par contre l'idée c'est vous voulez faire du coton, donc parmi ces types de coton voilà ceux qui ont ces caractéristiques.

FX : ou qu'est-ce que vous cherchez dans le coton, est-ce que c'est à ce qu'il y ai marqué coton dessus, ou est-ce que c'est l'aspect

AB : de manière générale on évite les comparaisons inter filières. Le brief de départ c'est d'avoir un vêtement en lin on va chercher soit le meilleur lin, soit des textiles très approchants. On a un parti-pris soit esthétique, soit fonctionnel… […]

FX : ou alors tu démontres la complexité du truc, tu vas chercher plein de référentiels pour dire regardez : il y a 18 sortes de tri, donc c'est qu'il y en a pas

AB : on se reprends souvent, soit tu rentres par la matière, soit la matière est une réponse technique, en général quand on arrive dans le textile, la matière va plutôt être une clé d'entrée, ça va moins être une réponse technique à une exigence du produit, ou alors si c'est une réponse technique on est rarement en habillement, au quel cas on ira plutôt sur du recyclé. Parce que si on arrive à avoir une matière recyclée qui répond aux exigences techniques …

FX : déjà de base on sait que tu divise par deux l'impact, c'est la solution simple

LF : après tu reviens à des questions de durée de vie

FX : oui c'est ça, et à durée de vie équivalente, grosso-merdo tu sais que t'es dans le bon 50%

FC : Il y a un truc sur la durée de vie qui est très spécifique à la mode, et qui est un peu différent de la durée de vie fashion, c'est l'effet d'accumulation

AB : c'est pas un déchet que tu peux capter

FC : en stratégie d'éco-conception la question c'est pas forcement comment je fais pour que cette personne elle garde le plus longtemps possible le vêtement, c'est comment je fais pour qu'elle en achète pas plus

FX : d'où l'interêt de la customisation, de l'esthétique, qui peut être un vrai argument

LF : mais du coup hyper difficile à quantifier

FX : ouais, sauf si tu le formalise avec un produit, avec un business model

Fredy Baumeler, Climatex

26/07/18

Recording started after the conversation started, Fredy Baumeler has introduced the company, the history of how they have got to developing the DuaCycle Textile Lock: it is linked to the recession (2008) and loss of industry in the area and Europe generally, needed to focus on innovation to stay competitive.

LF: There are a lot of studies that show that when sustainability startegies are trying to be implemented in a design studio, for a brand, then it's difficult to keep the attention of the designers. There is one specific study that has been done with H&M and it's such a past paced rhythm, that trying to implement these sustainability strategies doesn't really function on the same level….

FB: Ok this is really nice, one thing in kind of thinking clearly… This is a strong approach to bringing together completely different materials. In a textile, such as upholstery, you have to deliver one fabric. Of course we can have two sides, we can have an upside and a downside, it can have different materials in it, but in the textile industry it's too… Doing design and to combine materials for colour fastness, for good abrasion value, for elastic values, etc.. to combine yarns of fibres into yarns, it's something that is given by hundreds of years. More strong approach to combine natural fibres with synthetic fibres, there is an issue of natural fibres for comfort aspects, for example the polyester world combining with cotton etc.. These are really long term development processes and to change this thinking, because if you bring together a polyester with a cotton or something like this, or a polyamide with a wool, all these things are existing in the world and many times they are combining two, or three, or four, five fibres in one yarn and this one yarn they are weaving into a weaving construct. The question that I had in my mind when I found out the construction of DuaCycle— we call it DuaCycle because we have materials in these two cycles. It's the same in the mechanical world, if you think about a car or a machine without locks, you can't just bring them together without separating them, without de-assembling. And I think about this: how could we manage this so that we have something like a lock with a key. I am thinking about how to bring together the things, if you are melting or if you are in the machinery industry, if you have just one part and not different parts that you bring together with screws, then you cannot de-assemble this one part. So, I think we have had about 200 years since the screw was given by the mechanic, in textiles it doesn't exist. This will mean, you have to change, to bring the screwing together into the construction at a macro-level. Not on the micro level, on the micro level, the fibres, it's not the work… the de-assembling process could be chemical-wise, it could be, in some ways when it's really demanding from the chemicals, for the processing etc… Then I thought: ok, we are weavers, we have a second level, we have the first level of yarns and on the second level we are doing a weave into fabric. This means, this could be the chance to arrange the things so that we can de-assemble it. And what a nice result of the thinking it is, that the fibre that you are placing not only together, that they can do what they have to do, you place it on this part, on this side of the fabric where they are bringing more, for example comfort, or more abrasion, or, or, or… So this will mean, not only mix, the mix of some functionality, but also de-assembling into parts where clearly in a layout into the fabric will bring you also some functionality during the use of the fabric. And this is one of the important things for marketing. Because if you are doing design, what is the first thing you'll have in mind, touching, looking, they like something, but at this moment, when they are designing to take this product, they are not thinking about throwing it away, if they are thinking about putting it away, they don't like the product, they won't buy this product. So we have some additional function there, if you put things together the right way for de-assembly, so we could also have the chance to re-arrange the components into the product in the right way so that the product has some additional functionality during its life time, during its use cycle. So if the idea of doing the products different, de-assembling, then we have to add also something additional for the customer. He is using this product because something more is there, also the price, the price is a little higher, there are more technical inputs, more to do, more to think about how to do, and this of course it arrives at the end of the day as a reason to discuss a higher price. Not in all cases, but many times if you are combining natural fibres with synthetic fibres, for example in a yarn, and you are doing this in our construct, in the same mixture for example 70% of synthetic fibre and 30% natural fibres, of course the simple mixture in the yarn is what is given by 200 years of experience in industry and it is not the reason the de-assembling is the reason why [?] but every time it's done this way the industry is running this way, you get this of course for a lower price than if you take the materials in their own construction and you bring them together into a weave. So this is just a question of time. If the system is changing then this system would be of course at lower cost than this. But initially, you have to talk to your customer, of course that you have a product that is better in the use phase, and this is possible if you are re-thinking the product, and one of the key figures, one of the strongest approaches of Cradle to Cradle is the re-thinking part. You start to completely re-define all of what you are doing, in the industry, in many cases, one does not know what they are doing, if they are using chemicals for finishing or this or that. We are combining things where other people, knowing or not knowing people, are taking decisions for you. And you are using this in confidence of them but you don't really know what you put in your product. So this re-thinking process, is for me the strongest approach. If you are not able to bring it to a de-assembling level, at least to know what you have and how are what you are doing and what you are bringing together. The difference between a positive list and 'we have none of this' is such a big difference that the quality of the product for the user, for the use part of the cycle, is so different from the other product that also the initialisation of the re-thinking process is a really strong approach. If you have this approach—I can show you a little bit how our materials is…

LF: just before you move on to something else: when you are talking about how the two layered material adds value to the use cycle, is this something that you have tested against an existing product in the range that had an intimate blend in the fibres?

FB: Yes

LF: So how did you go about testing this?

FB: You are sitting on it, the Climatex Duacycle. We have now been talking for how long? 20min? After 20mins if you sit on a normal polyester seat, you can feel something more or less bad, you can feel humidity more and more. We are able to know are show that have measured that we are able to transport humidity completely away from your body, from the skin surface to the other side where the humidity can then leave from the seat. This a functionality we are strongly selling in the architectural sector, for example in 24/7 chairs, like for call centres, when the people are always sitting, for policemen video-watching and controlling situations in energy station where the people are I their seat hour after hour, they cannot leave the seat for even 15 mins, if you are on the seat only 15mins every hour then it's no problem. So the function we have on top we can show and we can also show for example abrasion values that are incredible, the use time of this

in a 24/7 environment would be 3 to 4 times longer than a normal fabric.

LF: And this is due to the way in which very different materials are assembled or is it intrinsic to the quality of the individual fibres that you are using?

FB: The quality of the fibres that we are using brings us some principle advantages but this is given by the material that has to be recycled. And usually people's understanding or recyclability is that it is low quality. Recycled material or recyclable material [=] lower quality. In our case, we have a fibre, in use, for the upper side of the fabric that brings ten times more abrasion values, it's bringing recyclability on the level of depolymerisation and repolymerisation, not only of thermal processes or of something like this, you leave all the dyes, all the additional product and they will be a short polymer which will be re-assembled to an absolutely identical material, no genetic difference in this material, no loss of quality. This quality of this material also brings a functional addition into the core, but I will show you some examples and you will understand and see how it works. OK?

First of all when I start with an explanation of the product I have this small model here [3D printed colour coded model of the textile lock, see pictures]. When we are calling textile lock, of course when I take it out like this, in the approach of de-assembling this is completely different, but in this way I took it out and I will explain a little bit what we have.

We have a weave in layers and these layers are woven together in the way that you don't have a two layered—a double weave, it's one weave. This line of one part of the material is cutting the other line, both materials are on both sides, this is the key of the functionality. Why? For de-assembling it is not necessary, but if you are combining polyester with a cotton fibre, between the polyester and the cotton is a functionality, there is an interchange. This interchange is happening inside the fabric, not inside the yarn. So we have to check that the fabric has the same interchange functionality between two fibres as we have in a yarn.

LF: So the aim is to have it as combined and close together as possible?

FB: Yes. I can show you why.

LF: It's like trying to reproduce what happens inside a yarn but at the textile construction scale?

FB: Yes. Now this is the reason. If you look like this you see the red part and you see the blue part, the blue part is the synthetic fibre, and the red part is the natural fibre. The mixture of this material and the arrangement of one layer is more on the underneath side and the other is more on the top side, but in the middle of the fabric they will come together, they will interchange. This is a really strong approach for example. Look here I pour a little bit of water on this and you see what happens?

LF: It goes in.

[turns over the fabric and the water mark on the other side is about three times bigger than on the side the water was poured on.]

FB: This is really huge. What has happened in the textile? This transport mechanism is given by the interchange between this layer and this layer. This layer is capillary, the synthetic fibres, and this layer is naturally storing the humidity into the fibre. And if you look to the back side, the humidity now goes wherever it can go.

LF: It’s going back on the capillary side.

FB: Yes, the interchanging is done by the lock. In this position here, where one material is crossing the other material and where the lock is bringing these materials under pressure, there is the interchange between the upper layer and the lower layers. And the layers of the material are crossing. Its not, if you bring a cotton layer onto a polyester fabric, and you do this [?] they have to interchange. And the interchange is given by the textile lock.

LF: By the pressure of the lock. Does the material that the lock is made of have a function of its own?

FB: Yes, it is strongly hydrophilic. So the capillary system in the synthetic fibre is taking the water as a transport system, but the fibre is not storing the humidity. This is absorbing, and this layer is regulating this absorption function. And this gives you a completely different approach to the functionality and how it works to cover a seat. The function of this seat cover comes through the way we are assembling so that we can de-assemble. This approach brings us a completely different view on a product, on the use of the product, and advantage in the product. So I think, if we are talking about recycling systems, if you are talking about de-assembling, you have to add functionality into the product so that the product has more value in the use, not only the aim that the product could be recycled or de-assembled and recycled. Of course, the difference between the fastness of fashion and recyclability or recycling systems is quite far. So here they are producing ten times more ideas than they can deal with in their systems. Of course, this is wrong. But if the understanding is there that you can do this on any kind of fabric, this fabric [his shirt] could be de-assembled if the construction is done the right way. You would understand that it’s quite easy and it’s not a limitation for the design, you can do design. You are adding functionality to the product. And this I think is the key figure to go into the market.

So, this is a plastic model, I’d like to show you… You see now where the humidity is going. And on this side it feels just a little bit cool, it’s not really wet. If you do the same with polyester, then it’s completely wet. The back side of this is this side of the chair.

LF: So looking at the model here, do you describe the lock as a 3 component combination or blend? Because in a sense you have the lock material, but it’s nowhere near passive, it has a function during the use cycle, so it’s not just about combining a natural and a synthetic material?

FB: The lock—any material in the fabric has a special function. It is clear that in the world that we are in today, we miss-price fabrics, it’s more or less a low-cost business, people are driving a Mercedes but buying cheap clothing. So if you put in a material, if you are melting materials together, what function does the melt have? I would say the melt also has something different from assembling and de-assembling. This is the difference between a system like this where we are combining different materials with different functionalities into one fabric and rearranging the different materials in this way so that we have a functionality more different than a normal fabric. You can understand here you don’t see the difference, this is the normal fabric, we have done some extra weaves.

[34:35 presenting different samples, not possible to transcribe, a lot of ‘here’ and ‘this’]

This [one layer of the de-assembled duacycle] is completely recyclable in the chemical cycle, decomposing the polymers. You can see this on the homepage

of econyl, this is the material in the econyl cycle. This [other layer] is natural based and could be composted, it could also be burned without any strange chemicals in the air or something to make energy… but burning is not the way we like. But de-assembling the fabric will bring this: clearly separated layers, clearly separated materials. To open this lock, we are using pressure, water and [?], you have to have about 105°, about 3 minutes, under pressure, in water, the lock is destroyed.

LF: And that is conditions that cannot happen in any normal use situation?

FB: Yes, in these conditions we are dead! This is important because it cannot be destroyed during the use, so the de-assembling process has to be something that is out of the normal use range of the product, but it has to be something that you can find all over the world. What we are finding all over the world is a machine we call a high temperature colourising machine, any textile factory producing polyester can open this. So we don’t have to bring this back to Switzerland. Wherever it is and wherever the quantities are enough we can separate it, we can de-assemble it and bring it back to the recycling point.

LF: but that does require then that you have a label that says what is going to happen. Because if we imagine a crazy scenario in which a roll is bought by someone to dye it, then it would come apart?

FB: Yes

LF: then how do you make sure that people know what is going to happen to this fabric, the potential that it has for recycling.

FB: It is normal in the industry, like the chair industry, we are really close to all of the process and we can be part of these processes. For the end user it’s really complicated. In the chair industry where we are in project and where we are running and selling, it’s much easier because today a chair manufacturer with some reputation, he would have a chair that we can take back and he would implement a take –back system. This is a service and a strong approach to the next selling point. This is something that many haven’t understood before but big companies that are offering take-back, they are sure to be there at the right moment. You can go there a hundred times if you don’t know if they need new chairs, but if they have a take-back request, ten of course they will have some new chairs. And this will mean it’s also your sales point.

It’s a strong approach. This comes back together with the chair to the factory for de-assembly the wood could be de-assembled by cutting—we have an Italian company who is doing it quite differently. They are sewing in a certain way, just one end of the sewing will be fixed .

So the de-assembling process is just something that you have in the construction of chair.

LF: Yes and it’s really linked to thinking about the end of life of the product at the moment of deisigning.

FB: And this in the chair industry is given, in the office chair industry. In the home chair industry, I thinks it’s not given, not yet, not in all cases. With office chairs, where companies interact with companies, it’s much more easy, also because the number of products are in a certain dimension. It’s not only one chair, you have it at home and bring it wherever. They are taking 100 or 200 chairs and they are changing a lot of times these 200. So there are numbers , it makes sense.

In this case, this chair is also tagged by an electronic tracker, so they know how old this chair is, how it is used, where it has stayed during its life Today they have facility management systems where they can say—ok these fifty chairs we took out and we bring them to service, they are changing this, they are changing the foam, they are repairing some defects and then the chairs come back… This is an implemented system today, it is running. We started this in 2012, a normal use is about 12 to 15 years so the first goods that we have to recycle, and de-assemble the good itself and go through the process, that starts in about ten years. But the cut materials, the rest of the materials during production, we do this right now. We send about some tonnes of materials that come out of the fabrication process every year to the econyl process. So this is the starting point. We are into a recycling system that is running, because for a textile company it's not so easy because you are not all the part, we a part of the world but with recycling you have to get to get together with the recycling systems that are everywhere where you are exporting, if not, what can you do? You lose the materials.

So to come back to any of these materials, to understand the cradle to cradle approach in a fabric like this, any material in a fabric is recyclable. We are calling this duacycle because we have one part that is natural materials, the other part is synthetic materials and these are brought together with the lock, and this is the reason why we are calling this duacycle because in the cradle to cradle world, it is technical cycle or it is bio-cycle. We are combining both of them.

We have other products also where we are combining just natural fibres, with dyestuffs they are biodegradable. Also this kind of fabric we are producing for airplanes for example, with a strong approach to fire retardancy.

In an other way of duacycle, the idea to combine and to give the possibility for de-assembling is a completely different approach also. If you have —this exists in the textile world.. if you have materials that are necessary but that are not… lovely, that are problematic, chemically problematic, or really strong material like Kevlar or like these things where you have to wait 300 years until they are consumed by a recycling process. Or problematic materials for flame retardancy reasons we need this flame retardancy: London subway, you cannot have a material that burns. First comes security and under security aspects it could be helpful to have a de-assembling aspect so that you can de-assemble this part from a product that has problems to go into a normal cycle and the other part can go slowly and easily into a recycling path.

LF: that's interesting, that's the way that design for disassembly in electronic products works, it's to allow toxic materials to be put in toxic waste and the rest to be managed.

FB: Yes this is other key figure in the duacycle story. I will show you a product that really has implemented this [puts flame against material] You cannot burn it. This kind of flame ability is given by a product on the back, it's a coating. How could you take away 85% of a normal, good, material, how could you take a coating away from a product. Coated products are a massive problem.

LF: So how do you take them apart?

FB: Duacycle

LF: So you have the same system as…

FB: One layer, you put it into the fabric, you stop it from going on the layer with the textile lock, you open the lock and you have one layer with the problematic materials, the toxic—I use this as an example but it's not toxic, it's a really interesting chemical application, but it's not toxic

LF: so that is actually recyclable

FB: Yes. Now what do we do about this layer. We have many types of flame retardancy where they like to have solutions because it's also something that has a high price. By using these layers, for example in felts, we can give it a second or third life. Not as it is ..

LF: that's really interesting because then you wouldn't go back—for example this would be depolymerised and repolymerised…

FB: 70-80% goes back in the cycle

LF: that is actually reused?

FB: yes. That which is not recycled the normal way, with this system we can divide it, we can deassemble away what we don't like to have inside the cycle, because it's not possible to do it. Today you will burn 100% of it. Of course, no chance, a coated product, you have to burn it. This is about 20% of the material, plus coating, on the left hand side, this could be recycled, it could have a second life it could be something else, but for us that is not recycling.

LF: yes it's down-cycling

FB: But of course you can divide something which is more or less that, from something that is really good, or something very costly from something very cheap, etc., etc., etc.

This is very important also for the next generations of textiles how we could reuse about 70-80% if we have to fulfil some norms, to fulfil something, that you cannot without the coating or something. The normal way is destroying the recyclability or the possibility to de-assemble. With this kind of fabric we can solve this problem.

LF: so in this case it's the same weave as the other one here, you've still got that penetration that goes really deep (FB: yeah) and is that not a problem? Because the aim of the textile lock is to have these materials very tightly combined, so if you coat one side, does that not impact all of the fibres?

FB: no. This is the layer between these two layers, what is stopping is the lock.

LF: ok so it's one the lock?

FB: It's one the lock and the lock is going out from these two layers, if you open it you have not any more now. And the two layers are divided into these two materials, it's the same as this. You see the back of it, it's a little bit different.

LF: so that would be the equivalent of that white part. Okay

FB: It's not a fibre. Here the fibre is that like coating, and here a fibre that doesn't like the coating. SO the coating goes into the layer and stops into this layer, this layer is, in this dimension, doing so as the coating is not penetrating into this layer, it's penetrating into the lock of course, but in the use, the coating is just on the upper side here. In the depth of this layer here, it will stop it on the interchange of the lock into the other layer. And this is the result, so we are able to fulfil flame retardancy norms, for example for drapes, really high demanding in flame retardancy. And this is normally not a given, any kind of coats is a problem.

I will show you this… [leaves the room to get another sample] Many times a fabric is together with a felt or a foam for upholstering processes. Like this. If you open the lock…

LF: then you retrieve

FB: Foam or felt goes on the left side, fabric goes on the right side, you divide also, you can open coatings. So this will mean that the upcycle system could be not only fabric what is given as the upper side. This could be for you in your studies, and interesting idea, that I am thinking long time, not starting today: how we could bring together two things, flexible textiles, combine materials where vapour and humidity can happen… How could I divide it? If you have two materials that you like. Something outside, something inside, today you are coating: finished de-assembling, no way back. If you are interlaying with the duacycle, like a functional textile like a coating system, you can interlay the left of the duacycle fabric to one material, the right to the other material, you open the lock, and you get two layers.

LF: So you use the duacycle as the lock.

FB: yes, you can combine different materials by using duacycle as the lock system, this is a completely new thing, because today, we are in the fabric, the lock is in the fabric, we have the fabric, the down side, the functionality of both together. If I think about layers in clothing, or systems like this, then duacycle could be the intermedient between outside and inside, it could be the intermedient for the de-assembly. And this is a really simple weave, it costs nothing, you just have to look that this material is compatible and you can bring together these materials on both sides, and duacycle is the intermedient and you combine in one.

LF: and you would have to… the material let's say, you wouldn't need it to be all over the fabric, so you could have like zones, you don't need the material everywhere.

FB: you don't need it in all the places, you can do this here, or here, or where it has to be closed. In other areas it's not really nice to be closed, because you have the interchange, you like the air, so it could be

LF: that's a very interesting way of looking at it. So in this kind of sample, the bit that's white here — so in the original duacycle the blue bit here is a synthetic material, the white bit is a natural material, and here, I'm assuming the white bit is the same as this, it's compatible with the felt

FB: the felt and this has to be recycled. And this is the idea that I want to give you, if you are searching — if I see this interlaying systems and how to open it, it could be a solution where you have the left where you are connecting your fabric A, this is the same material, and you have a materiality B, the same materiality, you bring it together, by coating, by any exisiting king of… the coating could also be polyester or a polyamide, or whatever, you are just looking at how to do.

LF: very interesting

FB: I was thinking about this: how, in cars door panels, the roof, how these things, how to open these? It could be a really simple weave in the duacycle technology that could give this functionality, because we need a felt or a foam, it's given by function, it doesn't work without because the systems are done like this, how can we bring these things together for de-assembly later. So this could be an idea.

LF: the whole textile lock innovation, how did that come out of the earth, was it

like team work? It sounds like it came from an engineering and life cycle perspective, but what's your story?

FB: the story is what I said at the beginning: Michael tells me, if you take a horse and a donkey, you get a mule. This is the story that got me thinking and the idea I had in my head, and I knew from experience that we have materials that we can destroy in other processes. And then I have started to research myself, I'm the inventor of the idea, but of course if you have the idea, you need the team. I get a really strong person in design, I get a really strong person in the fabric construction CAD etc. etc. together with me in the team, Roberto Mayone, years ago [other name inaudible] then we start to do primary trials, and you will see about three meters of papers where we start with primary trials: how to combine and how to bring these thing together, what is possible, how these layers are to be arranged on the machine and all these things. Of course we used about one and a half years of just invention time to decide, this is the right way to do it. And at the same time, I start with the patent lawyer and he begins to write down all these things, and you have to be careful, you cannot go out and show to any person what you are doing and "is this something nice" or "what are you thinking about this?". Close close close, two yeas just invention and write down the patents and then start. Yeah it is a team work of course. The product it is not possible to do it alone in a whole range of textiles, but the invention was an idea!

