Disassembly Discussed: creative textile sampling as a driver for innovation in the circular economy

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Bio

Laetitia Forst is a multi-technique textile designer trained at ENSAD Paris in skills covering weave, knit, print and other textile embellishment techniques. Her practice explores the tension between technical challenges and creativity in sustainable design for textiles. Her ongoing PhD research project at the Centre for Circular Design at University of the Arts London aims to explore design driven solutions for incorporating ease of recyclability into textiles. The project takes a pro-active approach to developing alternatives to the unsustainable status-quo the creation of blends through the use of design for disassembly (DfD), the design of products and materials that can be taken apart to divert their components from waste streams.

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 (Ostlund, 2015), to achieve fibre-to-fibre regeneration simple and mono-material textiles are still more economically and environmentally sustainable (Maldini et al., 2018). Creative textile design is, however, intrinsically linked to the juxtaposition and combination of different materials and techniques (Dormer, 1987). Moving away from a mono-material 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, 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 which can not only lead to original recyclable materials which combine resources for optimal performance and aesthetics, but also to elicit guidelines for the creation of textiles in the circular economy.

Keywords
design for disassembly; textile design; circular economy; making, sampling; design research

1. 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 simple or 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 blend recyclability barriers. 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, 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 the use of samples as tools for conversation, these strategies and further uses of the results of the making indeed point towards the development of guidelines for DfD for textiles.

2. 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 are first understood as a design flaw, and 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.

2.1. 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 also 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. Indeed, while 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 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 technique effective way. This ability to create combinations is an essential part of the textile designers 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 impede 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 suggest 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.

2.2. 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.

3. <u>Methods</u>

The work described in this article follows a design project method as described by the design council (Design Council UK, 2019). 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.

3.1. 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 resits 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).

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), 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. 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.

3.2. 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 is very much a gathering of data and inspirational concepts that feed in to the creative process that follows (Cassidy, 2011; Studd, 2002). Indeed 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).

3.3. 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 elicit patterns, as a powerful way of demonstrating 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.

4. Making Textiles for Disassembly

Based on a loose 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 with at which 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.

4.1. 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 therefore 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 involving 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.

4.2. Yarn based samples

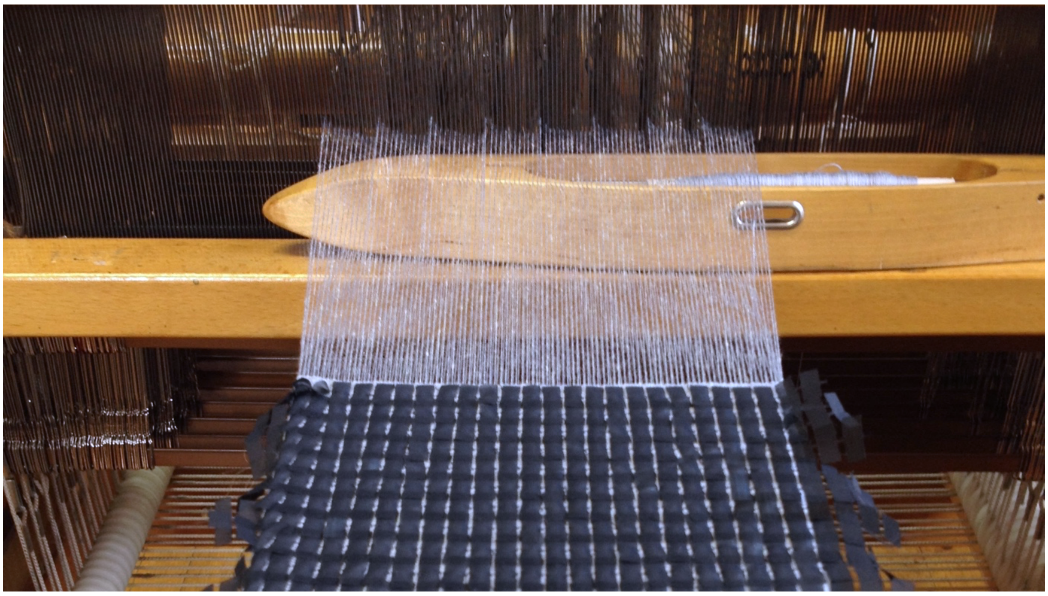

Figure 1. The warp on the loom

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 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, 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 two-sided samples, this varied from custom-made laser-cut yarn to nylon thread. Indeed, these samples followed closely from the insight gained through the interviews and mapping processes that some main barriers to recycling came in the form of coated and laminated textiles as well as in elastane blends which are made to achieve stretch. This phase therefore set out to suggest alternatives to these types of materials using DfD to enable potential recycling. As with the use of DfD strategies in other fields, this way of making textiles elicited new and specific aesthetic and haptic qualities.