I know you collaborated with Ina from circular fashion. How did that happen because it's quite a step

FB: Yeah we supported this just for the reason that the fashion industry is not really something sophisticated… Of course you can use materials that are in one cycle, or course there are systems implemented for recycling, but in the cradle to cradle area, there are no manufactures. So we decided to give them some of our fabrics because they are in an initial phase. They can also use fabrics, lighter fabrics of the upholstery of the interior part we are producing. The background of this is not only to support young people, this is one of the stronger approaches, to support young people to transform, to go further with recycling systems with the cradle to cradle idea. This is one point. The other point is, we are sure that the day will come, that we, or we together with companies will be doing clothing. Because in the clothing industry, in most cases, you can use this technology. And what I said before, assembling zones… You live textiles, you are textiles.

LF: yes what you showed me with the capillarity of the material made so much sense for and outer garment. In furnishing it's already in contact with the body, in garments it's just a little bit more in contact

FB: but we are sure that the day will come when we are working with the fashion industry. Of course if you look at the movements for jeans, cotton recycling all these things, all very nice. But think about de-assembling the construct of clothing: pfff! I could open… [shows the complexity of his shirt as not possible to take apart] This technology is key to bringing it in the right condition to take back what you would like to take. Just picking. And of course we can open sewing lines with the same technology.

LF: Yes and different technologies can also be assemble in this sense [talks about resortecs] all these different things combine

FB: yes, what do you think about stopping the interview and eating something?

11.3. Papers

11.3.1. Towards a Design-Led Understanding of Blends for Recyclability

TOWARDS A DESIGN-LED UNDERSTANDING OF BLENDS FOR RECYCLABILITY

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Keywords

Blends, circular design, recyclability, textile design, information visualisation

Abstract

The concept of the circular economy emphasises the value of waste textiles as part of the resource pool to draw from in future creation, however in the case of materials blended from resources which belong in separate recycling systems, this recovery is made economically and environmentally unsustainable. This research project aims at providing design-led solutions to this issue, moving away from the prevalent approach of mono-materiality, through the implementation of design for disassembly principles within blended textiles.
This paper focuses on the intermediary stage of the research, questioning the current classification of materials for recycling, using Gulich's ranking of material types in 'Designing textile products that are easy to recycle' (2006), and laying out a classification of blends suitable to inform design briefs for design for disassembly. The methods to achieve this understanding include the 'translation' (Baule and Caratti, 2016) of technical information into visual mappings and the making of explanatory samples. Through this approach the varying levels of complexity of different types of blends are revealed.
Design's approach to environmental issues as a creative challenge has an important role to play in providing models for textiles in the circular economy, however this may be impeded by an incomplete understanding of the existing situation. Indeed, the structures of blends and corresponding end-of life scenarios for material recovery and recyclability are often invisible to the designer. Highlighting the gap in the information that is available for designers to take the issue of blends into their own hands and design waste out of the system, this paper proposes design methods that can make this information visible to inform the creation of materials whose resources can be easily recovered for a circular economy.

1. **Introduction**

The global environmental issues that we currently face are calling for new models in various fields. Approximately 25% of the environmental impact of European goods consumption is due to the production and end-of-life treatment of materials (Coopérative Mu, 2014). One of the main issues affecting this end of-of-life processing in the field of textiles, is the existence of blends combining two or more resources that cannot be recycled together in an environmentally or economically

sustainable way. Whether their aim is to provide aesthetic pleasure or functional performance, this approach to material design condemns quantities of materials to landfill (RSA, 2015).
The role of the designer in the creation of the landscape of materials that surround us has been argued as important to the creation of materials that consider the user's experience as well as the functional requirements of the product (Van Bezooyen, 2014). The designer's role is however more complex than simply catering to client and user requirements. In the development of more sustainable production processes and consumption habits he must rather act as a systems designer (Manzini, 2008). In this sense, the designer's responsibility must be extended to the inclusion of recyclability issues from the very first stages of the design process. Indeed, design is held accountable for up to 80% of the environmental impact of the final product (Graedel and Allenby, 1995). To make this possible however, designers across all fields must be given the tools to allow an understanding of these issues that may lead to potential solutions to the recycling barriers imposed by blends.

However, literature in this field, demonstrating the impacts on recyclability and potential solutions for blends in the circular economy, is scarce. Indeed, textile design relies heavily on tacit knowledge (Igoe, 2010) which is expressed on a case-by-case basis and is not easily generalised. The approach to examining the existing situation regarding blends in various types of projects has generally been to analyse available samples. For example, the H2020 funded Trash2Cash project examined a sample of approximately one ton of post-consumer textile waste in order to assess the potential of sortation technology (Wedin et al., 2017). Similarly, different groups such as Circle Economy or Worn Again have carried out trials to assess to composition of similar samples. While these methods can provide valuable information that is directly relevant to the project at hand, the complexity and vastness of the textile industry dwarfs the quantities of garments that it is possible to analyse and makes such results non-representative of the industry at large. Indeed, within the Trash2Cash study, 90 different types of materials (14 mono-materials and 76 blends) were found (Wedin et al., 2017). This complexity is one of the elements which prevents a global overview and understanding of the situation from being provided to stakeholders in the field. In the absence of a large-scale study of blends and recyclability which could provide guidelines to designers, this approach to understanding materials aims to provide a framework for a case by case understanding of blends in the circular economy.

This paper first assesses the context of the circular economy and the position of blends in this area. The literature addressing this topic is then briefly reviewed to point at the scarcity of data in this field. The methods section focuses on the design-led approach of this study and the way in which it can provide tools for the development of solutions to recyclability issues in blends. The outcomes of the use of these methods are then presented in section 4 and 5, relating respectively to the translation of existing classifications to a design-led approach and to the opportunities of making in understanding blends. These results are then discussed in section 6 and followed by concluding remarks.

2. **Context**

2.1. **The circular economy**

The circular economy has been set as the goal to achieve for re-imagining the world that surrounds us in a way that prevents resource depletion and other negative impacts of industry

on the environment. The global implementation of such a system would allow to move away from a 'take, make, waste' system towards a restorative one which allows for resource preservation (Ellen McArthur Foundation, 2015). In the circular economy model, materials could be used in perpetuity through re-integration in the technosphere or the biosphere (McDonough and Braungart, 2002). Indeed, synthetic mono-materials such as polyester or some polyamides now have corresponding technologies that allow for total regeneration through depolymerisation, mimicking the process of biodegradation and re-growth of natural fibres in nature (Ostlund et al., 2015).
To comply with the requirements for a circular economy, products and materials must be designed with their entire life cycle, and particularly end-of-life, in mind (Bakker et al., 2014). By bearing these requirements in mind from the outset of the design projects, the creation of barriers to subsequent recycling processes can be avoided and the materials' capacity to be recovered and recycled can be preserved.

2.2. Blended textiles

Materials combining different fibres, such as a flax warp and a cotton weft, can be traced back as far as 150 B.C. Blends continued to be used through to the 18th and 19th centuries, mainly as a way of reducing costs through the combination of a cheap yarn with a more luxurious one (Hatch, 1993). With the development of synthetic fibres, this drive to decrease costs and increase performance, led to the combination of natural and synthetic fibres. With a large variety of available fibres, blends are used for many different outcomes concerning performance, aesthetics, or a combination of both. Blends are defined as the combination of two or more different fibres in the same yarn or cloth with the fibres differing in colour or fibre type (Hardingham, 1978). This broad definition is detailed by Hatch (1993) by classifying these blends into three types according to the level of intimacy of the blend. The first type is intimate blends, combining different fibres spun together within the same yarn. Next comes combination yarn, made of several different strands of mono-materials spun together into one yarn. The last type is mixture materials, combining different yarns within the textile structure, such as in a plain weave in which the warp and the weft are different or in the case of stripes in a jersey knit. Of course, these categories are porous and a mixture material may be made of a combination of intimate blend yarns and of mono-material yarns for example. These categories do not either take into account the possibility of combined fabric elements into a design, such as is the case in some types of quilting or laminating for example.

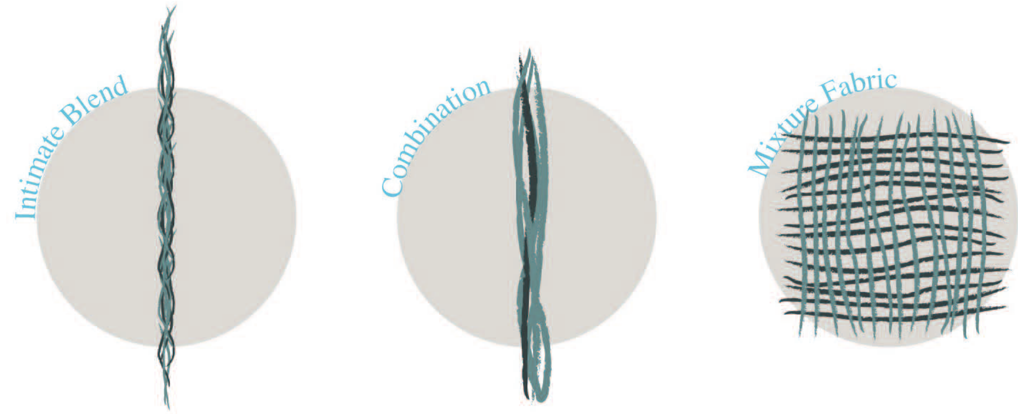

Figure 1. Types of blends, adapted from Hatch (1993). Source: author

2.3. Blends and recyclability

While partly revealing different layers to the complexity in textile blends, this definition does not however highlight the consequences to recyclability or situate blends in the context of the circular economy. As the emphasis here is on the role and place of blends within the circular economy, a new definition that allows for their consideration in this context is therefore needed. This study is part of a larger project which aims at exploring the potential of design for disassembly strategies for blended textiles in the circular economy. The phase referred to in this paper contributes to 'framing the problem' (Cross, 2011) and providing an understanding of the existing situation which may lead to an informed design brief.
The perpetual reuse of resources prescribed by the Cradle to Cradle model requires that materials fit within the distinct cycles of biologic materials or technical materials without contamination of one by the other (McDonough and Braungart, 2002) . Within this context, blends that impede recyclability can then be identified as materials combining resources from the two afore mentioned cycles in a way that prevents either from being extracted for recycling.
In *Recycling in Textiles*, Gulich (2006) describes the various degrees of ease of recycling in materials. This classification separates materials into 5 categories according to the complexity of their composition and how this may affect the potential for recovery of the resources. These range from 'multi-material composite systems with permanent connections', the most difficult type of material to recycle, to 'single-material systems', the easiest to recycle. One of the most interesting aspects of this ranking regarding this study, is that it does not rule out entirely the categories that are harder to recycle. Instead Gulich's point of view acknowledges the trade-off between simplification for recyclability and functional performance. In the case of simpler mono-materials, allowing for easier recycling, some of the functional aspects allowed by the combination of different resources are lost. Thus, diversity and complexity are maintained, providing an interesting starting point for the explorations of these issues.
From the point of view of the textile designer however, this classification seems very abstract and while it provides broad categories, it does not describe the materials within them. This study therefore aims at complementing Gulich's work by providing an interpretation of this information that draws on textile design-based experiences of materials.

3. Methods

3.1. Design-led approach

The creation of blends can be seen as the essence of textile design; the designer's creativity is expressed through the combination of materials for colour or texture effects. This complexity, while still posing problems for the integration of textiles in a circular materials system, is nevertheless a feature which seems important to the field and deserves to be maintained (Fletcher, 2008).

It is a common saying in design that constraint breeds creativity. The case of designing blends for resource recovery is particularly illustrative of this approach. Indeed, as assembly techniques are conventionally geared towards blending and mixing in permanent ways, designers may seize this opportunity to question the status quo and prove that alternatives exist or can yet be developed. The tight limits set by recyclability criteria should therefore be seen not as barriers but as opportunities for creative challenges. Furthermore, as argued by Ehrenfeld (2008), design has the power to script new behaviours that may lead to positive, sustainable consumption and use patterns. This may be implemented through designing the tools for these new behaviours. This study therefore aims to provide an understanding of blends that can act as a creative impulse in developing solution in this field.

3.2. Full cycle approach

The material designer's field of action is generally concentrated in the pre-product phase. The interactions with the materials or various resources are then under the form of yarn or finished fabric. The designer's comprehension therefore lies with things that can be seen, touched, that have a weight and a colour. The description of the issues related to blends and recyclability thus need to address this scale of textiles. What's more, the full material life cycle must be taken into account, rather than limiting design to planning up to the point of sale (Ryan, 2013). For designers to address the issues of recyclability from the outset, the challenges of end-of-life must be made visible and understandable (RSA, 2015). Indeed, from the very first stages, design thinking should be considering the systems of collecting, sorting, deconstruction and regeneration that the material is likely to undergo as well as the use phase. This aspect of textile design brings to light not only the need for a more universal vocabulary surrounding these stages, but also for a shift in the perception of materials and a need to allow technical issues to become visible and associate design qualities with them.

3.3. Translation

To allow for designers to develop potential solutions to recyclability issues and eliminate the barriers to efficient material recovery from the very beginning of the process, the information must be made readily available. Current approaches to these matters concern primarily the fields of engineering which are difficult to access for designers. Indeed the information provided from this angle lacks a visual approach, an important part of the design thought process (Earley and Hornbuckle, 2017). This study therefore aims at offering a 'translation' as understood by Baule and Caratti (2016). In their introduction to the 2016 Design Research Society symposium, they describe the designer's capacity to perform 'transformative design activit[ies]' in order to not only generate new concepts but also define the tools to do so (p.201). It is this angle of the design process that this study aims to harness in order to generate an understanding of blends that may help in developing solutions for the circular economy.

This is attempted firstly through the interpretation of Gulich's classification from a materials-driven angle, and partly through the confrontation to the materiality of the structures of blends from the making of models of textile blend archetypes and their subsequent classification.

4. Classifications

4.1. Gulich's hierarchy

As a designer, one of the first stages of this review was to visualise the types of textiles described in Gulich's classification, reversing the author's work of conceptualising materials back to a grounded experience of materials and blends. Using cotton, flax and polyester as examples of fibre types that could represent the different categories allows to bring them closer to tangible materials that a designer would use regularly. However, these examples are only one possible option amongst many types of blends from different fibre types that may enter any of these categories.

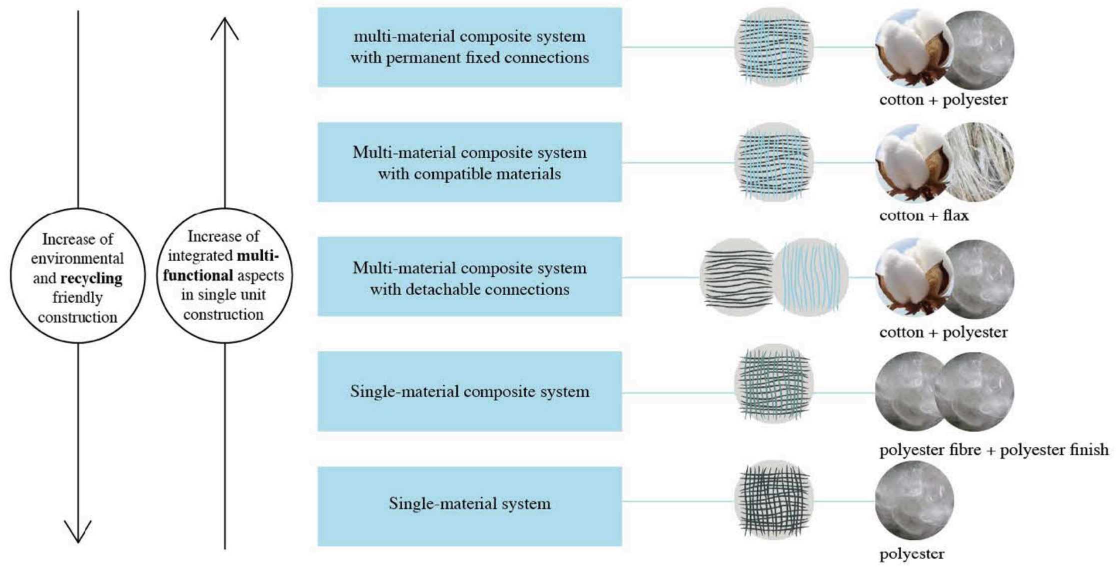

Figure 3. Ease of recycling in materials, adapted from Gulich (2006). Source: author

While Gulich's original representation of recycling-friendly constructions takes the shape of a pyramid diagram with the 'multi-material composite systems with permanent fixed connection' category at the narrow top of the diagram, representing the fewer possibilities for recycling, this representation focuses more on the interpretation and understanding of each individual category. Following Tufte's (2006) approach to information visualisation, the emphasis is put on the information relevant to a textile design approach and other parameters are filtered out to allow for better comprehension. By rearranging information in a way that suits the context of blend recyclability, the selection of relevant information allows to analyse the context for future design concept developments.

This return to the materiality of textiles also highlights the prevalence of certain types of materials described in everyday interactions with materials. When describing these materials through examples, one sees that the category of blends that is the most ubiquitous in today's textile production (cotton/polyester) is in fact also the type that hinders recyclability the most. While mono-materials such as 100% polyester garments or even composite systems with compatible materials such as linen/cotton blends may be found in conventional garments, the use of materials made of multi-material composite systems with detachable connections is a lot less common. However, the top section of the visualisation seems the most common and wide spread. Multi-material composite systems with permanent connections can be found in clothing in a variety of materials such as cotton/elastane, viscose/polyamide, or cotton/polyester blends, to mention only a few. As one focuses on this category, the various levels of complexity within it start to appear.

4.2. Adding granularity to blend categories

Based on Gulich's analysis of the levels of blends between different types of materials, this paper aims at pursuing this classification further and to question the complexity within the main category represented by multi-material composites. While these materials are described by Gulich as blends with permanent connections, they are not characterised according to the nature or the scale of these connections.

When experiencing materials through the activity of textile design, the various levels of textile construction become apparent. In the choice of yarn, of weave or knit, or through the finishes applied to the fabric and even into the premises of the development of a product, the complexity and intimacy of the blends increases at every stage.

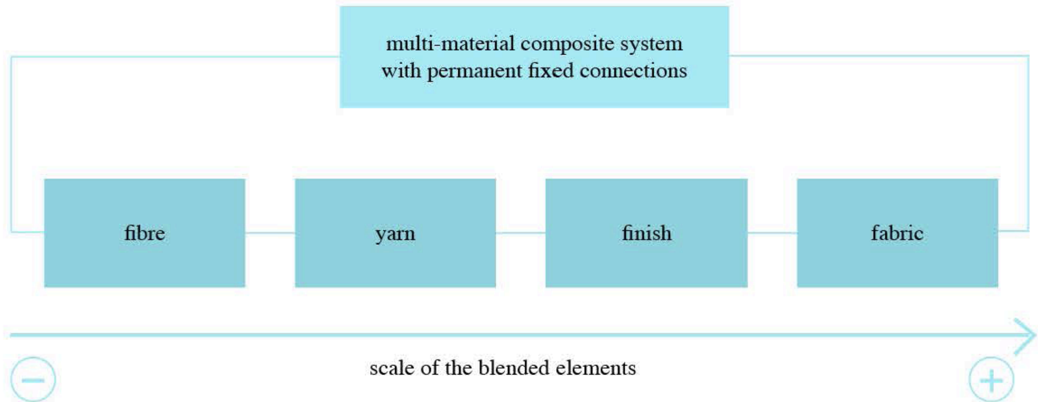

Figure 4. Zoom in on Gulich's classification. Source: author

This expansion on Gulich's classification of types of blends looks further into the nature of the connections between different materials. It allows to consider the different elements that the designer may be manipulating while creating new textiles. In the same way that Gulich's categories challenge recycling to varying degrees, these scales may also imply different paths to recovery of the raw materials. Hence a better understanding of these differences seems necessary to developing the ways in which the various elements may eventually be recovered.

5. Understanding through making

5.1. Textile archetypes

Following a design research methodology (Cross, 2011) this project uses iterative hands-on making processes both as a way to gain an understanding of the issues at stake but also as a means of communicating these findings.

By drastically enlarging the scale of the materials, yarn that would in the original textiles represented, be but a fraction of a millimetre in diameter is now shown as a seven-millimetre diameter cord. This blown-up vision of textile structures allows to visualise and understand how yarns are linked, highlighting the connections between fibres, yarns, finishes and fabric. The simplified schematic representation of the blends also allows to focus only on the issues at hand. Colour and structure are entirely aimed at clarifying the understanding of blends. The binary colour code allows for an abstract visualisation on which different types of resources can be projected. This selective interpretation is led by the focus on problematic blends in recycling. As this study is guided by a questioning of the role of the designer, rather than drawing from science-based or quantitative data, the samples are drawn from experience of different archetypes of textile construction as a textile designer.

Figure 5. Types of blends

The act of making is also highly important to this process. Through assembling the models, the connections between different elements become more evident. The difficulty in the act of making also leads to reflecting on the potential difficulty of un-making which is the focus of the overarching research. As defined by Cross in Designerly Ways of Knowing (2007), this process is a way of "framing the problem". This approach to problem solving provides a way of defining the problem and breaking it up into smaller issues that give a more complete comprehension of the matter in question. Following Cross' definition, the problem concerning the recyclability of blends could be described as an "ill-defined" problem, which therefore needs to be explored and re-defined to lead the way towards possible alternatives.

This re-framing of the issue at hand allows for a deeper understanding of the different levels of complexity in blends. For instance, this simplified representation considers a dual approach to blends, in which only two materials make up the archetypal fabrics. However, this is rarely the case in the reality of materials as these are often made of a combination of several resources in varying proportions. This leads to question the relevance of these variables in the context set by recyclability of blends.

5.2. <u>Hierarchy of blends</u>

The use of material elements such as yarn in colour a or b, of the mixed yarn used to represent intimate blend yarn or of the foam used to represent mono-material fabric in larger scale assembling techniques such as stich or lamination allows to make the distinction between these types of blends more clear as well as informing a classification which highlights the interconnectedness of these types of blends.

Through mapping of the relationships and crossovers between the different levels of intimacy in the blend and the different types of connections, the creation of samples to visualise these elements allows to develop a new classification, closer to the requirements of a design-led understanding of recyclability for blends.

The relationships between blends described through the classification of the samples highlights the different levels at which the combination of resources may occur, therefore requiring different approaches in the exploration of solutions. Indeed, the level of intimacy of the blends may be seen as expressing different characteristics expected in blends. While some blends such as stripes in knits may be pattern-lead and focussed on the aesthetic qualities of materials, other more intimate blends such as yarn with a technical core material may have a more function-focussed approach. What's more the different levels in the classification highlight the number of hypothetical stages necessary before returning to a mono-material. As this return from a blend back to a mono-material for ease of recycling at the end-of-life is the main aim of the overarching project, this classification may lead to strategies for esign for disassembly.

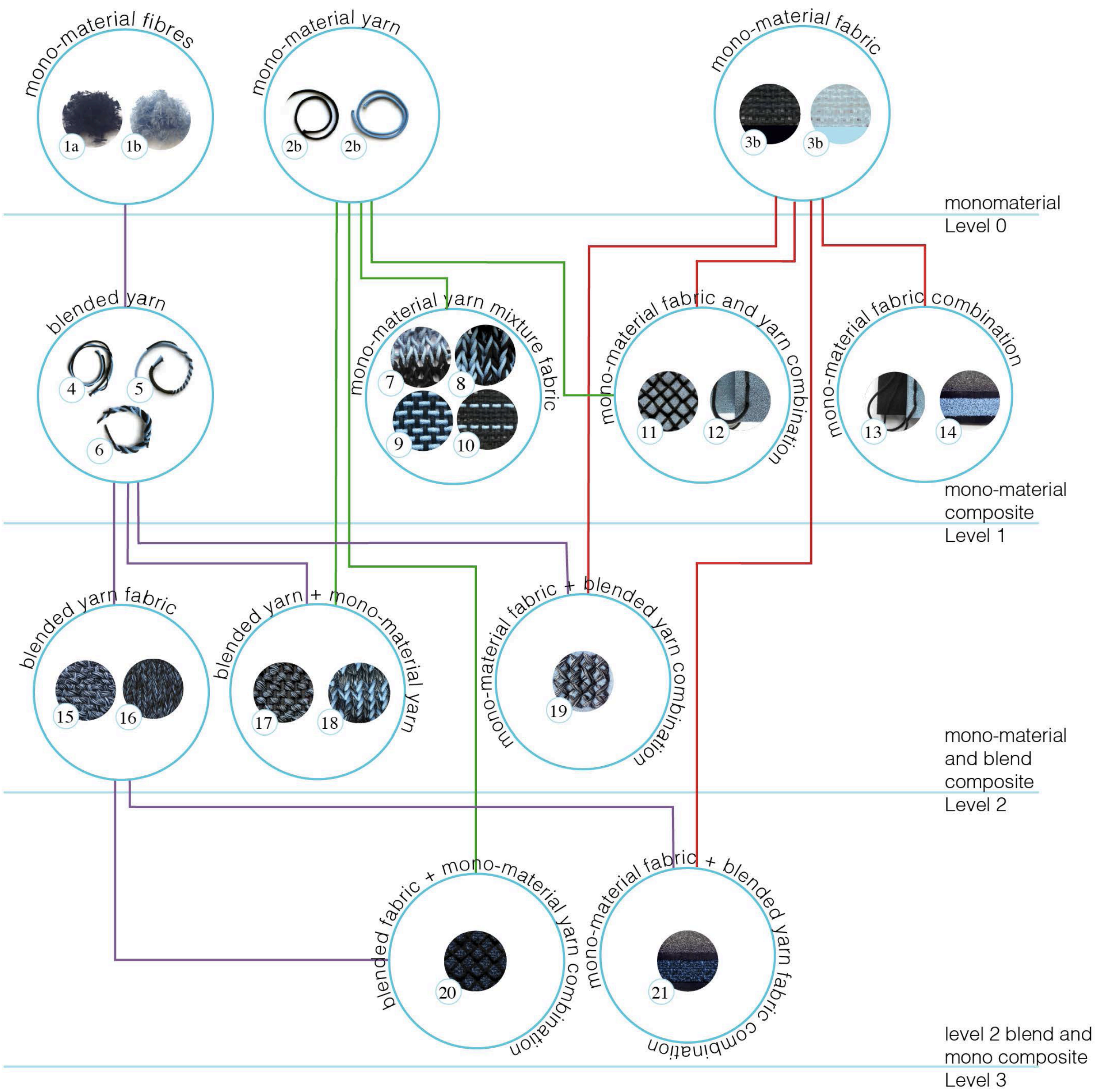

Figure 6. Mapping types of blends

6. Discussion

This expansion on Gulich's work focuses on the category which is classified as the most difficult to recycle and provides details as to the different ways in which the recovery of the various mono-material elements is impeded. This approach to the complexity of the typologies of existing blends follows the intention to provide a framework for the analysis of blends regarding recyclability which can help in overcoming the difficulties encountered in assessing the existing context expressed by unrepresentative samples. In this sense, a design-led understanding of the implications of blended textile structures can be transferred for a case-by-case application to design projects.

While Gulich's work suggests a recycling system modelled on the re-melting of synthetic polymers for example, many different technologies have been developed and improved since the publication of Recycling in Textiles. For instance, the Fibersort process, leading to high value textile to textile recycling based on automated infrared optical sorting processes, allows to sort and therefore recycle some types of blends in an effective way. This adds yet more complexity to the paths towards recyclability that may be adapted to different types of blends. What's more, since 2015, Worn Again, with the support of H&M and Kering, has been developing a type of chemical recycling which would allow to separate polyester from cellulosic fibres in an intimate blend. These developments shed a new light on Gulich's work and stress the importance of designing products and systems which allow materials to reach these recycling processes and meet their specific standards.

Matching recycling processes to the different scales of blended elements may also be seen as a way of innovating in this area by, for example, drawing attention to yarn as an element to retrieve. These ways of retrieving the value of materials along with the raw resource are not yet developed, principally, one may assume, based on the small scale, crafts-based aspect of these techniques. However, this points at the opportunities revealed through a hands-on approach to understanding a problem.

Raising awareness concerning the ways in which barriers to recyclability occur in blends can provide valuable drivers towards a proactive approach to circular design. Rather than addressing end-of-pipe issues and reacting to the waste that the industry generates, this approach provides a vision that suggests re-designing the products and materials that are part of the circular economy in ways that eliminate hurdles from the outset.

7. Concluding remarks

Some limitations regarding the simplification of the information occur, mainly from the choice of a binary code for representation, using either blue or black to represent materials from opposing cycles. This mode of representation therefore fails to show examples in which there are more than two different fibre types and in which the proportions may vary widely. However, this simplification allows to project any fibre type into the set model, providing a tool for the understanding of blends in this context. What's more, it allows to define categories which add a deeper layer of understanding to the current approach offered in Gulich's classification. This is seen as the main contribution to knowledge of this phase of the work. Indeed, this classification allows for an adaptable model for analysing blend construction in regards to potential recyclability. This tool is used as part of this research project in guiding potential solutions for design for disassembly for textiles in the circular economy, but can also be a base for other approaches to blended materials life-cycles. Indeed this approach to describing blends allows for designers to appropriate the technical aspects of blends which impede recyclability and apply this new understanding to the creative process. In the work regarding design for disassembly, this information feeds into a process similar to reverse-engineering, where the structures are reimagined from the perspective of their ability to be taken apart at the end of their useful life.

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11.3.2. Teardown and Redesign: Dis- and Re-Assembling Textile Blends in the Circular Economy

Teardown and Redesign: dis- and re-assembling textile blends in the circular economy

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Abstract

Purpose: exploring the potential of DfD to enhance recyclability in blended textiles

Design/methodology/approach: using the creation of blend models as a tool for understanding, followed by free-flowing textile sampling in a redesign process, a thorough understanding of material combinations is distilled into creative textile design practice and leads to experimenting with new ways of constructing textile blends so that they may still be disassembled for recycling at the end-of-life.

Findings: validation of the use of DfD within the material itself as conducive to ease of recycling but also in adding functionality or extending the use cycle of products facilitated through the retention of blends

Research limitations/implications: a certain level of abstraction has been maintained in the sampling which, while it allows for the samples to serve as models for other practices, also removes them from the reality of recycling systems and the resources that they can take in.

Practical implications: these models offer new ways of thinking about material combinations at the textile level and the design-focused perspective allows for the inclusion of these within a creative textile design practice which can be artisanal or industry-driven.

Originality/value: the paper presents the creative textile designer as a potential driver for sustainable innovation which rather than suggesting end-of-pipe fixes, proposes to design waste out of the system from the outset.

Keywords
Textile Design, Blends, Design for Disassembly, Circular Economy, Redesign, Recycling, Making

Article Classification
Research paper

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Introduction

The 2018 Design Research Society conference was held under the theme 'Design as a Catalyst for Change', placing designers at the spearhead of much needed sustainable innovation. Indeed, a design-led approach to sustainability challenges provides opportunities for radical change in polluting industries, suggesting new products and systems that go beyond a localised fix and reassess the need that these fulfil in the first place. As early as 1960, the designer has been pointed at as enabling futures which require ever increasing consumption (Packard, 1960), this power now needs to be harnessed toward sustainable change in modes of production and consumption. Victor Papanek (1985) goes on to describe how the skills of designers are particularly appropriate in solving problems created by design itself.

Multiple initiatives have therefore suggested approaches which give designers the keys to understanding and addressing these issues. These recommend taking a systems-focused approach, opening-up the designer's perspective to the wider framework involved in any product (Thackara, 2006; Okala, 2014). In the highly polluting and resource wasteful textile industry, this systemic approach needs to be applied to all the phases of the life cycle to allow for materials to be regenerated in safe and efficient ways.
Considering the rising awareness regarding the damage caused to the environment by unsustainable practices in the fashion textiles industry, a general overhaul in production and consumption habits is needed. In the current take-make-waste model, as clothing production has doubled over the past fifteen years, reaching an excess of 100 billion units in 2015, only 0.1% of the materials going into textile production are recovered for regeneration or high value recycling after use, mainly ending up in landfill or incineration (Ellen MacArthur Foundation, 2017). Beyond the systemic barriers to textile collection and recycling, the intrinsic qualities of the materials make them very hard to recycle. Blends of resources that cannot be recycled together are the main barrier to a circular economy for textiles that this research aims to address.

Traci Bahmra describes the redesign process as consisting of two phases. The first one aims to an in-depth understanding of the issues that the original product represents in terms of environmental impacts and functionality in order to pinpoint where meaningful changes may be implemented. In the second phase, the most crucial elements are tinkered with to achieve an optimal review of the original product which provides an efficient balance between functionality and environmental benefits (Bahmra, 2013). Here, practice is used to reach an understanding of existing blends which is then applied to a redesign process for material combinations, experimenting with new textile construction techniques which allow for separation and effective recycling at the end of life.
This paper starts with a study of the context in which unrecyclable blends exist, looking at how they prevent effective recycling, the designer's role in their production and how alternative systems and models such as the circular economy and design for disassembly may provide useful leads. It then goes on to analysing the redesign process as a potential method for devising new approaches to blends which do not hinder recyclability. In the third section, free-flowing making and the samples that come from this approach are assessed as to their potential to present design for disassembly in textiles and to trace thought processes in the making. These are finally discussed against their potential for innovation in the circular economy.

1. Blends in the Circular Economy

1.1 Barriers to Textile Recycling

It is generally accepted that textile blends are a hindrance to effective recovery and recycling of the resources they are made of. This is due to the reduced profitability of more complex recycling processes, as well as to the unsuitability of some types of blends for secondary markets (Cupit, 1996). Indeed, to achieve acceptable levels of quality for the input, this must first be separated, whether this is through manual sorting of colour or fibre types, or in a chemical dissolution process. While recycling technology is constantly improving, the solutions which allow for highest grades of value conservation thus mainly concern simple or mono-material textiles and garments. However, an overwhelming majority of our textiles are made from a combination of two or more resources that do not belong in the same recycling system (Wedin et al., 2017), preventing either from being recovered and regenerated. This study therefore looks at ways of re-evaluating the way in which blended materials are designed so that the materials that constitute them may be economically and environmentally sustainably recovered at the end of life.

In this study, blends are described as the combination of two or more different fibres in the same yarn or cloth (Hardingham, 1978). The emphasis is particularly placed on the notion that the various fibres combined cannot effectively be recycled in the same process without impacting the quality of the outputs.

There are many reasons for combining fibres, but these can roughly be grouped under the following headings (Hatch, 1993):

- To compensate for weak performance in one of the parts of the blend and improve the overall performance of the output
- To improve the efficiency of processing
- To reduce costs
- To improve or provide different aesthetics

Different material types and applications involve an immense variety of fibre combinations. These can range across various assembly techniques available in knit, weave, or other textile manipulations, adding another layer to the complexity of blends.

1.2 Blends and Creativity

Beyond the output-focused approach to blends, this study also takes on the designer's perspective and argues for the making of a blend as a creative act. This research proposes that, as described by Arthur Koestler (1989), "*the creative act consists in combining previously unrelated structures so that you get more out of the emergent whole than you put in*". This '*bissociative*', or combination, process as coined by Koestler, is indeed present in textile design creativity through the playful and creative combination and juxtaposition of materials, colours and textures.

As described by Hirshberg (1998) and further developed by Moxey and Studd (2000) regarding the creative process in textiles specifically, '*unprecedented thinking'* involves the connection between apparently disconnected or conflicting elements. Hirshberg goes on to describe the particular feeling experienced by the designer when ideas emerge in this process. This 'sense of lift' is one of the joys of designing and an essential component of this approach. This study therefore looks at ways of maintaining this degree of creativity without involving the permanent combination of incompatible materials. Existing approaches have used mono-materiality as a strategy for ease of recycling such as with Puma's collection of garments made either of 100% polyester or of biodegradable cotton (Puma, 2013). Furthermore, Kate Goldsworthy's research has shown how process innovation allows for extensive creativity in mono-material finishes with laser treatments on polyester. Exploring new approaches to blend recyclability, this research focuses primarily on material construction techniques to circumvent this limitation and maintain the benefits of material combinations while allowing for recyclability.

The approach to textile design used throughout this project uses the constraints of recyclability as a creative impulse. Indeed, it is when the conventional ways of designing materials seem closed off, due to the environmental damage that they cause, that problem solving approaches can be intermingled with aesthetic creativity to produce original outcomes. Dormer (1997) uses metaphors to dance or jazz to highlight how the presence of rules in a field, in his case weaving, can encourage innovation. Indeed, the rules of the circular economy embodied through the two separate cycles for resource reuse provides the frame within which core innovation may take place. Design for disassembly can therefore be used to combine high levels of creativity with compliance to recycling constraints. The positive constraints of designing for the circular economy are described by Tim Brown (Ellen MacArthur Foundation+IDEO, 2016) as providing a 'sense of meaning' in being able to design in a way that not only does not damage the environment but can be carried out perpetually in a regenerative way.

1.3 The designer's Responsibility in the Circular Economy Model

The circular economy has been presented as a framework for decoupling economic growth from resource consumption and pollution. Its main requirements concern the diversion of waste from landfill or incineration and its perpetual reuse as a resource. Following the Cradle-to-Cradle model (McDonough and Braungart, 2002) this relies on the compliance with the specifications of two separate cycles: on the one hand the biological cycle which comprises of materials which can be safely composted at their end-of-use, and on the other, the technical cycle, in which materials that can be regenerated in industrial processes circulate. Any contamination of one cycle by the other leads to the impossibility of economically and environmentally sustainably recycling the resources. Designers must therefore take into account the nature of the materials they use and the type of recycling systems they belong to from the very first stages of the design process.

As described by Fuad-Luke (2009) it is one of the designer's characteristics to be comfortable with dealing with both 'things' and 'systems', this allows to incorporate end of life thinking from the very beginning of the design process to avoid any hindrance to recycling. This holistic view is key to developing sustainable design practices (RSA, 2016) and eventually eradicating the concept of waste to be left only with nutrients for the next lifecycle. With the notion that 80% of a product's environmental impact is defined at the design stage (Graedel and Allenby, 1995), the designer is given a significant responsibility in reshaping the industry. However, this is not limited to the mitigation of environmental harm, in this approach to design-led sustainable innovation, challenges can be seen as business opportunities, leading to innovation, opening up new markets, and enhanced competitiveness (Stahel, 2006).

1.4 Design for Disassembly

To allow for multi-material creativity in textiles while not impeding the capacity for material recovery, the approach the project explores here is *Design for Disassembly* (DfD). DfD is defined as the creation of materials or products that can be easily and economically taken apart at the end of their useful life (Fletcher, 2008; Manzini; 2008; ISO, 2016) allowing for re-use in appropriate cycles. DfD has mainly been developed in product design as a response to Extended Producer Responsibility (EPR) regulation (Lindhqvist and Lidgren, 1990). As designers and manufacturers are required to think beyond the end-of-life of products, a systems-thinking approach to design involving DfD will become necessary (Ellen MacArthur Foundation, 2013).

This technical approach to DfD in products was mainly developed in Chiodo's work on active disassembly using smart materials (2012) and Ziout's approach to disassembly for sustainable product recovery (2014). Using shape memory, or other smart materials, this engineering approach to DfD follows EPR guidelines, allowing for efficient recovery of valuable technical components from complex objects. Active disassembly is offered as a model for cost-effective disassembly of technical products made of many different elements. This allows for sorting into same material categories and maximal value recovery at the end of the product's life. This can be achieved using technologies such as biodegradable layers, thermally-reversible adhesives or shape memory materials. While this approach is different from the more intuitive and craft-design led position of this research, it provides many insights into DfD systems and inspiration for textile design practice.

Apart for two specific examples: the Climatex DuaCycle textile lock, and Interface's EcoMeTex carpet system, DfD is practically non-existent at the textile level. There seems to be two main reasons for this. Firstly, textiles being embedded within products, the assessment of their life-cycle and recycling process are complex matters. The complexity of systems is seen as a barrier to recyclability in many fields (Murray, 2002), in the long supply chains of the textile industry, this is only exacerbated. The second barrier to the use of DfD in textiles could be related to the scale of the elements and the ways in which they are combined. While connections in electronic goods are often limited to a small number of points such as a series of screws, in textiles the connections between different elements are far more complex and sometimes not even visible to the naked eye. Vezzoli's Design for incompatible materials disassembly list (2014), while providing important guidelines such as the need to prioritise the recovery of elements with higher economic value for example, also suggests a number of strategies, such as the use of snap-fit connections or of hexagonal headed screws, which do not apply to textile design. There is therefore a need to develop guidelines for the recovery of the materials which enter the composition of textile blends.

While the need to recover metals and rare minerals has become obvious, as reflected in policies such as the Waste Electrical and Electronic Equipment regulations (WEEE), similar frameworks are still needed to enhance the potential for recyclability of textiles. The components that come into the making of a textile blend all have their own levels of embedded energy and associated environmental impacts, and in the same way that we strive to keep metals in circulation, polyester and viscose should also be valued as resources. Intrinsic material lifespans need to be considered as part of the product's or, in this case, of the blend's lifespan (Earley and Goldsworthy, 2015). This research therefore aims at overcoming the barriers perceived for DfD in textiles, shifting techniques and scale to enable a shift from product design concepts to the field of textiles.

2. Teardown and Redesign

2.1 Teardown: Understanding Through Making

As part of the H2020, European Union funded Trash-2-Cash project, a team of researchers analysed approximately one tonne of non-re-wearable textile waste to test the efficiency of near infrared spectroscopy (NIR) for sorting processes. This trial revealed the presence of 90 different materials, of which 14 were mono-materials and 76 consisted of different fibre blends (Wedin et al., 2017). Considering that this was only a small, non-representative sample which excluded multi-layered, unlabelled, or garments containing more than 3 fibre types, the complexity of blends cannot be overstated. A full quantitative assessment of the different types of textile blends at end-of-life has not been identified in this review, however, various reports signal that cotton, and cotton/polyester blends represent a large proportion of blends (Chang et al. 1999; Ward et al., 2013).

The high levels of complexity involved in blends are often seen as a barrier to the implementation of recyclability strategies, there is therefore a need to clarify the different parameters involved in problematic blends so as to point to opportunities for improvement. Bahmra (2013) describes different levels of sustainable design, ranging from an incremental approach through the improvement of products and services, to more radical strategies such as systems innovation. According to these descriptions, DfD classifies as a redesign approach. It involves the careful consideration of the product which is in need of changes to identify the sections of its lifecycle which have the most potential to reduce its environmental impact. In this project, existing blends have been studied through the lens of a creative textile designer's perspective to pinpoint the ways in which DfD may provide benefits in terms of use as well as recyclability.

Few studies provide an overview of blend types as reviews often focus on a specific system or commercial application. Moreover, the information is often given from an engineering perspective, and removed from the experience of a textile designer which revolves around more aesthetic and tactile qualities. For this study, an exploration of the field was therefore carried out using making as a way of analysing textile blend constructions. Using colour coded elements: threads for fibres, cord for yarns and foam for fabric, enlarged representations of archetypal blends were made to chart the different ways in which resources are combined in textile blends in a way which is easily communicable to designers. The black and blue elements stand in for any type of materials which might be used together and help in showing at which level these occur within knitted, woven or laminated textiles. The making of these representations itself has been a crucial part of the understanding, allow for reflection in action (Schön, 1983) over the complexity of combinations.

Figure 1. Types of blend archetypes

These representations were subsequently used in a mapping process (Figure 2) to shed light on the different levels of complexity in textile construction and the number of steps separating them from the mono-material or recyclable components that need to be recovered for regeneration processes. This mapping work in a similar way to a family tree, tracing the different types of blends back to the original mono-materials which might have entered their composition. This return to the mono-material state in the mapping also reflects the aim of the DfD process in taking the components apart for recycling. The different levels represent stages in which the complexity of the blends increases, due to the combination of a blended element with another blended or mono-material element as part of the material, thus adding another stage before the return to mono-materiality.

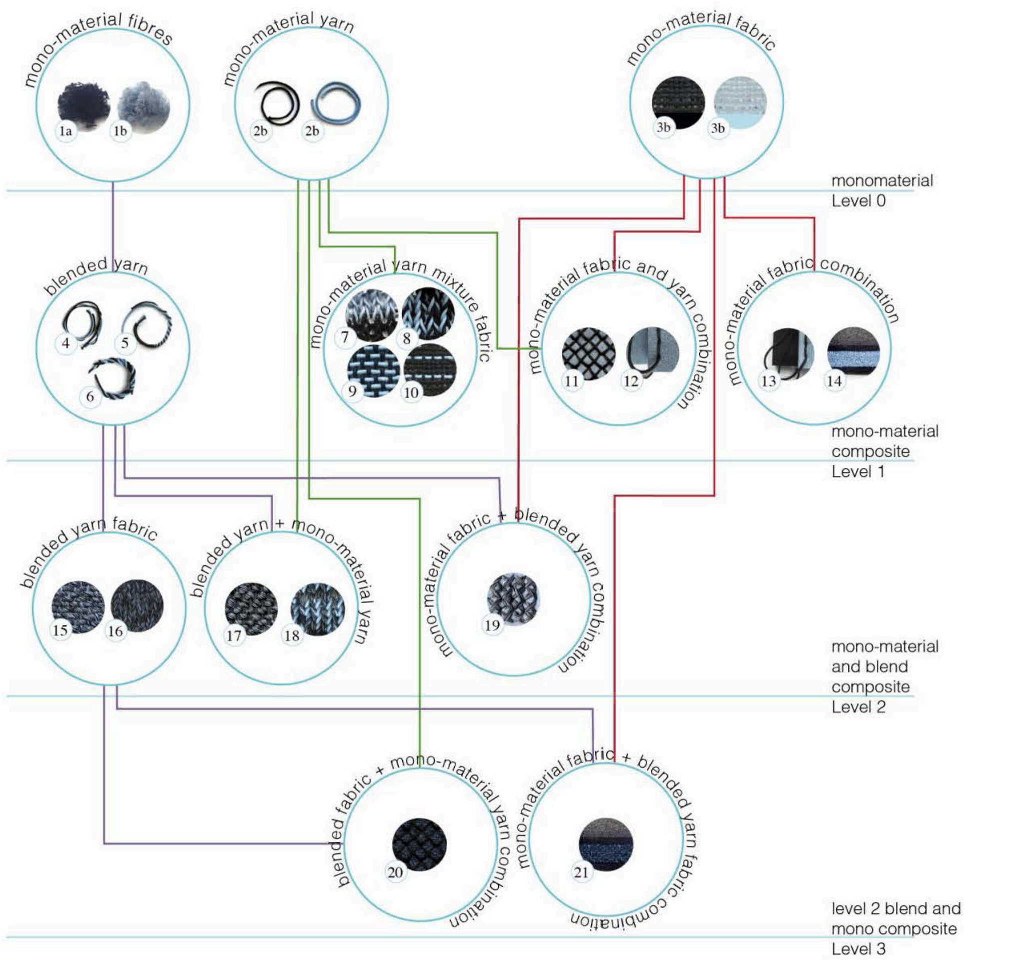

Figure 2. Mapping the levels of complexity in textile blends

The main insight from this process was to identify the specific type of blends that may be addressed in the redesign process within the limits of a creative textile designer's skills. Indeed, the first level of blends comprises of structures that bring materials together in ways in which the individual components are still recognisable at the scale at which a designer is used to experiencing materials. It is at this level that the creative 'bissociative' process is most relevant, in the combination of materials whose individual qualities are perceived as potential elements of an original effect in a blend. It is therefore at this level of combination that the subsequent sampling phase took place.

2.2 Proactive Approach

Relating to Bahmra's listing of sustainable design strategies (2013), this research explores how designers may be able to provide new approaches to barriers in recycling by taking on a redesign process. Current solutions in development for improving the recovery and recycling of textiles are mainly technology driven, looking at ways of fixing the issues in the existing system, thus employing Bahmra's 'systems innovation' perspective. The very promising work in chemical recycling of blends pioneered by Worn Again, for example, shows a way in which existing non-recyclable blends may be decomposed into recyclable polymers before regeneration through a chemical process. While progress in this field will provide a solution for vast quantities of waste textiles, this research project attempts to look upstream of the creation of blends which prevent effective recycling. The work therefore takes a proactive approach which, rather than addressing the system, aims at designing products which fit in the existing recycling streams and potentially to design waste out of the system from the very first stages of the process. Textile design practice must therefore take on board the inherent recycling criteria for each material. Kate Goldsworthy's (2014) work with polyester is a striking example of how proactive lifecycle thinking can remove obstacles to the recovery and regeneration of resources at the outset of the design process. In the same way, materials that belong to the biological cycle or to other industrial processes must be treated in ways which consider these end-of-life options.

Material recyclability is however a complex domain, there are no comprehensive roadmaps for how to recycle different types of resources as this will depend highly on the local industrial context, available partners and their requirements. This approach to DfD in materials therefore retains an element of abstraction which may allow to project context specific parameters when applying the strategies. To develop the range of samples, a best-case scenario was imagined in which resources would be allowed to return to systems such as depolymerisation or composting at their end-of-life. In a real-world situation, however, the elements of the blends here represented by placeholder materials, would need to be identified and the paths to their optimal recycling stream should be mapped to allow for effective recovery and reuse or recycling.

2.3 Redesign: Exploring New Ways of Combining Textiles

Following from the understanding of blends gained from hands-on experimentation with archetypal blend structures, a second phase of making was initiated to test the hypothesis of DfD in this redesign context. This practice-led research is driven by experimentation with textile construction in the studio, following a 'free-flowing' or 'playful' approach (Philpott, 2013; Marr & Hoyes, 2016). Series of samples were produced to test the applicability of DfD strategies at the textile construction scale. The sampling was carried out in parallel to the theoretical studies and used two main techniques: laser cutting and more broadly, textile manipulation on the one hand, and on the other, weaving on a semi-electronic dobby loom.

The constraints of recyclability are used as a creative challenge and a driver to innovation, emphasising the opportunities brought on by a circular economy brief over the limitations it may seem to entail. This phase of making was similar to a discovery phase as described in the design innovation double diamond, testing the array of opportunities offered by the brief. The indications for this phase of making were derived from the analysis of a series of interviews with experts in the field of textile recycling. This gave two broad directions in which to take the experimentation: the inclusion of elasticity, and the creation of layered materials.

In a redesign framework, this allows to explore the alternatives to the conventional approach which is being challenged. In this case, the take on this process does not merely suggest partial improvements on elements of the initial design, but considers the essence of material combinations and structures as the starting point for a new design. The tacit knowledge involved in skills regarding textile techniques here is essential as it allows a creative approach to the design of new structures which do not hinder the recovery of the recyclable components at the end of life. The brief is therefore the impulse for innovation in both the recyclability aspects and the aesthetic and functional characteristics of the material.

3. Sampling Hypotheses for Design for Disassembly in Textiles

3.1 Textile Design Practice

As described by Csikszentmihalyi (1990), flow is a form of mind-set which can induce breakthroughs in multiple types of creative practices. It involves a balance between the level of skill of the practitioner and the challenge at hand that maintains a level of tension conducive to innovation. The practice here relies highly on tacit knowledge that is expressed in the application and combination of traditional textile techniques, the state of flow is therefore essential to allow for the expression and combination of these different types of knowledge. In textile designer Rachel Philpott's work, these conditions are exemplified through the 'washing line' method in which all samples are correlated to draw impulses for the next iterations (Philpott, 2013). In this way, the abstract space of the 'studio' combines the necessary conditions for flowing creative practice. This is mainly a place to visualise inspirational examples, pictures, or texts, the access to prototyping tools and surfaces to spread previous samples out for an overview of the work in progress.

Studio practice goes beyond the making of samples, it is also a way of thinking that is influenced by the practice and is specific to the designer. These sampling sessions embodied Schön's concept of action research as a 'conversation with the materials of the moment' (1983) in allowing to materialise imagined solutions for textiles for disassembly and thereby providing props for further reflection and evaluation of the potential of the DfD hypothesis. As described by Harrisson (1978) this form of creativity is inherent to the exploration of making: setting out without a specific idea of what the desired outcome is exactly and letting it materialise through various iterations. Rowe (1987) describes this approach as generate-and-test, a more controlled and self-aware approach to trial-and-error which builds on observations of each iteration and uses the tacit sense of adequacy described by Schön to gradually achieve an optimal outcome. Following these principles, innovative approaches to textile combinations may be achieved through a hands-on process which would not have been accessed through a more methodical approach as in technical problem-solving methods. The value of hands-on experimentation can be recognised in the exacerbated possibility of dealing with uncertainty which is itself an essential characteristic of design-led approaches when grappling with wicked problems. Using the specifics of this approach to making which is also defined as 'textile thinking' (Igoe, 2013), a series of samples were made to explore the ways in which DfD could be applied to materials themselves.

3.2 Sampling Textiles for Disassembly

The laser cutting and textile manipulation was carried out in a community-led maker space, which allowed to span out the making sessions over several months, returning several times at weeks of interval to use the machines. These samples are the most directly related to the use of DfD in product design, transferring modularity concepts and assembly techniques from a furniture to a textile scale. Using the principles observed in various examples of modular design whether in architecture, product or fashion design, different types of combinations were tested as can be seen in Figures 3 and 4 where a form of dovetail assembly usually found in wooden products is adapted to the weight and scale of felt and canvas. In other samples, technical approaches such as hot-melt polyester welding are adapted to the craft-based prototyping techniques used here, as in Figure 5 with needle felting. Overall these trialled various ways of combining materials with contrasting characteristics such as thickness or stretch in ways which allow them to be pulled apart when needed for recycling or upgrading of the item. As in the case studies that inspired these techniques, the new structures prescribed by the DfD brief create original patterns and textures that can have use and aesthetic benefits beyond the ability of the material to be disassembled for recycling.

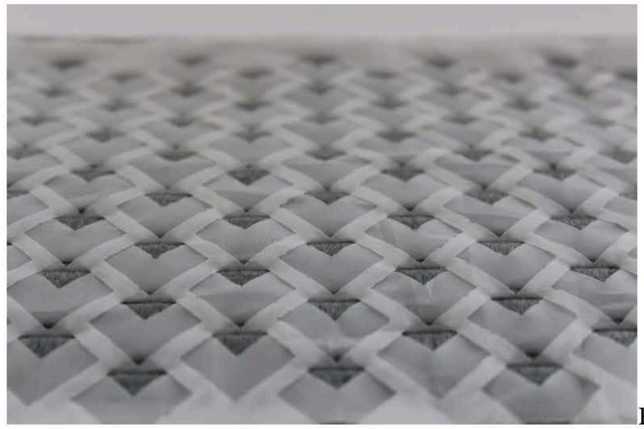
Figure 3. Dovetail assembly sample

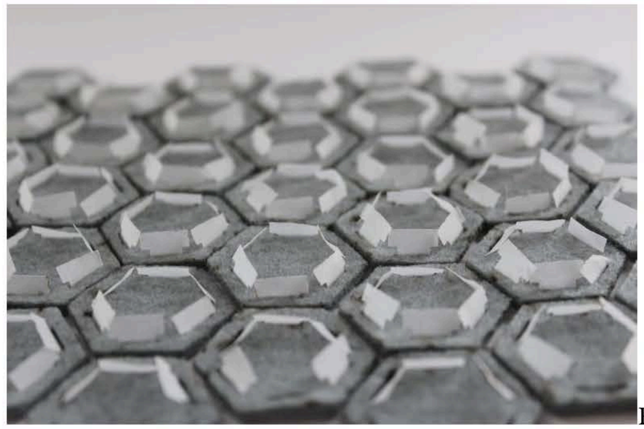
Figure 4. Hexagon modular sample

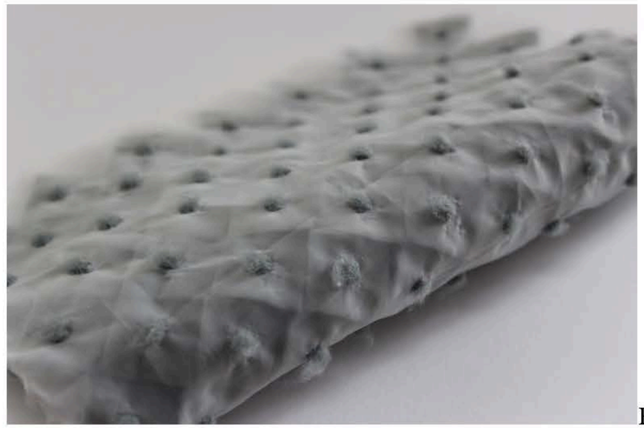
Figure 5. Felted tiles sample

The weaving was carried out in a condensed week-long access to a dobby loom at Chelsea College of Arts. This timeframe brought on a different way of planning and thinking through the making process. A plain set-up and warp was used to experiment with techniques in layering a base against a 'décor weft' which could provide structure or properties similar to those of coating or lamination to the material. Here the extra layer is either a protective or reinforcing element, or it provides elasticity without intimately blending the non-recyclable stretch element with the main body of the material. Experimenting with weaving allowed to test the DfD principles at the smaller scale of yarns as opposed to fabric elements in the felting and laser cutting. This leads to a series of samples which can be more easily projected into a fashion context whereas the sculptural aspect of the previous, laser-cut or felted samples displayed the DfD concepts in a more dramatic way.

Figure 6. Woven layered sample

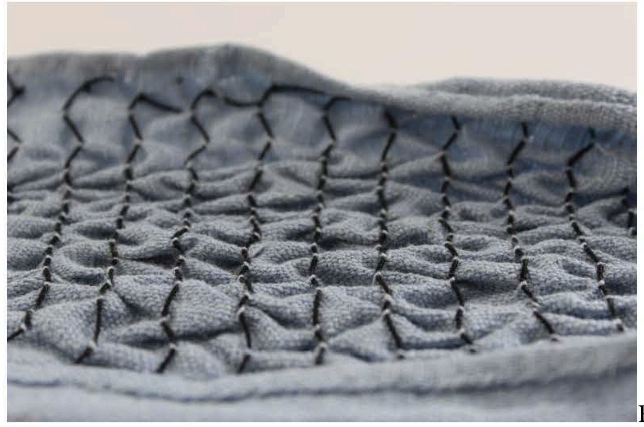

Figure 7. Woven elasticity sample

Across the different techniques, these samples all use place-holder materials which in themselves do not have any particular recyclability characteristics but are instead used as codes in the same way as with the enlarged blend archetype models. This lays the ground for the application of these strategies in different product types. Indeed, the level of abstraction maintained throughout the experimentation keeps options open for fashion as much as for interior uses. The samples highlight how a textile design approach which is led by a haptic bissociative creative process can generate new ways of combining materials which not only provide clear paths to recycling, but also build in new aesthetic or functional characteristics for the material.

3.3 Tracing Thinking Processes Through Samples

As well as formulating hypotheses, the samples are a way of keeping track of the thought process involved in the making. Indeed, techniques and concepts can be traced back chronologically through the various iterations, showing how the use of the DfD brief influences the design process and highlights the way in which design processes more broadly can be influenced in following such strategies. The constraint of only combining elements of the textiles in ways that allow them to be taken apart has guided the creative process and forced the making into unexplored paths. Textiles are a particularly rich field in this regard as the discipline already relies on a variety of technical constraints linked to the tools or the materials used (Dormer, 1997; Sutton and Sheehan, 1989).

In several instances whether in the laser-cut or the woven samples, the evolution of the techniques can be traced from the initial inspiration found in case studies, through several iterations to adapt the form and scale of the components to the materiality of textiles, experimenting with different types of combinations until the idea runs out of breath or a level of satisfaction or of frustration in the results is achieved that allows to move on to a new concept.

In this first stage of prototyping, there is no set industry brief to define the criteria for the textiles, instead their qualities are entirely defined by the DfD function. This means that the DfD concepts drive the creative process and dictate the aesthetics as well as the structural or functional aspects of the textile. The samples that are produced in this way are raw ideas, prototypes that are ready to be used as the starting point for applied sampling.

4. Collateral Innovation

4.1 Innovating at the Material Level

Rather than suggesting new construction methods for garments, this work proposes new ways of thinking about textile structures that can be applied to different types of design practice. Indeed, DfD strategies have already been applied in textile products to disrupt production and consumption habits, such as in the Post-Couture Collective collections (http://www.postcouture.cc/), or to allow for end-of-life recycling as with the Resortecs project (https://resortecs.com/). This project suggests innovation by taking this approach deeper into the material itself and fundamentally challenging the use of default or traditional material combinations.

As described in setting the context for this work, the emphasis here is on the appropriate use of resources to avoid contamination which hinders recyclability. However, implementing DfD strategies in a redesign process may have potential for additional benefits. In reviewing the field, the potential of DfD to elicit parallel design features in objects was noticed as an important characteristic of the strategy. Indeed, the redesign of a product can be an opportunity to improve its function or re-think the scenarios in which it is used. Several of the design examples analysed as case studies in the initial literature and practice review seemed to display DfD features as 'accidental' aspects that occurred as a side effect of other intensions such as allowing for customisation or modular possibilities in the object. Reversely, as DfD strategies are applied to materials in the samples, they may produce collateral effects which can trigger new ways of using the material or of including it in an object. This points at the high potential for redesign and specifically for DfD to suggest meaningful innovation.

In sampling and testing DfD in textiles, these characteristics seem to have been effectively transferred to a material scale. What's more, the potential of such techniques to become tools in material driven design provides exciting prospects for the application of DfD in design for the circular economy, but also more broadly in providing opportunities to challenge the status quo in product and materials production and consumption

4.2 Collateral Benefits of DfD

During the initial literature review, which analysed 21 examples of design across different fields which represented different ways of applying DfD strategies, several common themes were found to bring together various examples. These were mainly based on who enacts the disassembly and at what point in the product's life cycle the disassembly occurs. On one end of the spectrum for example, DfD aims at enabling the recovery of the resources, usually in the form of a pulp or of fibres which can then be regenerated into new materials. At the other end, DfD involves the user into the product's life cycle and extends it as much as possible with features such as upgradability or an approach to material lifespans which considers the longevity of resources as part of a poetic evolution of the objects through time. Similarly, the different techniques used for DfD in the textile sampling provided different opportunities at the point of disassembly.

The strategy developed in the woven samples can be closely related to Climatex's textile lock, allowing to recover the resources in the state of yarns which can then be introduced to a mono-material chemical or mechanical recycling process. This type of approach provides little change to the use of the material; however, this redesign may be used as an opportunity to enhance the functional characteristics of the material. For instance, the type of stretch or of reinforcement achieved is quite different when the functional element is not blended-in uniformly as with conventional materials, but is instead added on as an extra layer. No testing has yet been carried out on these samples to assess the difference in functional characteristics, however, the Climatex DuaCycle mentioned previously shows an example of

enhanced wicking properties from the fibres being woven side by side for disassembly rather than intimately blended together.

In the case of the larger scale samples with reversible connection such as the laser cut samples, the modularity and upgradability concepts seen in product and fashion design translate in a direct way to the material scale, thus allowing for more interaction between the user and the textile's life cycle. This allows to imagine uses for the materials in which they enable life cycle extension by for example suggesting that worn elements be replaced by the user without needing to replace the whole product. On top of providing this practical way of making products last longer and therefore reduce waste, the involvement of the user in the reconfiguration of the objects has been argued as creating attachment which further postpones emotional obsolescence (Chapman, 2005).

Overall, the way that DfD is adapted to the textile scale in these samples suggest the potential for innovation at the material level. By embedding the possibility for disassembly within the material, new behaviour patterns for the use of the objects they are part of may emerge. Moreover, the abstract nature of the samples which at this stage use placeholder materials leaves room for the application of these principles to many different products and situations.

Conclusion

This paper has laid out the potential of a redesign strategy to provide solutions to improve the recyclability of blended materials. By asserting the responsibility of the designer, and moreover, their capacity to provide valuable skills in this process, the 'teardown and redesign' process can be taken on to challenge the status quo for materials creation in the wasteful and polluting textile and fashion industry.

The importance of understanding the issue at hand from a creative textile designer's perspective, using a scale and representation methods which are familiar to this field, is particularly important in pointing at the levels at which the designer's set of skills may have a meaningful impact. This in-depth understanding then translates into the prototyping phase when experimenting with solution hypotheses. In this case, free-flowing experimentation with DfD in textiles through various techniques such as weaving, felting or laser cutting explored how the combination of different textile elements following the rules of DfD for the circular economy may lead to original effects in terms of functionality and aesthetics. This paper argues for the value of textile thinking and playful methods in the design process, enabling a thorough exploration of the potential of DfD at the textile scale, both in terms of the quality of the output and regarding the richness of the creative process.

While there may be some limitations to this study due to the abstract nature of the sampling, its disconnect from real recycling systems and the use of the materials within products, DfD presents a major opportunity for innovation in many fields. Furthermore, this paper argues that through the implementation of circular economy rules as a constraint to the creative process, potentially unforeseen benefits may occur as collateral features of the new material or product. This high potential for innovation shows one of the essential values in a redesign process for the circular economy.

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11.3.3. Disassembly Discussed: Creative Textile Sampling as a Driver for Innovation in the Circular Economy

Disassembly Discussed: Creative Textile Sampling as a Driver for Innovation in the Circular Economy

Laetitia Forst

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ABSTRACT This article argues that in order to face current and future sustainability challenges in the textile industry, the hands-on approach of creative textile designers can be harnessed not only to develop new solutions to material recyclability issues, but also to help in developing new design mind-sets in the circular economy.

The article will focus on the importance of making in the textile design process. This research addresses the challenges posed by blended materials to efficient recycling. While technological progress is enabling us to recycle more types of materials (Östlund, 2015), to achieve fibre-to-fibre regeneration simple and mono-material textiles are still more economically and environmentally sustainable (Maldini et al., 2017). Creative textile design is, however, intrinsically linked to the juxtaposition and combination of different materials and techniques (Dormer, 1997). Moving away from a mono-material

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approach to recyclability, the project explores the potential of design for disassembly as a solution to replicate the qualities and attraction of blends while allowing the individual components to be recovered for recycling. Thus, the constraints laid down by recyclability criteria can be creative impulses rather than limitations (Brown and Katz 2009).

Current approaches to sustainable innovation mainly come from a problem-solving perspective which is removed from the textile designer's experience (Igoe, 2013). Through playful experimentation in sampling textiles for disassembly, this research aims to explore solutions from a design and making-led perspective. Textile design practice and material experimentation in the studio have been used as drivers for material innovation. The samples not only lead to original recyclable materials which combine resources for optimal performance and aesthetics, but also draft guidelines for the creation of textiles in the circular economy.

KEYWORDS: Design for disassembly, textile design, circular economy, making, sampling, design research

Introduction

The extreme consequences that the textile and fashion industry are currently having on our environment need little introduction. Beyond the pollution and depletion of resources occurring at every stage of the production of textiles, the system itself is ultimately flawed as it follows a linear model, often described as a "Take-Make-Waste" model (Ellen MacArthur Foundation, 2015). The circular economy provides a framework for the perpetual reuse of resources in a regenerative system (McDonough and Braungart, 2013) and a set of recommendations must be followed for this model to be applied to the textile industry. Blends are currently a hindrance to the effective recovery and reuse of materials in a circular economy as they combine resources which belong in different recycling streams and prevent the components of such blends from being recycled in environmentally and economically sustainable ways (Cupit, 1996). While recovery and recycling technology is expanding and increasing in quality of outputs, the systems still favour mono-material inputs (Östlund et al., 2015).

This research proposes that beyond a limitative approach of mono-material design, the creativity of the textile designer can be harnessed through design for disassembly (DfD) to suggest new ways in which to design blends to proactively comply with the limitations of a circular system. Considering blending as an inherent element of textile design, intrinsically connected to the playful act of creating new textures and patterns through contrasts in material types and colours, this research uses the same tools to suggest new ways of designing blends in a circular economy.

This article first lays out the context for the study, acknowledging blends as a product of creative textile design practice. The framework of design for disassembly is then presented as the strategy which is adopted here in the exploration of solutions to lift recyclability barriers for mixed materials textiles. The methods section shifts the focus away from a purely technical problem-solving approach inherited from engineering, towards questioning the reasons why designers combine different materials despite the recyclability barriers this creates. Following the double diamond design method described by the Design Council (Design Council UK, 2005), the question is thus explored through this approach before being redefined and narrowed down into a specific brief which then leads to a phase of experimentation and retrospective analysis of the process. This article then proceeds to describing the sampling of textiles using DfD strategies at the scale of threads and of fabric components. The discussion elaborates on the use of retrospective visualisation of the design process and of samples as tools for conversation, this use of the results of the making points towards further potential for the development of guidelines for DfD for textiles.

Context

In designing for a circular economy, blends that combine resources from different streams and belonging to separate recycling systems must be avoided. To challenge the current status quo in the creation of textile combinations, these blends are first understood as a design flaw. This issue is then turned into a challenge that can be met using design for disassembly, translated from its extended producer responsibility origins into the creative practice of textile design. The methods section reinforces the role of a textile design approach in exploring the potential of DfD through playful iterative sampling and retrospective mapping and visualisation of the thought process.

Blends, Recycling and Creativity

Across history and different sectors of the industry, blends can occur for a variety of reasons. These are often connected to the performance of the materials, either to increase or balance the characteristics of the different components or with a consideration for cost and production optimisation. However, this study is particularly interested in the creative process involved in blending. Beyond considerations for the technical properties of a material or textile, blends also may occur from a desire to achieve aesthetic effects or motifs by contrasting textures or colours as part of the same fabric.

This study therefore takes on the designer's perspective and addresses the making of a blend as a creative act. This research proposes that, as described by Arthur Koestler (1989), "the creative act consists in combining previously unrelated structures so that you get more out of the emergent whole than you put in". This "bisociative" process (as coined by Koestler) is indeed present in textile design creativity through the playful and creative combination and juxtaposition of materials, colours and textures. While technical literature on material combinations focuses on the functional complementarity of the different elements, Hardingham (1978) for example, considers blends which bring together different colours of yarn of the same fibre type such as in patterns in tartan fabric. Dormer (1997) describes quality creative textile design practices as relying on a tacit skill to combine materials with contrasting textures and shines within the same cloth so as to create surprising and pleasing effects. In common forms of textile design, the blending of different yarns or the application of a finish or paste on the surface of fabric often results from a need or desire to achieve a specific pattern or finish in the most cost and time effective way. This ability to create combinations is an essential part of the textile designer's work and is a central element of this study of blends.

In this study, blends are described as the combination of two or more different components, fibres, yarn or fabric elements, in the same yarn or cloth (Hardingham, 1978) to create a variety of technical or aesthetic effects. The focus is particularly placed on the notion that the various components combined in these blends cannot effectively be recycled in the same process without impacting the quality of the outputs.

Indeed, blends are commonly considered as a hindrance to recycling, in an industry constantly struggling to extract the highest value possible out of waste resources, the complexity and variety of blended materials impact the process and make recovery more complicated at all stages, adding extra steps along the line. In some specific cases, the inclusion of fibres such as elastane impedes the efficiency of the shredding and pulling machines for mechanical fibre to fibre recycling (Östlund et al., 2017); or in other instances, multiple layers of fabric or lamination prevent the waste garments from being accurately sorted (Interreg and Fibersort, 2018).

While mono-materiality offers a solution to the problems caused by blends, it also tends to limit the scope of materials that are used throughout the industry (Fletcher, 2008; Niinimäki, 2013), and seems to be in contradiction with the belief that sustainable design should also celebrate diversity (Benyus, 2002; McDonough and Braungart, 2002). While many functional or aesthetic aspects can be replicated using mono-material textile design, the creative challenge found in combination is still an element that is very specific to blends. What this research aims to achieve, is to replicate the attraction of material combination while allowing for individual recovery of these mono-material elements at the end-of-life.

Design for Disassembly

To allow for multi-material creativity in textiles while not impeding the capacity for material recovery, the approach explored here is *Design for Disassembly* (DfD). DfD is defined as the creation of materials or products that can be easily and economically taken apart at the end of their useful life (Bakker et al., 2014; Fletcher, 2008; International Organization for Standardization, 2016; Vezzoli and Manzini, 2008) allowing for re-use in appropriate cycles. DfD has mainly been developed in product design as a response to Extended Producer Responsibility (EPR) regulation (Lindhqvist, 2000). As designers and manufacturers are required to think beyond the end-of-life of products, a systems-thinking approach to design involving DfD will become necessary (Webster, 2013).

While the need to recover valuable metals and toxic components which comprise electronic products has become obvious, as reflected in policies such as the Waste Electrical and Electronic Equipment regulations (WEEE), similar frameworks are still needed to enhance the potential for recyclability of textiles. The components that come into the making of a textile blend all have their own levels of embedded energy and associated environmental impacts, and in the same way that we strive to keep metals in circulation, polyester and viscose should also be valued as resources. This research therefore aims at overcoming the barriers perceived for DfD in textiles to enable a shift from product design concepts to the field of textiles.

Through the exploration of DfD across different scales and fields, from the use of smart materials in electronic products, to adaptable architecture, through various examples of modular products and fashion, different aspects of the strategy were explored. This review highlighted the fact that while DfD enables effective recovery and recycling, it also draws in additional characteristics involving different circular economy strategies such as design for emotional durability (Chapman, 2005) or design for repair. As argued in this paper, this potential for innovation and improvement on the original product is key to the approach taken to DfD in this work.

Methods

The work described in this article follows a design project method as described by the design council (Design Council UK, 2005). The question is first explored and narrowed down to a redefined brief. In this case this is achieved through the understanding of blends as a design issue and reframing DfD as a potential textile design strategy. This brief is then explored in the second half of this double diamond approach in which multiple solutions are investigated before a final analysis and selection for the articulation of a proposal. This article focusses mainly on the exploratory phase and the analysis of its results. In this way, a free-flowing and playful approach to textile sampling has been used, followed by a retrospective analysis of the thought process to draw insights from the making.

Textile Design Practice

While blended materials are an intrinsic result of creative textile design practice, there is still a lack of approaches using this perspective to tackle the problem. Issues of designing for circular systems have rather been considered from an industrial product design or systems design perspective (Bakker et al., 2014; Stahel, 2006), and the most widespread approaches to problem solving mainly come from this angle. The idea of a design "problem" in the terms understood by design thinking research (Brown and Katz, 2009; Cross, 2011; Rowe, 1987) is rarely present in the textile design process, indeed as argued by Igoe (2013), textile designers tend to "create problems for themselves, for their own satisfaction", further suggesting that the aesthetic component could be the main issue to "resolve" within this type of practice. It is therefore a form of activity which resists constraints. Indeed, textile design researcher Rachel Philpott describes how enforcing a protocol over the activity can inhibit the creative process and freeze the progress of the research (Philpott, 2011). On the other hand, examples of the use of play (Marr and Hoyes, 2016; Philpott, 2013) have shown how this approach can lead to high quality original outcomes and insights. Furthermore, the value of practice as a tool for research has been demonstrated in terms of advancing concepts and frameworks (Michel et al., 2012), but also in its ability to suggest fine-tuned and optimal propositions to a given problem (Kane et al., 2015). This paper therefore suggests a retrospective analysis of the free-flowing creative process through the mapping of textile samples.

In the case of DfD, which has a history of being used in industrial product design but only a handful of examples at the textile scale, there seems to be a wealth of unexplored potential in adapting this strategy to textile design. Indeed, recommendations and regulations for DfD in products exist (Autodesk Sustainability Workshop, 2015; International Organization for Standardization, 2016; Vezzoli, 2014; Ziout, 2014), but the methods they describe do not apply to textiles and are not either communicated in ways appropriate to easy integration by designers working with soft materials and at the scale of textile components. Following from this, this paper argues for the crucial role of hands-on experimentation with DfD at the textile scale as a way of further developing this strategy as a solution to unrecyclable blends.

Making Textile Samples

The sampling was therefore carried out in this free-flowing way, guided by the outcomes of each iteration, drawing on the tacit knowledge (Polanyi and Sen, 2009) which is a strong component of textile design practice, thus following a thinking in action process (Schön, 1983). The ongoing evaluation of the relative success of each sample follows a generate-and-test approach as defined by Rowe (1987), which is in this case seen as a way of shifting the brief according to the outcomes of each iteration in the making process as described in Scrivener's (2000) account of the research process. As will be demonstrated in the discussion section of this paper, by analysing each sample and assessing its relative success based on its tactile or aesthetic qualities as well as on its ability to be disassembled or its response to the technical brief, the most relevant qualities were singled out and expanded on for the next iterations of sampling.

Underlying this free-flowing and experimental approach to textile sampling, is the brief set by circular economy non-contamination constraints, approached in this case, from the specific angle of DfD. The work takes on a conventional design project method with an initial inspiration phase (Cross, 2011; Dorst, 2017). While this phase coincides with a research-focussed literature and practice review, it can also be described as an inspiration or mood-board phase, typical of the creative textile design process (Cassidy, 2011; Studd, 2002). The review of approaches to DfD in various fields and scales has proved that the strategy can be useful not only in facilitating the recovery of recyclable components in the appropriate end of life streams, but also that this end of life may be impacted and delayed through the inclusion of additional circular design strategies which are enabled by DfD such as reparability or emotional durability (Chapman, 2005).

Visualising the Thought Process

As described by Manovich (2011), a visualisation uses reductions of information, such as graphical primitives to represent pieces of data, in conjunction with spatial variables to elicit meaning through patterns and relations. Manovich also describes the use of direct visualisation or media visualisation, in which all or part of the objects are used in a spatialised representation to demonstrate patterns. The approach taken here combines direct visualisation with coding of the spatial relationship between the media and external references to other data. To retrospectively represent the thought process involved in the making, the samples themselves are laid out and analysed to understand how different techniques transferred from one iteration to the next. By drafting these causality links between samples and connecting them to influences from a prior case study review, all the information which has crystallised into the making is made visible at a glance.

This laying out of information coincides with Tufte's (1990) description of the potential of high density designs to put the information in the hands of the viewers and provide them with a tool to personalise the information to their own benefit. In this way the mapping of these blends in relationship to their ability to be fitted within a broader system in a circular economy provides material for the development of guidelines for DfD for textiles.

Making Textiles for Disassembly

Based on a brief to replace existing problematic blends, the samples took two forms, one was focused on the use of yarn as the mono-material element, whereas the other used fabric pieces as the building-blocks for the designs. These two scales of textile elements are chosen as representing the level at which a textile designer is accustomed to working, as opposed to the fibre scale of engineering which seems beyond the grasp of designers as defined in this framework. At these scales, the intrinsic qualities of each material entering the combination can be felt and seen, therefore drawing on the tacit knowledge and appreciation of these qualities.

The Design Brief

DfD is embedded within the design brief for this textile sampling and this research argues for the benefits not only towards developing recyclability strategies for blends, but also as a way of challenging textile design practice in a more general way. As opposed to a limitative mono-material approach, the research suggests that circular economy constraints should be taken on as positive creative challenges. Imposing the use of two or more different resources without connecting them in permanent ways therefore suggests a new way of creating effects in textiles and heavily influences the functionality and aesthetics of the outcomes. The samples described thus provide a proof of concept for the application of DfD in textile design as well as having intrinsic value as models for future circular textile design practice.

The sampling described here responded to a prompt given by a prior research phase based on interviews with a set of experts which suggested that two of the main characteristics which involve blending materials in ways which prevent recycling are the inclusion of elastane for stretch and the lamination or coating of textiles. Following from this, a series of samples were created to prove the potential of DfD to suggest redesigned alternatives to these problematic material types. In order for these proof of concept samples to be taken on by others in future creative textile practices, the samples were made using placeholder materials which can then be replaced by a choice of resources depending on the requirements for the textiles and their appropriate recycling streams.

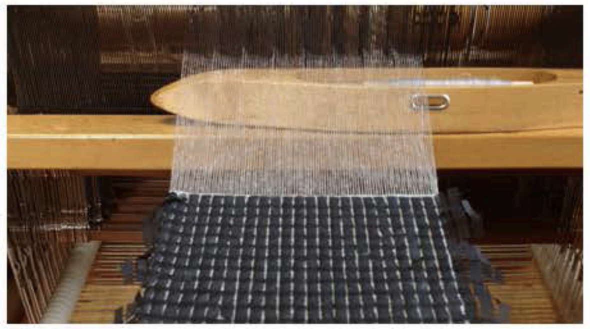

Figure 1
The warp on the loom (author).

Yarn Based Samples

The yarn scale was used as a way of staying as close as possible to the conventional making of a textile. Textile design practice is very varied in its forms; it can range from the application of colour or pattern to fabrics in dyeing or printing, to the combination of textile and non-textile elements in embroidery for example. But starting from the yarn scale allows us to construct the textile from what feels like the very beginning of the process. It also guides us towards more conventional studio tools such as the loom or knitting machine which have direct equivalents in industry and could therefore lead to more scalable outcomes than other, more hand-crafted, textile manipulation techniques.

This making phase was a way of experimenting with loose ideas for DfD in woven materials, rather than the prototyping of an already set and drafted concept; the loom (Figure 1) was therefore set-up in a generic way to allow for a variety of simple structures to emerge. Using a floating weft effect which had already been tested in previous work by the researcher relating to design for disassembly (Forst, 2018), the sampling aimed to connect a functional element; either elasticity or a form of coating, to a base cloth in ways which would allow them to be removed at the end of life. In all of the samples a pick (the line of weaving code for a weft thread to be added to the fabric) was added to allow the insertion of a "special" weft thread. In the case of stretchy samples this was an elastic rubber thread, and for the twosided samples, this varied from custom-made laser-cut yarn to nylon thread (Figure 2). Indeed, these samples followed closely from the insights gained through the interviews and mapping processes. The sampling therefore set out to suggest alternatives to stretchy and laminated materials using DfD to enable potential recycling. As with the use of DfD strategies in other fields, this way of making textiles elicited original aesthetic and haptic qualities.

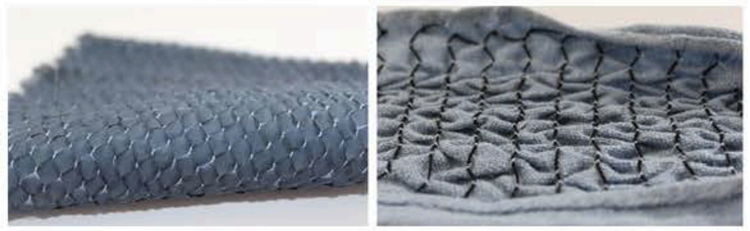

Figure 2
Examples of woven samples (author).

The visual effects in the case of the stretch samples was close to what may be achieved using smocking techniques which gives the textile a folded aspect by gathering strategic points across the surface of the cloth. However, the folds can be pulled flat and expand the material, giving it stretch-like properties. The thread which allows for the elasticity, being incompatible with biologic cycle materials such as the cotton used in the base cloth, and generally a hindrance to recycling systems, can be removed at the end of the product's useful life. This can be done by triggering the change which will dissolve the thread that connects it to the base. In this case, water-soluble PLA was used as a stand-in for other materials that react to conditions that will not occur accidentally, such as hot-melt polyester or other material such as Wear2's thread which can be dissolved by microwave treatment (Durham et al., 2014) or even Resortec's heat reactive thread (http://resortecs.com/). Once this thread is dissolved, the base material remains viable and can be used in other applications or recycled as a mono-material. This technique was applied beyond the brief of making stretchy fabrics and the elastic was replaced with other threads such as thick cord or metal thread to explore its potential in making more resistant materials, still externalising this functional component of the blend.

The same use of a "redundant" thread assembly technique was applied to the two-sided samples which suggest alternatives to coated and laminated textiles, allowing the upper-layer to be removed without damaging the base. In this case, the lamination effect is replaced by a special thread which is designed to cover the under-layer through a tiling system. This "thread" is prepared by laser-cutting a thin but dense polyester material in a way that allows it to connect and cover the surface when woven to the base fabric. While this approach does not necessarily deliver the same properties as a coated fabric, given that the added thread does not cover the base material in such an air-tight way as a polymer sheet, it still provides a form of protection and a double-sided effect. Moreover, the satisfying aesthetic effects achieved by taking this round-about approach to coating suggests an interesting path to explore further.

In both cases, whether the effect aimed for is elasticity or coating, these samples show some ways in which the narrow constraints of the non-contamination brief shape the outcomes of the work and lead to new aesthetics for functional textiles. Indeed, externalising the functional elements forces a change in scales and emphasises the textures with either a puckered or scaly effect. As suggested by Papanek's prediction for a future of design led by considerations for the environment, new aesthetics that are not only guided by a purely stylistic inclination may emerge (Papanek, 1995).

Fabric Based Samples

The series of samples based on fabric elements was made using laser cutting facilities in a local community-led maker-space (Figure 3)

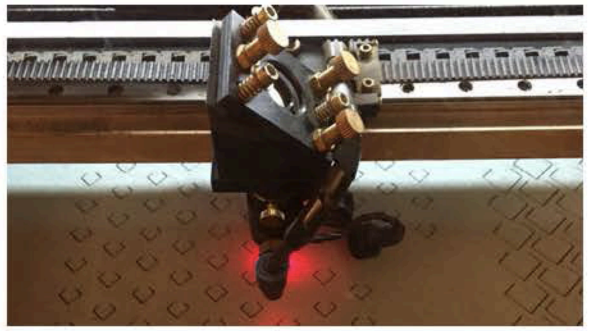

Figure 3
Laser cutting process (author).

followed by hand-assembly of the various components. This section of the practice specifically reflects free-flowing practice (Marr and Hoyes, 2016; Philpott, 2013) in the way that it emerged in a very organic way from the work carried out during the literature and practice review stage of the research. Indeed, being influenced by inspiring examples of DfD in various applications created an urge to try out similar techniques at a textile scale. The first samples mimicked the push-through technique and soft and hard contrast seen in Bjorn Ischi's Bone Chair (Ischi, 2011) and gradually evolved towards a more personal and textile-oriented type of materials. This experimentation then moved towards a "dovetail" assembly system which allows to connect elements in a reversible way. This system has led to a common aesthetic across the range of samples, and the modularity inspiration from the field of product design is clearly apparent.

The two placeholder materials were selected for radically opposing characteristics regarding thickness or stretch. In contrast with the yarn scale, the qualities of the material here seemed to bear stronger consequences over the processes and effects that followed. The activity of textile design is usually in conversation with the haptic and visual qualities of the materials used which have a strong influence on the design outcome and guide the process throughout. In this instance the use of different materials suggested different approaches to layering or modular combinations. For example, felt was combined with a tight canvas, contrasting the thickness and the surface aspect of the two materials. Taking this idea further, beyond the use of the placeholder materials, this type of sample suggests ways that a rough surface could be covered by a layer of waterproof or otherwise insulating material and still taken apart for different uses or for recyclability. Overall the insights from this phase of making, point towards the importance of acknowledging style as an integral component of design thinking (Tonkinwise, 2011). Indeed, the aesthetic qualities of the materials produced here are not an add-on factor but one of the ways in which the success of the trial is assessed and a way in which the samples point towards future potential iterations or further applications.

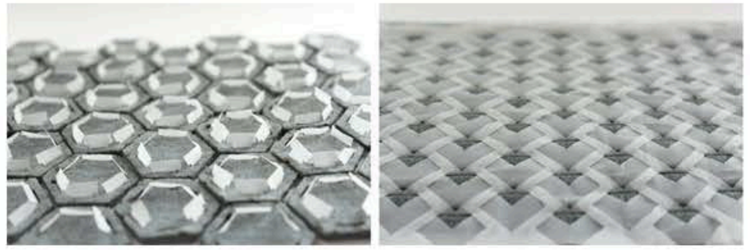

Figure 4
Examples of laser cut samples.

Figure 5
Inspiration from minimalist wood assembly systems: OOS Collection by Studio248 (left), and Nomadic Chair by Jorge Penades (right).

The laser cutting suggested the use of a form of dovetail assembly (Figure 4), directly derived from larger scale DfD approaches in product design such as with woodwork (Figure 5). Indeed, minimalist assembly systems are often used in this field to put forward the intrinsic qualities of the materials. Ingenious ways of assembling different materials with a light touch, avoiding sewing and gluing were thus experimented with at the textile scale. This interlocking of different textile elements led to a series of samples which explored modularity in layers of fabric or in tile-type components.

In the case of the layered fabric samples, the type of assembly defined by the laser cutting meant that the two materials would interlock rather than cover one another in the way of laminated textiles, preventing a straightforward covering of the base material. This therefore led to multiplying the layers of fabric to increase the covering of the felt, which collaterally created interesting mesh effects. These types of serendipitous findings are an essential part of textile manipulation and practice-based research. Indeed this material tinkering (Parisi et al., 2017), leads to designs that could not have occurred through planning as they emerge organically from the "trigger" (Studd, 2002) at the start of the making phase. Here the placeholder materials could be replaced by different materials that accentuate the aesthetic and potential functional benefits of such structures.

The same dovetail assembly systems were used to assemble pieces of fabric in a tile- or patch-like way. Once again, this approach was closely derived from the product design case studies. In these cases, the interactions between the linking elements and the tiles

created interesting effects due to the varying thickness or stiffness of the materials, thus generating combinations that either drape in specific ways or have a spring in a given direction. Moreover, this type of assembly allows to detach zones of the material from the main body of the fabric, therefore hinting at the possibility of replacing localised used parts for extended lifespans in products using these materials.

Discussion

Creative textile design is heavily reliant on tacit knowledge which limits the potential to describe and systemise the stages of the process. This article suggests the retrospective analysis of the samples as a way of drawing insights from the free-flowing making and translating these into an understanding of DfD which can be useful in applying this strategy to designing textiles for recycling. This was achieved through the mapping of the sampling journey, and through seeking feedback from experts using the samples as boundary objects.

Prototyping Textiles for Disassembly

While design for disassembly is fairly established in product design, and some instances of modular fashion, it is virtually inexistent in textiles. Indeed, disassembly for recyclability as defined by this study has only been found in the instance of the Interface carpet (Institut für Textiltechnik of RWTH Aachen University, Gloy, and Schröter, 2015) and the Climatex's Duacycle (http://www.climatex.com/en/sustainability/textile-lock/) furnishing fabric. The production of this range of samples therefore provides proof for the applicability of DfD techniques at scales which are familiar to the textile designer. It demonstrates a range of techniques which can be applied to future practice to enable DfD. These have been classified into four categories: light connections, redundant thread, dovetail assembly, and textile lock. These represent the different ways in which textile components can be assembled to allow for future disassembly that have been explored in this work. These new cases for DfD act as proof of concept for the strategy, adding to the corpus of work which argues for the benefits of this approach both in terms of recyclability and of added functionality.

The making is central to the development of these DfD techniques. Indeed, the scale at which these have been developed differs from the conventional engineering or material science approach to the problem of blend recycling. This sampling has focussed on the assembly of components at a scale which can easily be appreciated in a craft-based creative textile design process. The four techniques therefore offer a valuable contribution towards implementing DfD in textiles. These samples therefore illustrate the ways in which DfD may be applied to the scale of textiles and effectively test how these concepts react to the materiality of the fabrics, yarns and techniques used in practice. These large-scale textiles, playing with different levels of modularity, suggest that the user or end-of-life handler can take the elements apart either to recover the materials in appropriate streams, or to update worn elements and extend the product's life cycle.

The samples also prove themselves useful as tools for further developments. Indeed, in the same way as the original case studies which the ideation phase relied on, they are used as inspiration for further iterations within this project and potentially beyond, in a wider application in the discipline of textile design. This experimentation is a form of prototyping as described by Brown and Katz (2009), highlighting its importance as an ongoing process throughout a project, helping form, as well as present, ideas. This also aligns with Horváth's (2007) approach to research by design in which the prototype is central to generating hypotheses. The hypotheses in this case is that DfD can be applied to the production of craft-based textile making and replace the problematic status quo in material combinations which leads to barriers in recyclability.

Tracing the Thought Process

As well as suggesting assembly techniques, the samples provide the basis for a more accurate understanding of the effect of a circular economy brief and of the use of DfD as a strategy to design recyclability into a blend in creative textile design practice. Indeed, techniques and concepts can be traced back chronologically through the various iterations, showing how the use of the DfD brief influences the design process. Whether in the laser cut or the woven samples, the evolution of the techniques can be traced from the initial inspiration found in the case studies, through several iterations to adapt the form and materials of the components to the materiality of textiles, experimenting with different types of combinations until the idea runs out of breath, or a level of satisfaction or of frustration in the results is achieved that allows to move on to a new concept.

The practice of design, and even more so of textile design, relies heavily on tacit and experiential knowledge (Igoe, 2013; Karana et al., 2015; Polanyi and Sen, 2009). As a craft process, it is articulated verbally only with difficulty (Harrison, 1978), these samples therefore help in materialising the journey through the design process and act as a form of journal to be reflected upon and retrospectively understand the causality between ideas. This allows for thorough examination of the components of the design process without interfering with the flow of the activity in the making.

Looking back on the trail of samples created in each iteration of the concept of DfD applied to textiles allows to see the evolution of the ideas through the making process. By laying out and mapping these samples, the causalities between each iteration can be represented. In Figure 6, the different elements of the samples, techniques or specific material characteristics such as elasticity for example, are traced through the various tests and show the evolution and refinement of the techniques and concepts. As shown in the mapping of the samples,

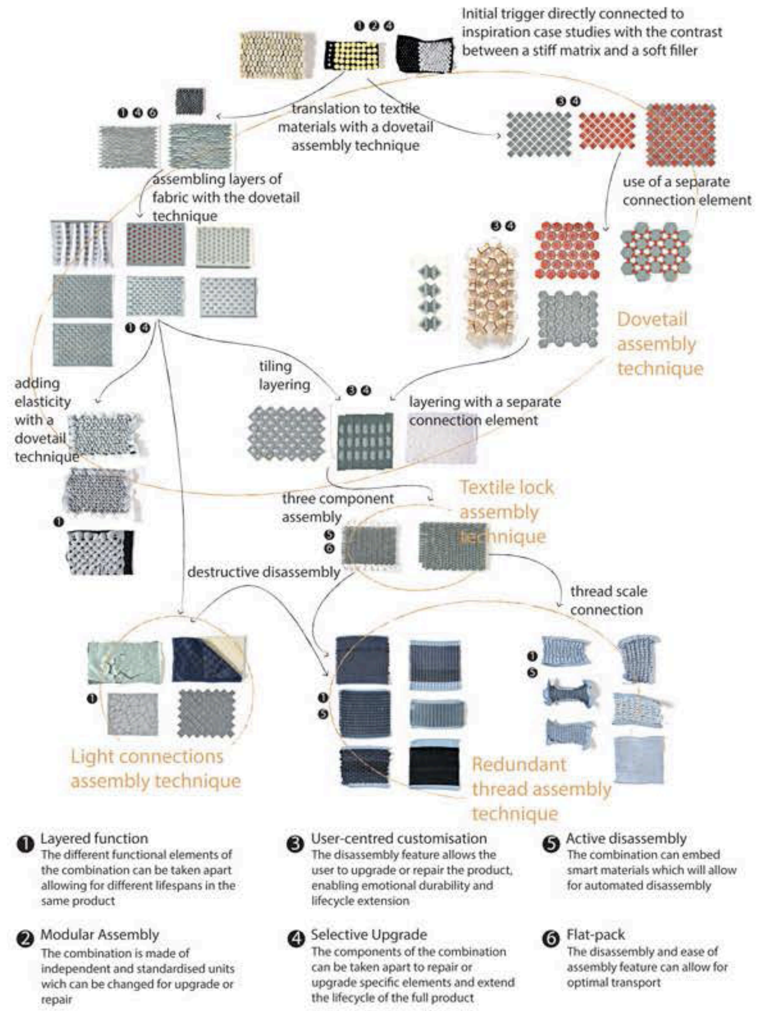

Figure 6
Sample mapping (author).

the types of assembly evolved through a generate and test approach to suggest a range of samples that demonstrate the applicability of DfD along four types of techniques as describe earlier. Additionally, the samples are connected to categories of DfD defined in an earlier literature and practice review. This initial phase of the research suggested different motivations and effects for disassembly, in this mapping it shows how the abstract samples can be connected to a broader systemic view of a circular economy. This also allows to connect the techniques to this inspiration phase, highlighting the influence of DfD case studies on the application of these concepts to textile design.

The meandering path of the evolutions from one sample to another demonstrates the complexity of "textile thinking" (Igoe, 2013) and argues for the specificity of this approach in exploring design challenges. As suggested by Marr and Hoyes (2016), the documentation of the process is crucial to the creation of new knowledge, and allows us to mine the failures in the process as well as the relative successes. Rather than a linear process, the mapping shows how the exploration process branches out in many directions and highlights the areas that are yet to be investigated. Indeed, with every decision, a range of options are left aside and can potentially be picked up in the light of a new brief or perspective on the work.

In mapping out the samples, the characteristics of the different types of making involved either in weaving or in laser cutting and assembling can be demonstrated. For instance, the chronological unfolding of the warp in weaving has led to the combination and merging of the initial two instructions, whereas the simultaneous and more profuse experimentation with laser cutting has created a more fanned out array of examples of the use of DfD in textiles. As defined by Tufte (1990), visualisation assists in the recognition of patterns and generalisations, already inherent qualities of the human brain. The mapping of the samples created in this experimentation with DfD for textiles makes the hidden process of textile thinking apparent and connects it to the making experience. In this way it may be developed into guidelines for the further use of these techniques.

Tools for Discussion

The approach to textile design in this project is led by a playful and free-flowing method which relies to a large extent on the design sensitivity and tacit knowledge of the designer. Opening this process to outside criticism is therefore crucial in grounding these experiments within the realities of designing for circular systems. Bringing the conversation around circular design back to the materiality of textiles can potentially help in making sense of broader systemic issues. Wilkes et al. (2016) describe the use of "boundary objects" which satisfy the requirements for information of each of the participants in a discussion. In this sense the samples, using tactility over words, can bridge multi-disciplinary language barriers (Earley and Hornbuckle, 2017). Building on this notion of design objects as translators, Hornbuckle (2010) expands this role to the materials expert as a boundary-spanner and an instrumental actor in bridging gaps between different experts, allowing for fluid dialogue that all parties can understand. In this way the samples enable further exchanges in a second round of interviews using conversation as a way of eliciting insights (Ayres and Hall, 2008), and checking the validity of the use of DfD in different contexts. They cement the roles of the different parties in providing examples for what DfD for textiles can be and defining the author as a specific type of material expert and designer.

Three new groups of experts, from the textile manufacturer Climatex, the eco-design agency Cooperative Mu, and the start-up Circular Fashion, with experience respectively in textiles for disassembly, life cycle analysis, and circular fashion, were consulted. The main insight across these three conversations concerns the potential for innovation

through the application of DfD strategies. Indeed, the samples proved to be valuable props to start imagining ways in which DfD could be used in the type of products that the experts had some experience with, thus starting to solve issues that they may have encountered in their own work. Moreover, opening the research up to outsider's points of view allowed the researcher to return to the work with a fresh perspective and challenge some elements which had been taken for granted from the beginning of the project, such as for example the end-of-life recycling phase as the ultimate aim of the textiles. While DfD is a useful strategy to allow for recycling at the end of life, designing only for end of life with no consideration for the use phase should be avoided. Disassembly for the sake of disassembly is not enough. Quoting Mr. Baumeler from the interview transcript: "if a client is thinking about the disposal of the fabric, they are not liking it, you have to convince them through positive use phase characteristics".

This therefore sets a marker for the assessment of the DfD models developed in textile design practice. In this way, while the DfD principles must allow for the resources to return to their optimal recycling streams, there must also be an emphasis on how these specific constructions benefit the user experience during the product's life cycle. As demonstrated in the mapping with the connection to wider circular economy considerations, DfD can be an opportunity for added functionality that improves the user experience and contributes towards expanding the use cycle of the object. It therefore becomes important to measure the effectiveness of these other design characteristics in the object and to assess the levels of innovation they display. As observed in the case studies for DfD in various fields, a disassembly feature can lead to various types of "corollary" characteristics, from ease of updatability to modularity with an element of play. In the same way, textiles designed for disassembly can provide added functions during their use cycle such as customisable surfaces or attractive functional elements.

Challenging the way textiles are assembled can lead to opportunities for core innovation. Starting afresh in combining materials in new ways can provide a blank canvas for the development of original textiles. As argued by Parisi et al. (2017), this type of material tinkering approach in building a design concept from the materials up, is instrumental in generating meaningful innovation. The mapping of the design process allows the creation of a blueprint for the integration of DfD within creative textile design practice, and these DfD strategies allow for the creation of a new impulse to solving blend-related problems within product design.

Conclusion

This paper has shown how textile design practice can be harnessed in response to a circular economy challenge. While this field is usually averse to a brief-based and problem-solving focussed approach, the free-flowing methods of making textile allows to explore the creative potential of challenging the status-quo in the production of blends. By creating textiles that combine different resources in a "bisociative" activity, while avoiding contamination between resources belonging in different recycling streams, a range of original techniques for assembling textiles components at the yarn and fabric scale have been tested.

Furthermore, the study of the results from this craft-base and tacit-knowledge rich practice in a retrospective visualisation of the design process has shown how the concept of DfD has been explored at the textile level through iterative making. This has allowed to draw patterns and understand the implications, challenges and opportunities of different techniques and assembly methods in the broader framework of a circular economy. Using these samples in further research has also shown their value as conversation starters with different stakeholders in the field, and let them become, in their own turn, triggers for innovation at a product design level. In discussing disassembly through these proof of concept textiles, guidelines for future practice can show ways in which to design textile blends in a circular economy.

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Product Lifetimes And The Environment

Everything That Went Wrong: challenges and opportunities in designing and prototyping long-life garments in a circular economy

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Keywords: design-led design research, production models, collaboration, communication
Abstract: This paper considers the case of the Service Shirt, a proof of concept prototype made as part of a design researchers in residence programme at a fashion brand, within a scientific research consortium. During the development of the concept to prototype stage, many problems arose. In this paper the two authors - co-creators of the prototype - explore the challenges encountered when confronting the theoretical framework of new circular economy business models with the material reality of design collaboration and prototyping. The authors argue for the potential of design-led investigation to expand the lifecycle of garments and offer new insights to understand the challenges of developing circular prototypes within a linear fashion production model. By analysing the different stages of the design and prototyping phase through a combination of adapted annotated portfolio and after-action review methods, four main elements of the project were identified as potential focal points: collaboration, the design challenge, manufacturing, and materials. Throughout these categories, it was found that communication and effective transfer of knowledge were keys to success. For each of these aspects, the authors suggest how the design process may be improved in future iterations.

Introduction

In the light of current environmental issues, it is widely acknowledged that new practices and business models for the production and consumption of goods must be put forward. The circular economy provides a model for the perpetual reuse of resources in industrial and biological cycles (Webster, 2017:19), and new technology developments enable recovery and recycling of an increasingly wider range of materials are making this increasingly attainable (Östlund *et al.*, 2015:15). Moreover, new business models are emerging to challenge linear and wasteful practices (Ellen MacArthur Foundation, 2015:4). In the case of fashion in particular, whole systems need to be redesigned to provide alternatives to the current fast fashion paradigm (Fletcher, 2008).

Yet for these circular models to be applicable to products and materials, they must be designed with their end-of-life in mind from the outset (RSA and Innovate UK, 2016:3). Indeed, design is considered accountable for a large proportion of the environmental impact of goods, pointing at opportunities to implement meaningful change, not only extending lifecycles, but also making sure that end-of-life can be the starting point for new products (Bakker *et al.*, 2014). Thus, textile designers are in a valuable position to tackle issues at the very beginning of the design process (Earley and Politowicz, 2013). Yet there is a distinct lack of research from this perspective; this work aims to explore the gap.

Context

In terms of a collaboration with industry, the Service Shirt takes a far-forward, or deliberate extreme perspective on long-life garments, pushing the concept as far as possible to explore the most ambitious components of new fashion systems. The Service Shirt suggests a model in which a polyester shirt goes through a 50-year lifecycle, first being overprinted several times, then combined to an outer layer to become a jacket, and then cut into strips and upcycled into high-end jewellery before being fed into a chemical recycling process at the end of this extended lifecycle. The use and business model surrounding this garment encourages sharing between users and brand responsibility over the resources.

Methods

This research puts creative textile design practice and reflection at the centre of this exploration into new fashion models. The discipline of textile design is characterised by

the importance of hands-on making (Igoe, 2013:59; Marr and Hoyes, 2016:3), and this has been used as a tool towards a better understanding of the potential for long life garments in a circular economy and has led to a first-hand experience of the challenges this incurs.

Three designers were involved in the different stages of the garment's transformation, a print designer and lead researcher (author1), a design for disassembly textile designer and PhD researcher (author2), and an artisan jewellery maker. In designing for end-of-life, each had to consider the next stage of the product from the outset of their own design process, and reversely, consider the state the garment would be in when reaching them and inform the designer of the previous stage of their requirements for their 'raw materials'. This meant that the design concepts for each stage of the shirt's lifecycle evolved concurrently, feeding into each other in terms of technical parameters but also of aesthetic inspiration. This sequential and iterative process can be compared to traditional prototyping (Brown and Katz, 2009:94) but the authors reflect through this paper on the ways in which the questions, conversations and decisions differ when making a circular prototype.

Figure 1. The adapted annotated portfolio process. © Author2.

To aid the reflection process, the prototyping stages were mapped out as a chronological sequence using an adapted annotated portfolio method (Sauerwein *et al.*, 2018:1157) (Figure 1). The insights from this process were then drawn and made into a table in an adaptation of an "After Action Review" (Morrison and Meliza, 1999) or de-briefing phase. Key moments for decision-making and where problems were experienced were identified, leading to a better understanding of the challenges and how they can be overcome and seen as design opportunities (Petroski, 2006:49).

Analysing Shortcomings

The prototype was successful in demonstrating the potential for long-life garments in a circular economy and this collaborative experimental work resulted in a series of aesthetically pleasing and conceptually strong garments. This paper focuses on the elements of the prototypes, either in the process or the result, which the authors consider as having potential for improvement.

Confronting the concepts of a circular economy for textile products to the reality of prototyping and production has led to a number of insights regarding the challenges that this may entail. Indeed, textile designers are versed in "the application of big ideas onto small rectangular pieces of cloth" (Igoe, 2013:19), and the application of these textiles to a garment often comes as an add-on. Here the function and use patterns involved in the garment were included in the design from the first stages, drawing the textile designers out of their comfort zone (Lawson and Dorst, 2009:170), but in the process, leading to ambitious concepts for the systems this garment represents. Thus, bringing together zero waste fashion concepts (Rissanen and McQuillan, 2018) with the use of recycled materials, design for disassembly strategies (Forst, 2018) and upcycling methods (Brown, 2013), and coordinating them as one product, led to a series of obstacles.

These weak spots revealed in the prototyping process born most often from miscommunication, assumptions, inflexibility and technical limitations led the authors to question how the concept would transfer to industry and start proposing how these could be amended in future iterations.

Upon analysis of the process and results of the prototyping, the researchers classified the different "things that went wrong" into four themes relating to elements of the prototyping: collaboration, the design challenge, manufacturing, and materials. Each of these themes led the authors to reflect on how future iterations may be improved.

Collaboration

The circular garment prototyping brought together three designers with different approaches to - and understandings of - products and systems. While this allowed for a rich diversity of perspectives on the work and helped in driving concepts forward through ongoing dialogue, the communication difficulties between the different members of the team led to some challenges which resulted in shortcomings in the final prototypes.

The main barrier was to circulate knowledge across the team. Indeed, while the two researchers had an extensive understanding of circular design parameters, these had to be communicated to the artisan jewellery maker. This led to an understanding that some of the aspects that were essential to the circular garment concept were not an inherent part of this practice and required additional inputs. This for instance, led to the use of superglue in the production of the jewellery which was part of the initial practice but was ill-fitted to a circular garment concept.

Different tools were used by each designer, ranging from hand-sketches and experimental modelling to the use of software programs (Figures 2 and 3). This added difficulty in harmonising the different prototypes into a standardised garment system. Coordinating these different approaches proved challenging and created some extra work and compromises.

To overcome the difficulty in communicating and aligning the expectations for the prototype, closer collaboration between the members of the team could have been beneficial. Indeed, in this project, the collaborative work had to be balanced with other commitments, which made it difficult for all three designers to meet simultaneously and work for any extended period of time. Den Otter (2007) also suggests that in collaborative projects, the means for communication should be agreed on at the start, enabling more effective progress thereafter. In an improved iteration, it could be imagined that the project could be carried out in a "hackathon" format. This would allow to bring the skills of the designers together and limit the need for cross-communication.

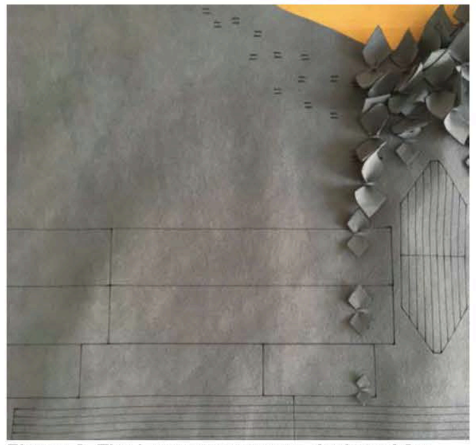

Figure 2. The laser cut garment designed for disassembly based on an Adobe Illustrator file made by Author 2. © Author2.

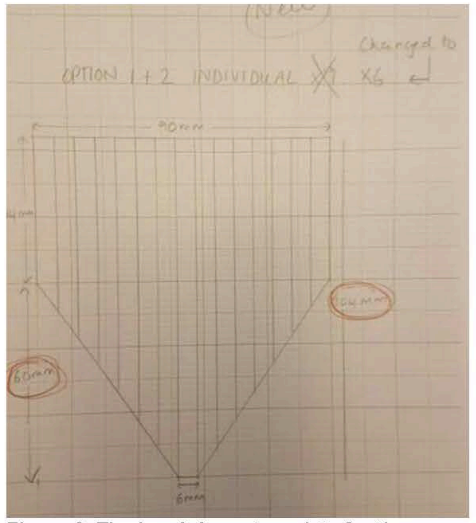

Figure 3. The hand-drawn template for the creation of jewellery which was then adapted into a computer file. © Author2.

The Design Challenge

In order to reduce the environmental impact of the garment, a zero-waste pattern cutting approach was taken. None of the designers involved in the project had expertise in this area and it was felt that bringing in an extra team member would add too much complexity as much time an effort was already invested in the collaboration between the three designers. It was therefore decided to develop a simple zero-waste shape that was within the limits of

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Everything That Went Wrong

the skills of the existing team (Figure 4). It was not anticipated how much the simplified shape would influence and limit the aesthetics of the finished garments.

The main aim of the prototype was to demonstrate the potential for a circular garment lasting 50 years in use through a series of remanufacturing stages. Adding a zero-waste component to the brief complicates the message and dilutes the findings. A more selective approach to the design challenge should be taken, picking the right 'battles' depending on the skills available in the team.

In the case where a zero-waste pattern concept should be maintained, then an expert in this field should be brought in. Circular design strategies very often work in clusters (Earley and Politowicz, 2013) and zero-waste would reduce the environmental impact of a long-life circular garment (Peters *et al*., 2018:22). In order to reduce the need to compromise on the aesthetic aspects of the garment, then a pattern cutting expert should provide key insights at the beginning of the process so that all the parameters of the zero-waste circular garment can be progressed simultaneously.

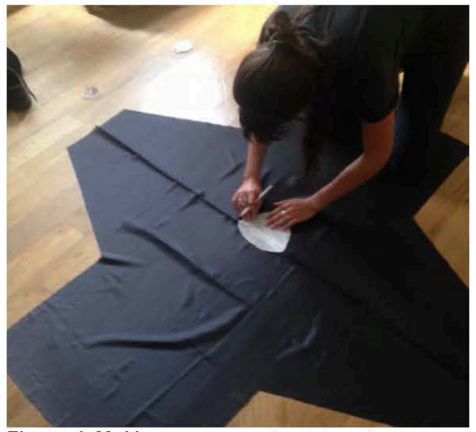

Figure 4. Making a zero-waste garment prototype. © Author1

Manufacturing

Given the limited skills of the design team concerning garment construction, help from the fashion brand's mechanist was sought. The fabric was sent to Sweden to be cut and assembled following instructions (Figure 5), however, the zero-waste concept failed to be appropriately communicated and the garments were made following traditional approaches. Furthermore, the finishing of the collar was inappropriate for an exhibition piece in which the inside of the neck would be left visible when presented on a hanger or on a flat table top. These prototypes therefore had to be amended by a seamstress when returned to London.

This failure to communicate circular fashion concepts to the production level is characteristic of the challenges encountered within brands to transfer sustainability targets to the shop floor (Vuletich, 2015:96).

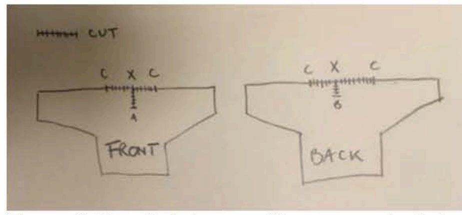

Figure 5. The sketches used to communicate to the mechanist how to cut the garment following zero-waste principles. © Author2.

Within the context of this project, this challenge coincides with the absence of a garment construction expert on the team and with the communication issues due to distance. To facilitate this phase of the prototyping it would be useful to collaborate more closely with an in-house mechanist with whom an ongoing dialogue regarding the expectations for the prototype could be developed.

Figure 6. The cut and sewn shirt. © Author2

Materials

The materials chosen for the prototype were a recycled polyester for the shirt and lining, and a polyester felt for the outer layer of the jacket. The polyester shirt had beautiful drape and shine qualities, however the felt proved to be too stiff for the pattern of the jacket and gave the garment a boxy look. While this can be a stylistic decision, it felt unplanned to the authors and would benefit from being an aspect of the garment which is more controlled. In addition to this inappropriate quality for the garment type, the felt was difficult to use in the jewellery making techniques, which were subsequently simplified and adapted, to the detriment of the luxurious effect aimed for with these products (Figure 7). Moreover, it was found in later stages of the project that the felt in fact contained a polyurethane binder which causes barriers to the recyclability of the garment, therefore undermining the circularity of the concept.

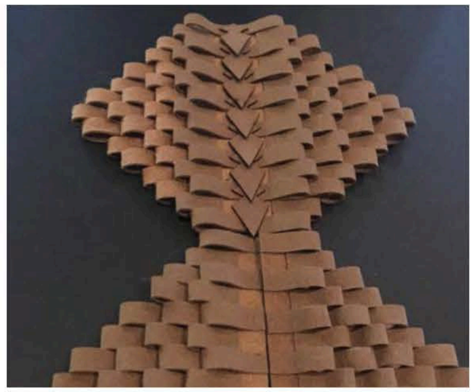

Figure 7. The new techniques for jewellery making based on the polyester felt material. © Source.

These issues highlight the complexities of material sourcing which many designers encounter when attempting to transition to more sustainable practices. Indeed, access to comprehensive information is often restricted. The difficulty in finding appropriate sources often leads to a design process in which the first phases of prototyping are carried out with placeholder materials. While this is common practice in product and interior design (Brown and Katz, 2009:90), when considering garment design, the drape and feel of the material is a major component of the product. It would therefore be useful to start the testing and intermediate prototypes phases with the correct materials and work in closer collaboration with the suppliers so as to better access key information.

Everything That Went Right

It is important to highlight some of the things that went right with the collaborative prototyping process too. Whilst all new collaborations have drawbacks – this one had clear benefits. The finished prototypes were shown in exhibitions in London and Stockholm in 2018 and 2019 (Figure 8), along with innovative work that explored 'ultra-fast' circular fashion. Showing and discussing the work in public has stimulated debate with both industry and academic audiences.

Figure 8. The final shirts, jacket and jewellery. © Jelly Luise for Centre for Circular Design, UAL.

Figure 9. The overprinted shirt patterns. © Author1

The collaboration between the project designers has enriched the respective practices – with the researchers understanding more about craft and industry practices, and the craftsperson understanding more about how research works. The designers at the fashion brand gained new insights from seeing how clothing can be co-designed with accessory

designers. The marketing team at the brand could see more clearly that being part of future circular projects would be beneficial. The over-printing shirt approach (Figure 9) gives clear guidance on how printed textile designers can design backwards from an end-of-life plan, using gradually darker tonal aesthetics. This print concept was directly informed by the work the jewellery-maker did.

Conclusion

Overall this paper suggests that to implement circular economy considerations within the design process, this process itself needs to be redesigned. Indeed, a truly circular fashion system cannot emerge from a linear design process. To achieve better outcomes for sustainable fashion, all the stakeholders must be involved in close collaboration at every stage of the design and things going wrong at least in this transition period must be expected and embraced.

The conclusions drawn from the four angles through which the challenges of designing long-life garments in a circular economy were analysed relate mostly to communication and the transfer of knowledge between the members of the design and production team. It is suggested that this type of prototyping could benefit from being carried out by the team in closer collaboration, sharing a studio and experimenting with materials and garment shapes simultaneously.

In a new iteration of the circular garment concept which was carried out following the analysis of the challenges, the insights from this process were taken on board and elements of the design were amended. In a similar way, it is intended for this analysis to allow for future circular design projects to progress with these challenges and opportunities in mind.

Acknowledgments

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11.4. Muto: Ecole Nationale Superieure des Arts Decoratifs Graduation Project

This appendix lays out the work produced for the final collection for the master's programme at École Nationale Supérieure des Arts Décoratifs Paris in 2015. As described in the introduction to this thesis, the Muto project laid the foundations for the exploration of Textile Design for Disassembly. While DfD is not directly mentioned in the Muto project, later reflection on the relevance of this approach led to articulate it as TDfD as defined in the thesis. This work explored how cotton and polyester, two incompatible resources when it comes to recycling, could be brought together in a home textiles collection without any permanent contamination. Some of the techniques developed in this project were later adapted to the TDfD framework. The text here is translated from French.

M U T O

Cyclic Materials

Laetitia Forst

Textile & Material Design - ENSAD 2015

How to introduce a cyclic vision of material temporality into contemporary habitats ?

The issues of environmental design and eco-conception are numerous and varied, and the questions that the urgency of the ecological situation pose have a strong bearing on me both as a designer and as a consumer. As a frame for this textile collection project, I decided to make a contribution to the exploration of one of these questions.
The subject I address here concerns the role that the materials of our habitats can have in a strategy for a more sustainable and resilient future.
First of all my goal is to envisage these materials within the frame of their cyclability. In this case the word cyclability is used in the same way as the designer and researcher Kate Goldswothy, whose work on the recyclability of textile resources has very much inspired me. A cyclic vision of materials therefore debunks fundamentally the idea of waste and advocates an eternal reuse of our resources. I chose to focus on the use of two basic materials, that, if used in a cyclic way, can be eternally recycled : cotton and polyester. Through ranges of interactions, juxtapositions, superpositions of these materials I explore the way they react to the passage of time. This project puts into perspective three different temporalities. The first one is the time of cycliclability as explained before. Then, throughout the use of these materials, comes the temporality inherent to their durability. This durability is defined by the wear inflicted by the user throughout the life of the materials. Finally comes the emotional temporality. Through my creative process I establish a form of unspoken contract with the user, inciting him to respect the ideas aforementioned and to establish a durable relationship with these goods.
My design research has been greatly inspired by the writings of various thinkers and researchers on the questions raised by different aspects of sustainable design. This project therefore aims at putting these ideas and visions into practice as a collection of materials for home design.

«Are we so hypnotized that we accept the mediocre and the noxious, as if we had lost the strength or the grit required to demand the good ??» Rachel Carson, *Silent Spring*, 1962

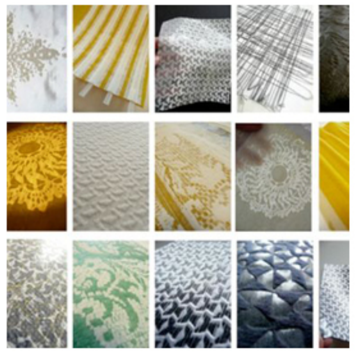
Cyclic design

Indeed, one the main problems caused by our rampant consumerism is the accumulation of waste in landfill that leaks noxious chemicals into the environment. This pattern is plainly unsustainable. To face the many issues coming our way in the context of demographic expansion, the idea of waste itself must be reassessed. Following the words of Michael Braungart and William McDonough from their manifesto for a cyclic industry, “Cradle to Cradle”, end of use products are to be considered as nutrients.
One of the causes of this waste of nutrients is the existence of what these authors call “Monstrous Hybrids”. A monstrous hybrid is a product or a material based on a blend that makes the different parts of that blend impossible to re-use as nutrients.
The notion of nutrient seems obvious is the case of nature’s bi-products : when an insect undergoes a phase of mutation, watever excess skin or matter it leaves behind is very quickly absorbed by the environment so as to fuel the development of other organisms. In the same way, since 2002 the Japanese company, Teijin recycles polyester through a chemical process that copies the ability of nature to melt down polymers back into monomers suitable to recreate a top quality polymer fiber. This allows the industry to recover the synthetic materials put into use for products and use them as “nutrients” for more desirable and new products. Thanks to this innovation, it is possible to recycle synthetic fibers in an eternal cycle, this as long as they are not contaminated by other compounds, thus becoming monstrous hybrids.
In a cradle to cradle industry, our waste should have the capacity to continuously feed a new and desirable production.

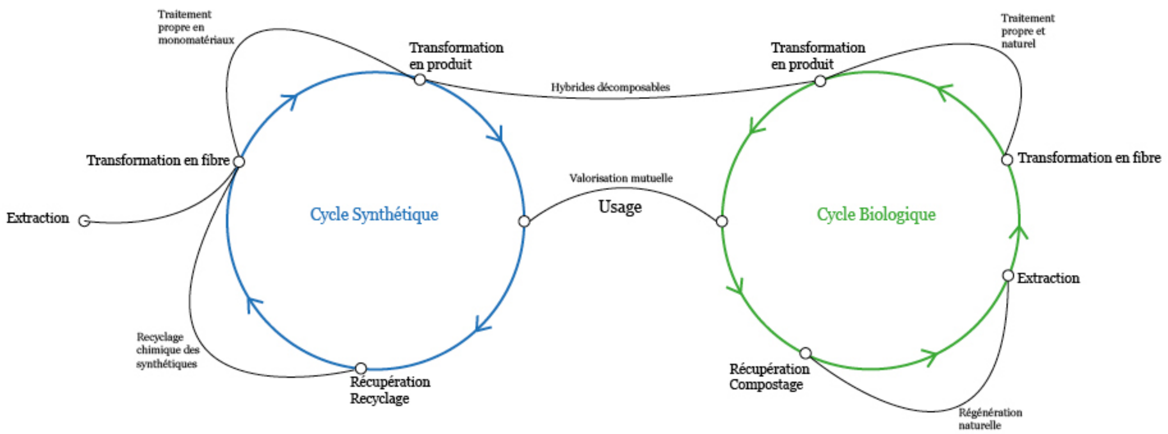
«Far more worrying is the waste of nutrients -a precious food for both nature and the industry- contaminated, wasted or lost.»

William McDonough et Michael Braungart, *Cradle to Cradle*, 2002

Susan Lee, Bio Bomber Jacket, biocellulose



Dr Kate Goldsworthy,monomaterial embelishment research



Material Temporalities

On the 31st of March 2015, Kering, in a partnership with the start-up Worn Again, publicized the development of their new technology allowing to chemically recycle textiles made of a blend of resources, allowing the inclusion of monstrous hybrids in a cyclic production and consumption model. However, what Cradle to Cradle fails to point out in relation to monstrous hybrids is the fact that in a very fundamental way, technical resources from petroleum are also a product of nature, only produced at a different time scale than other “natural” resources.
Although two resources such as cotton and polyester can seem radically distinct, one can still retrace their origins to a biological process. Our conception of petrol lets us forget that it comes from organic decay and is produced in a natural way.
The main factor that differentiates it from a material such as cotton is its temporality. If it takes up to hundreds of millions of years for nature to decompose organic matter to produce what makes possible the creation of all our synthetic fibers, it then seems obvious that the products made from these fibers should not be considered as disposable, despite what their very low market prices let consumers imagine.
This project aims to offer a new vision of the temporality and the weight attached to cotton and polyester, major participants in the creation of monstrous hybrids. In the cotext of my project, each of them are treated using techniques that are truly adapted to their specificities, they come together and interact to create a collection of home textiles and materials that express these material temporalities in a poetic way. In addition to the time scale differences concerning their production, cotton and polyester also have very different technical characteristics regarding their durability and their resistance. I chose to make the most of the functional distinctions of the materials in this collection by accentuating the way cotton wears and frays through time and by creating a narration around this process of deterioration.

«The rampant consumption and waste of natural resources so prevalent in the developed world is a legacy of modern times, born largely from the inappropriate marriage of excessive material durability with fleeting product-use careers.»

Jonathan Chapman, *Emotionally Durable Design*, 2005

"How can designers begin to approach working with materials differently, desi-gning them with a recycling system in mind at the outset?"

Kate Goldsworthy, Design for Cyclability: Pro-active approaches for maximising material recovery, Making Futures Journal Vol 3 ISSN 2042-1664

Carole Collet, Suicidal Textile

Emotionally durable design

Through the visible evolution inflicted by the user on the product, I aim to create an empathic bond and emotional attachment. As developed by Jonathan Chapman in "*Emotionally Durable Design*" the environment issues linked to the abundant waste that ends up in landfill can mostly be traced back to a failed relationship between user and product.
As part of a DESIS Philosophy Talk (ENSAD, 08/04/2015), Ezio Manzini concluded his speech by bringing up one of the aspects of a designers work that he considered most important concerning sustainable design strategies : The role of the designer is not only to resolve the technical issues in the environmental crisis, but also and more importantly, he could be the person who defines the new stories we want to write, the poetry of this new and more resilient world we are trying to build together.

"Keep the magic alive: make sure that a few cards are concealed up the object's sleeve, if a product relinquishes all meaning in a single fleeting glance —experientially — consumers have nowhere left to go. By designing products to patiently deliver a series of future discoveries and revelatory happenings, the life of an object is dramatically increased as users remain captivated in anticipation of the next event."

Jonathan Chapman, *Emotionally Durable Design*, 2005

Muto

The story of this collection called Muto, the words that carry all these fairly abstract meanings and make them more tangible and desirable, is that of a little insect. Moths evolve through many different stages, moments of slumber, of frenzied activity, latent waiting or wise maturity. These phases are like an expression of the temporalities of the materials. Each phase and the transformations it carries with it reveals many fascinating stories of natural adaptability and effectiveness regarding the environment. I am particularly fascinated by the idea of cycle and of perpetual regeneration that is illustrated in this symbiosis between the beauty and the poetry of the insect and the way it's adapted to its surroundings. It does not know the concept of waste since even if its multiple transformations leave some residue in their wake, they always have a part to play in a more global and cyclic approach to the environment.

Insects often have latin names and in this language, Muto means "I change". This collection expresses this idea of change at a very emotional and close to the user level. On one hand it shows the change I would like to see in the world : a more sensitive and reasonable approach of the place and the durability of materials in a global and cyclic understanding of our surroundings. On the other hand, this title brings to mind the change and progressive mutation of various parts of the collection according to wear produced by the users.

Through a survey on estimated life expectancies for home textiles and experiments of material decay in furniture upholstery, I explored the temporalities of interior fabrics and materials in the context of a living-room. This collection harnesses these evolutions and plays, in a poetic way, with our perception of the materiality of our surroundings.

The four main stages of the evolution of a moth dictate the structure of this project : Chorions, Caterpillar, Chrysalid and Imago. As they do in nature, these different stages coexist and create a balance that bears witness to natural cyclability.

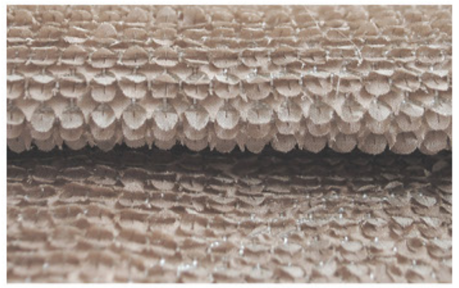
Testing and understanding material decay in a living space

To put into practice the issues that I am interested in related to emotionally durable design and develop materials that create a form of bonding with users through time, I investigated the possibilities offered by the huge gap in material durability between cotton and polyester.

By creating an assemblage of two materials that decay at different speeds, I offer the possibility of a form of story-telling that unfolds throughout the life of the material. It is subject to the passage of the users over time and bears the marks of their day to day use.

Through a series of tests enhancing the effect of different types of decay, I was able to select the shapes and materials that made this evolution the most obvious.

Accelerated use by rincing



New fabric

1 rince

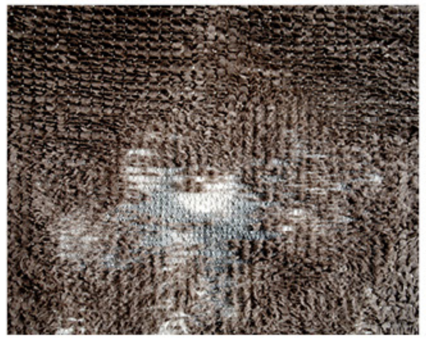
2 rinces

3 rinces

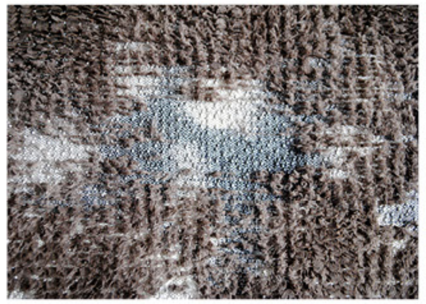
Accelerated use by friction

New fabric

10 min



20 min



30 min

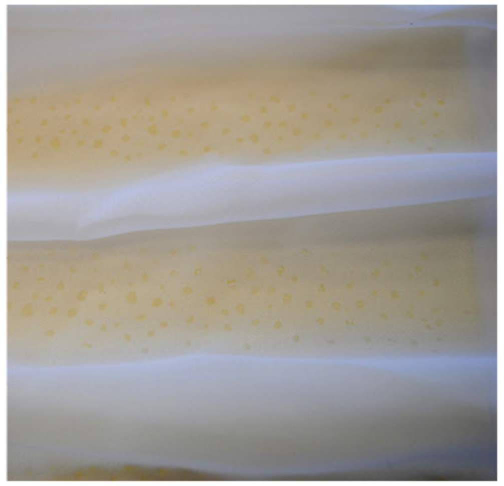
Material experiments

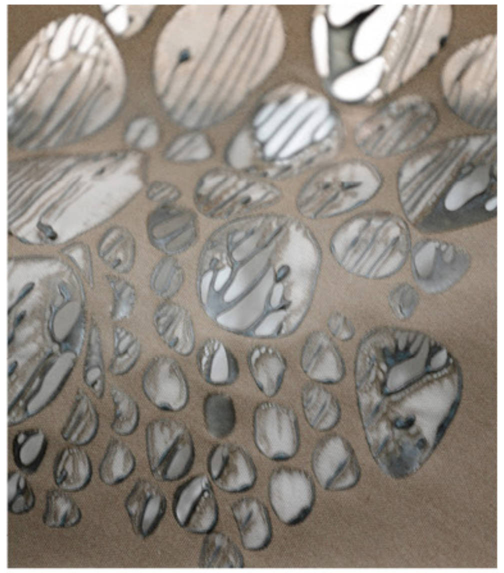
As I have developed an interest in two very specific and distinct resources, I first of all started by exploring the transformations and embellishments that I could develop based on their respective characteristics.
The essential choice that I made was to respect the recyclabilty of the resources. This guided my creative process towards the tools and compounds that could transform my two basic fibers, cotton and polyester, within this framework.

The products used to modify the aspect or the color of a fabric obviously have a very strong impact on their recyclability. I therefore specified the few compounds that I could use without changing these parameters.
In the case of cotton I use no dye or adhesive that is not completely biodegradable in its pure form. This brought me to focus on the use of natural dyes that don't require any toxic mordants and on various forms of natural starch.
As for polyesters, the company that offers the most effective chemical recycling can cope with a load of «impurities» that is up to 5% of the total weight of the fabric. My aim was to stay well under that limit, as close to zero as possible. To stay within these standards, I developed all the colors for polyester fabrics with transfer printing techniques. This treatment is the most environmentally light process for polyester since it uses no water and leaves no surplus of colour. I also used no adhesives that clog the fabric, focussing mainly on lazer treatments.

These «restrictions» became a form of creative boost, adding the thrill of a challenge to the pleasure of creation.

Polyester



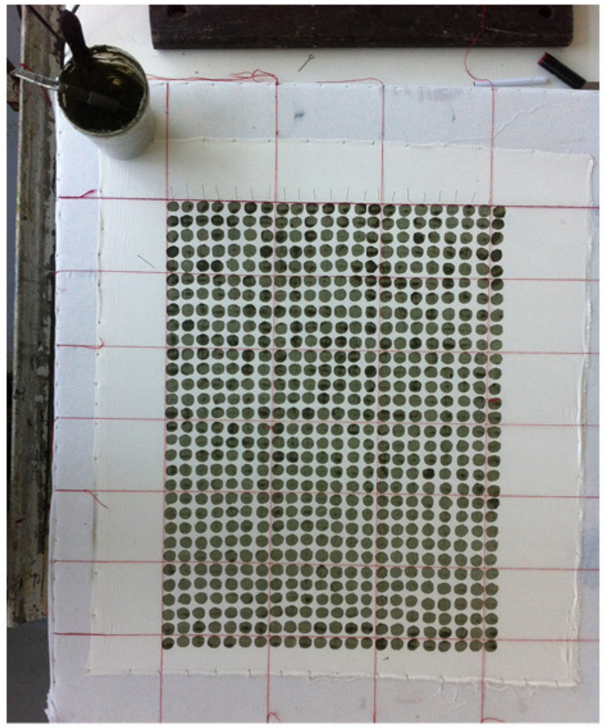


Cotton

Techniques

Concerning the tools I used, I chose them to fit the parameters I had established for my products. This led me to exclude the use of silk screens for printing. They are very often used in small or medium scale production to create patterns on fabric, however they are mainly made of polyester that is covered with a compound that reacts to light and makes it opaque in the desired places, this stops the polyester from being recycled once the tool is no longer in use. Hence I developed different tools for textile printing.

For cotton I developed and adjusted various traditional methods such as katagami edo komon, a japanese technique for reserve printing or papier maché so as to make them work with natural dyes and starch. As for polyester, it is a wonderful fabric that reacts incredibly well to heat so I explored the possibilities of laser cutting to create embellishment.



Moths

A story of cycles

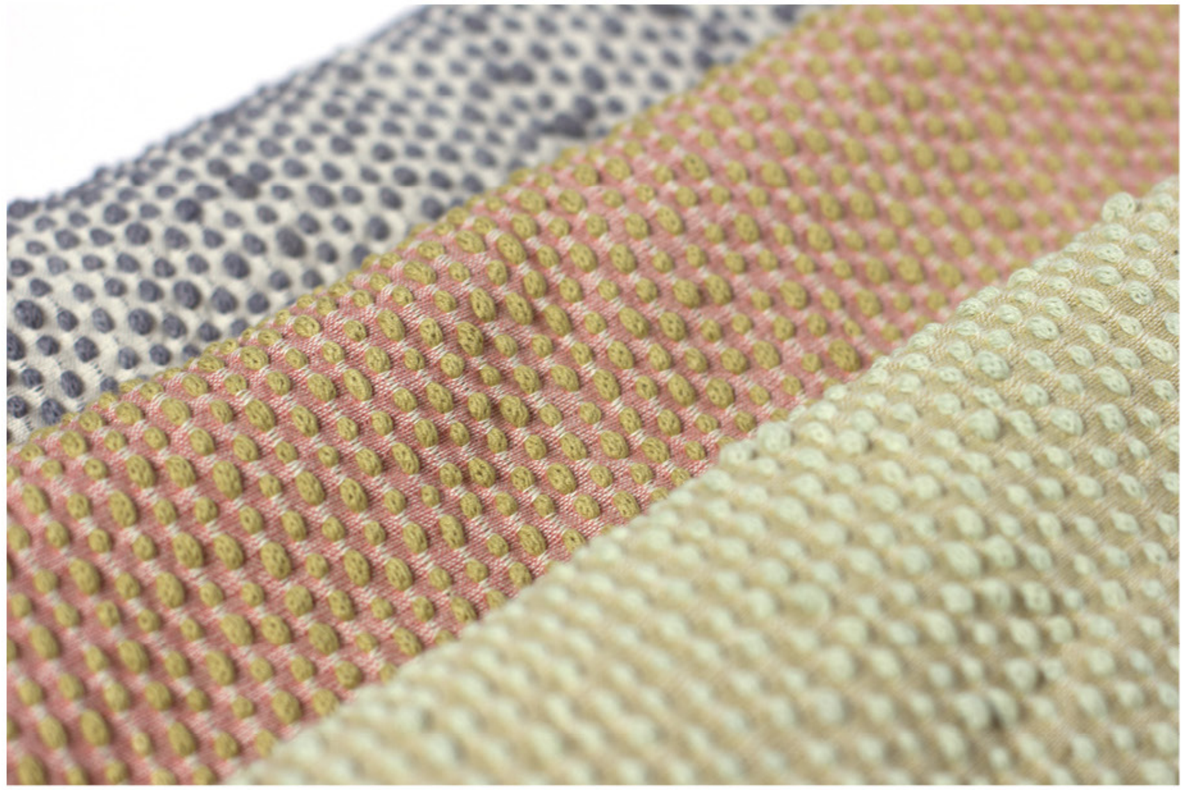
Since Greek antiquity butterflies have been seen as symbols of rebirth, the spectacular and very different stages of their evolution are considered to be metaphors of human transformation. This insect incarnates profound ideas on life after death and eternal souls.
I decided to set aside the exotic specimens of butterflies with colored wings and astounding patterns to concentrate on the more humble and often forgotten species of moths. The incredible stories linked to these insects led to the patterns and textures in this collection through the four main stages of there evolution : Chorions, the eggs about to crack ; Caterpillar, the active and voracious larvae ; Chrysalid, the latent transformation and Imago, the subtle adult.

Chorions

Moth eggs are laid on the leaves and branches that will serve as meals once the larvae have hatched. Creating various patterns according to different species, their shapes are often very intricate. Seconds before the eggs hatch, the shell becomes transparent, allowing us to catch a glimpse of the life within that is about to crack the surface. To stick the eggs on the leaves, the mother butterflies use a form of glue that leaves a small mark after the eggs are gone. The shells on the other hand are completely consumed as they are most often used as the caterpillar's first meal.
To tell the chorions' story I focused on small details and on patterns within patterns, created by arrangements of accumulation and proliferation expressed by these tiny shells.

Seeds

Developed using only one type of cotton thread dyed with natural colours extracted from plants, this series of textiles enhances the softness of cotton for a use as light cover.

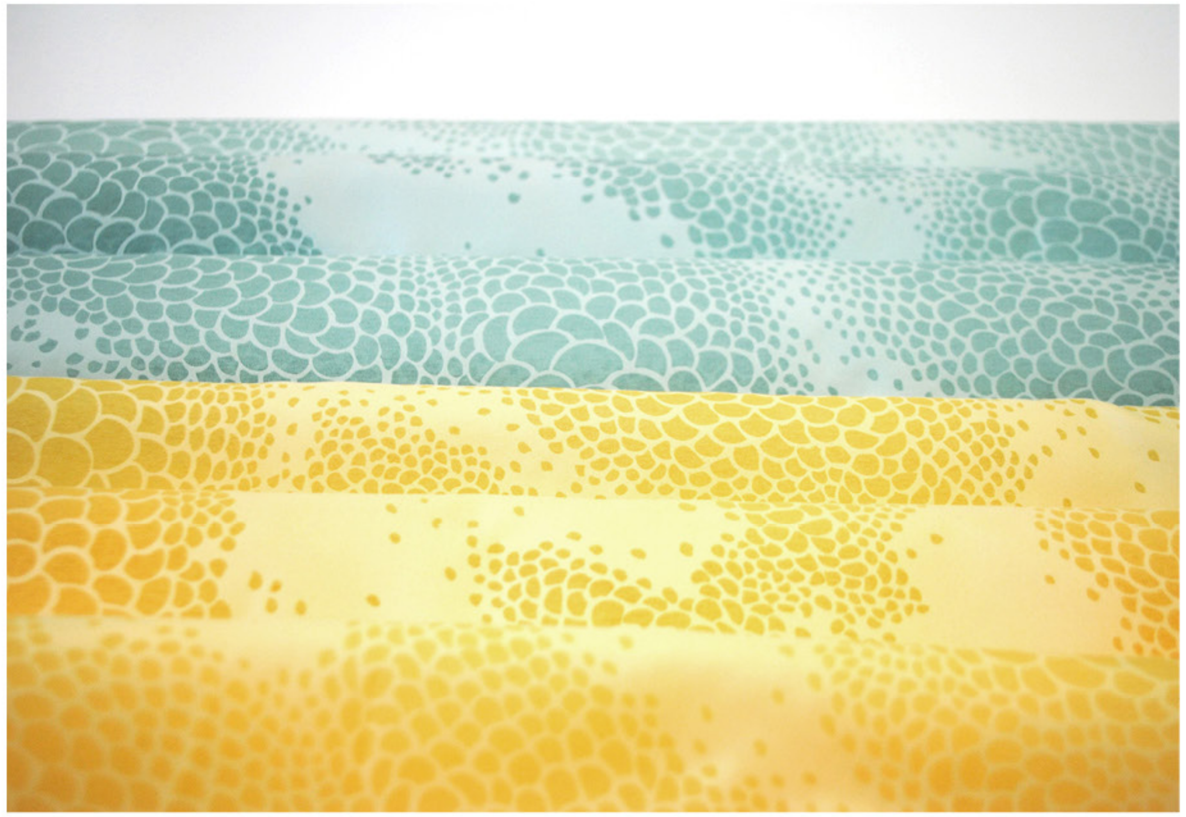


Shells

In soft hues of pink and brown these veils express that waiting state just before the hatching, slightly sleepy but already announcing the life to come.

Awake

The almost naive frailty and vitality of this primordial state of the moth finds its language in the colors and rhythms of these polyester veils.



Caterpillar

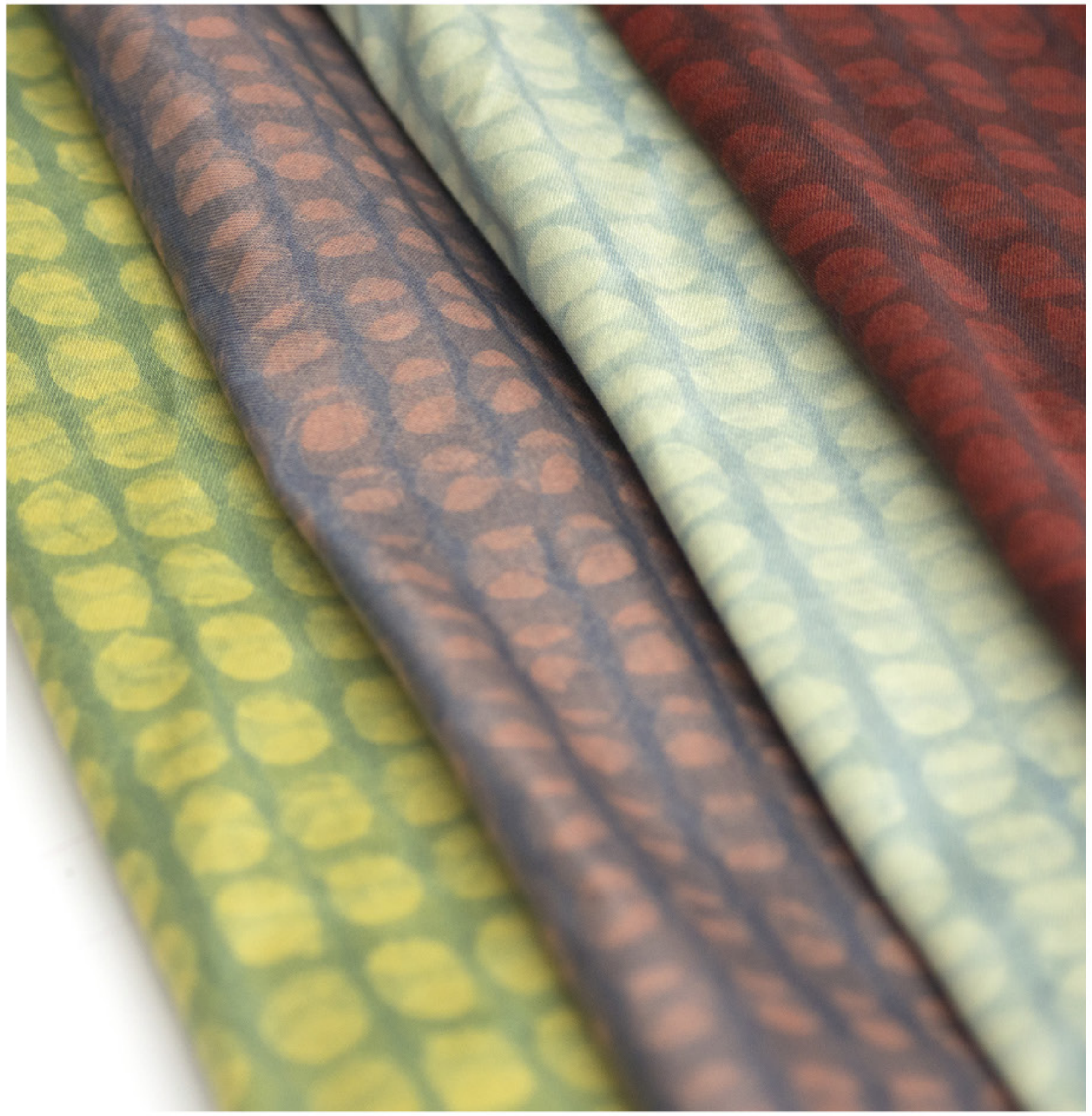
Caterpillars, or moth larvae show an incredible array of colors and patterns depending on the species they represent. Developed through survival of the fittest to protect themselves from predators during this vulnerable phase of their life, these guises allow them either to blend in with their environment or to send out toxic signals. Caterpillars also play mimetic tricks, pretending to have eyes all along their bodies so as to deceive their predators.
At this stage when they grow extremely fast caterpillars are vey voracious and change skin through a molting process up to six times before they reach their maximum size and settle to nymphose.
It is this dynamism and playful character that I wish to express through this series of materials, putting forwards surprising associations of patterns and colour.

Molts

These combinations of prints to be used as shades or curtains puts different techniques into play. Using katagami printing and natural dyes for the cotton bases, and transfer print for the polyester veils, I focused mainly on the interactions between natural and synthetic colors formed by the superposition of the different fabrics. The two patterns also complete each other, mingling the textures of the printed cotton with the color-blocs of the polyester. They incite to change your interior, using different combinations or only one part of the system so as to let one's interior evolve through the seasons.

Mimetics

Inspired by the dots pretending to be eyes on some caterpillars' backs, these prints on cotton satin highlight the possibilities of natural dyes for home furnishing.



Poisonous colours

This range of colours for upholstery makes the natural colours vibrate trough the thick weave, bringing to mind the strange colours that caterpillars use to ward of predators.

Chrysalid

This seemingly latent phase in the life of the moth is in reality a huge transformation. After having attached itself to a branch or burried itself underground, the caterpillars weave a silk thread around themselves so as to create a cocoon in which they will proceed to their spectacular transformation into an adult moth. All their body parts will be melted down so as to create the new organs and functions the moth needs to carry out the last phase of its life. This transformation can last only a few days or stretch out to several months, nothing is visible beneath the surface of the cocoon. Only a few seconds before the silk is broken, it becomes transparent, letting the crumpled patterns of the wings become visible for a few fleeting moments. Once the moth has hatched the cocoon is abandoned to be absorbed by the environment and become nutrients for other species.

The materials in this collection are inspired by the non-woven mantle the moth creates to carry out its transformation. Using recycled cotton dyed with natural colours, I developed a papier maché technique that can be shaped into various forms and uses.

Cocoons

These cotton screens create spacial boundaries yet still let the light through in a random and poetic way depending on the colours of the natural dyes, creating zones to rest and calm down.

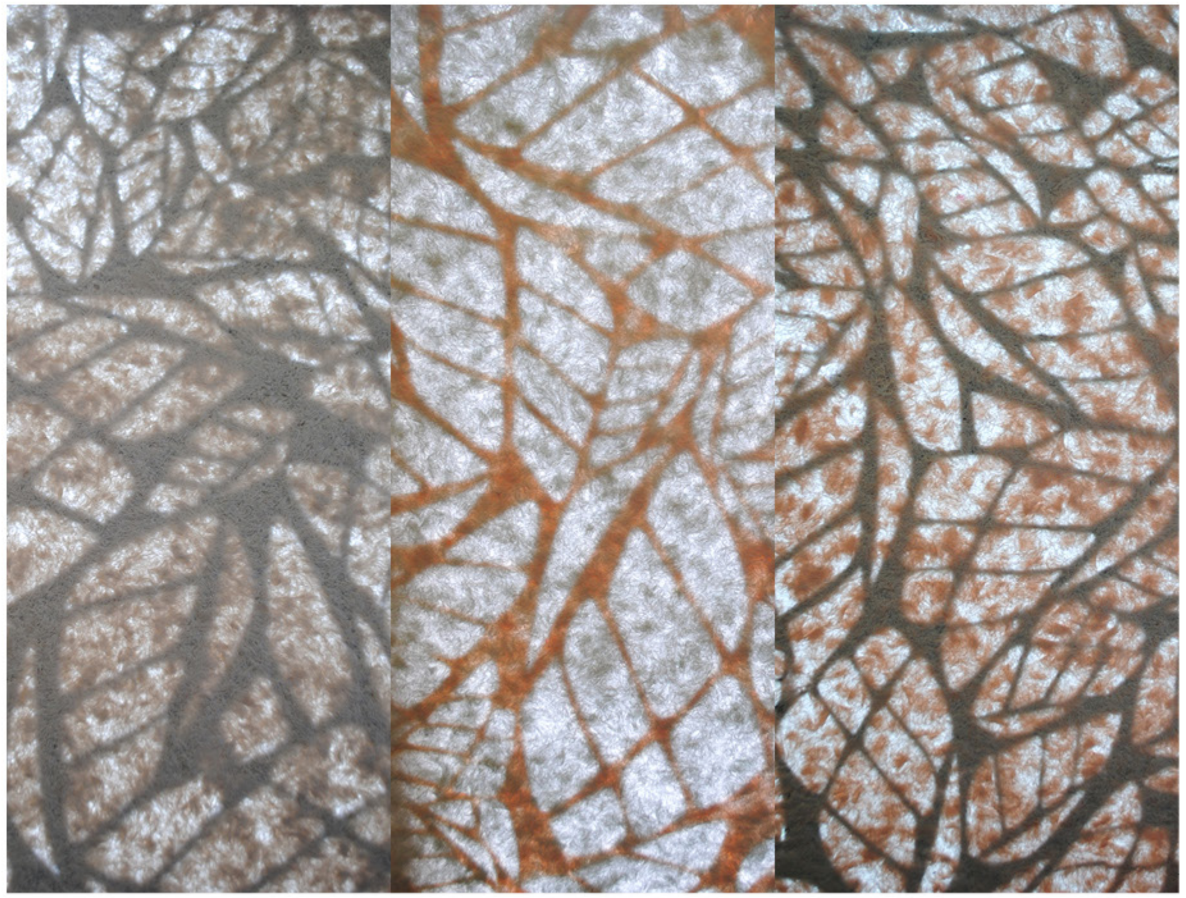


Hatching

This series of papier maché blocs, using a starch adhesive to enhance the time scale of cotton making the most of its capacity to age within a life time. The top level would wear off through time and reveal a new colour underneath creating a pattern under the steps of the users, marking the paths they use the most.

Transformation

Bringing to mind the few seconds before the hatching, these panels can be used as lamp shades or as screens to create a surprising effect when the light suddenly comes from behind and makes the patterns appear.

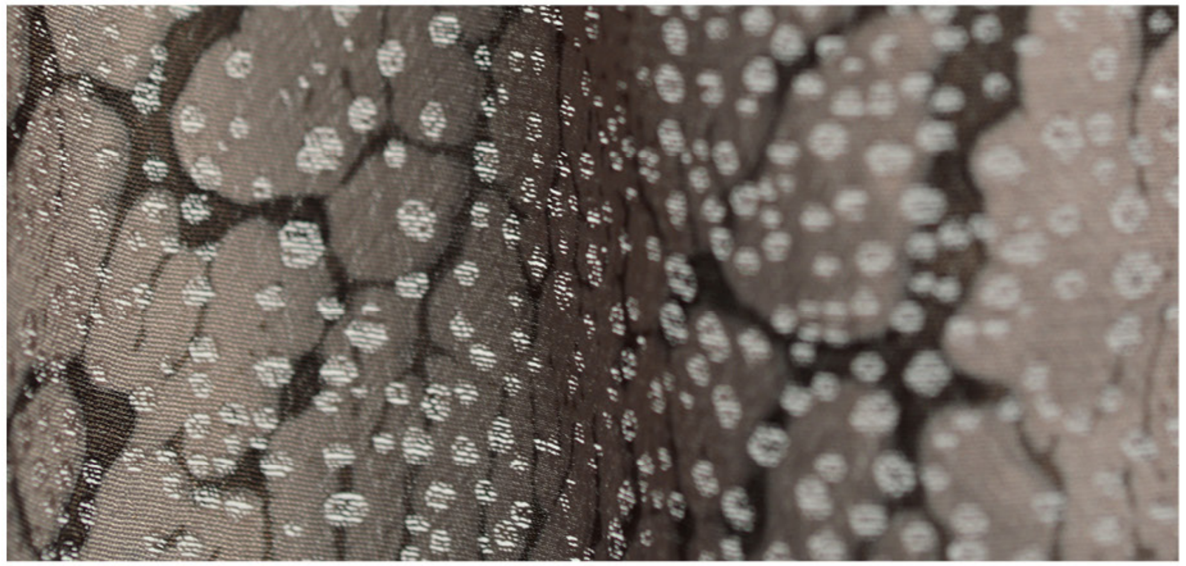


Imago

The adult phase of the life of a moth is often very short, it is however the shape we recognize the most. After having broken free from its cocoon, the moth seeks very quickly to reproduce, breaking its wings in the process. Some species don't even have a digestive system as their lives are so short.
I am fascinated by the subtle patterns that nature draws on their wings, in contrast to the bright colours found on butterflies, moths blend in with their environment, displaying subtle grey and brown shades that act as a form of camouflage. The scales on the surface of their wings give them a powdery aspect that wears off and turns into a shiny threadbare look.
I aimed to translate this frailty and beauty into a series of materials that evolve through time and take on more emotional value as they do.

Powdered wings

These polyester veils evoke the random patterns found on moths wings, and like these delicate limbs, when seen with the light behind them it shines lightly through them.



Traces of passage

Modeled on a view of a wing through a microscope, this material covered in scales decays under the feet of the users, letting a new pattern appear progressively. Using the different temporalities between the cotton scales that wear and fall off fairly fast and the polyester core that has a very long lifespan, this floor covering creates a narrative evolution based on how the users colonize the space in the room, highlighting the places that receive a lot of passage and leaving the ones that are hardly ever visited covered, thereby creating an emotional bond.

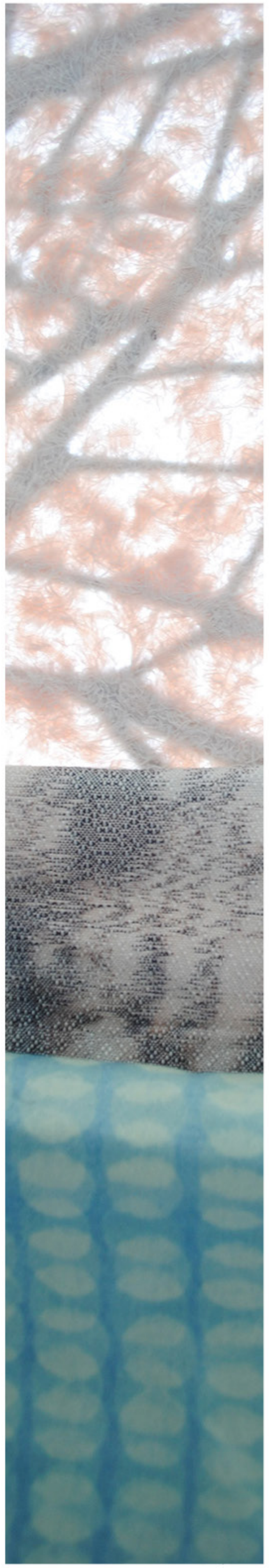


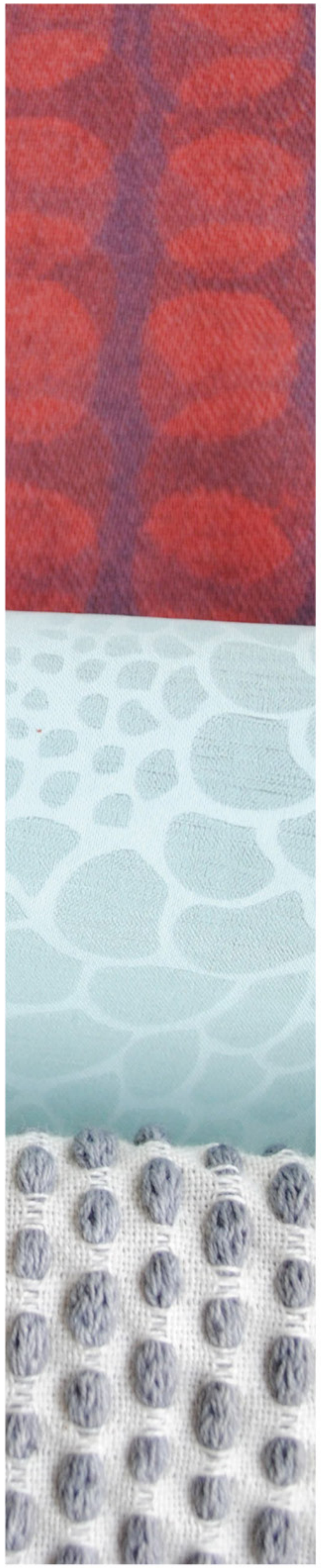

Ephemerals

Putting into action the techniques tested from the beginning of the project, this series of furnishing fabrics progressively evolves to let a new pattern appear underneath the scales.

Living spaces and combinations

In nature one often finds the various stages of moths in the same place, the phases being spread out over the season according to the individual specimen. In the same way, this collection is destined to be taken apart and recomposed to create new and different atmospheres in the living area through pattern and colour combinations. Through these interactions, the role each material plays regarding its temporality remains essential. The uses and the emotional weight of each product are balanced according to their environmental weight and the impact of its recycling. It was also very important to reunite the use of natural fibers with that of synthetic fibers, each resource having a role to play in both the development of a sustainable material production and also in the creation of a desirable and comfortable interior atmosphere.





Sustainable creation and theory

Beyond the collection itself, the research for this project allowed me to develop different processes to inspire a more sustainable textile creation.
The techniques that I initiated can be developed into a broader research into sustainability for materials. These techniques can be modified through the use different tools or new materials such as biocellulose or minerals, which have even more spectacular time scales.
These studies also allowed me to visualise the different paths to a more sustainable production and consumption. The people and ideas I met along the way opened my eyes to the numerous possibilities these environmental challenges offer.

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