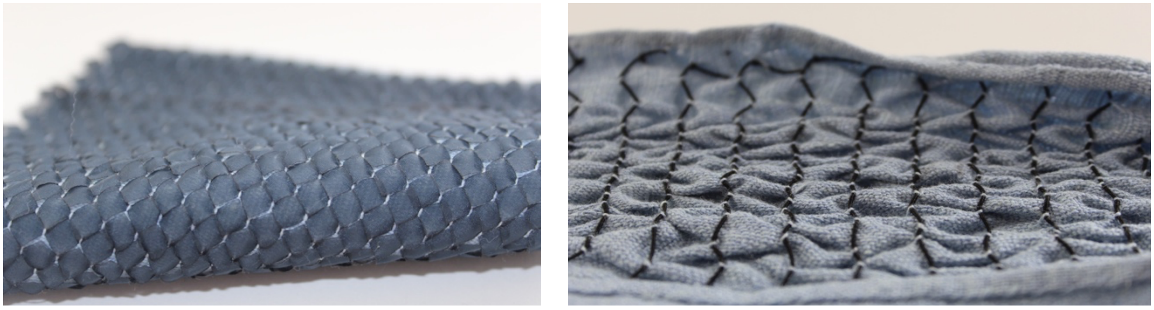

Figure 2. Examples of woven samples

The visual effects in the case of the stretch samples was close to what may be achieved using smocking techniques. 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 here, 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 Rosortec's heat reactive thread (*https://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, yet still externalising this functional component of the blend.

The same use of 'redundant' thread 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, yet 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).

4.3. Fabric based samples

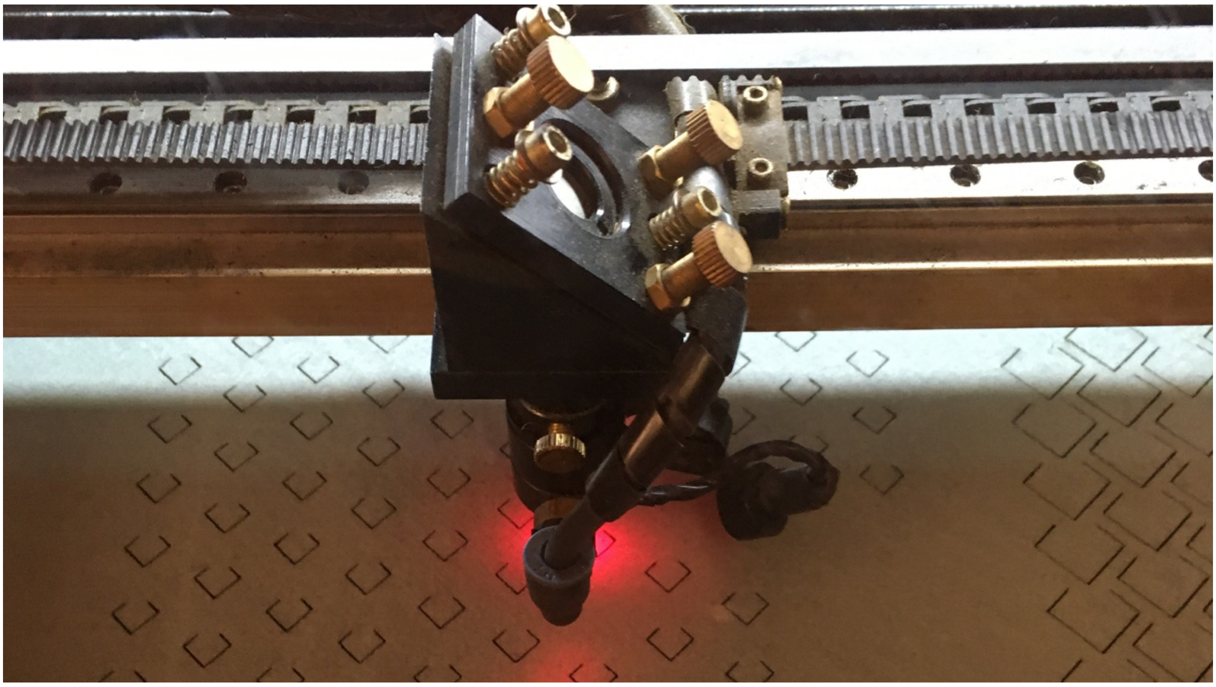

Figure 3. Laser cutting process

The series of samples based on fabric elements 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 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 similar techniques out 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 evolved 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.

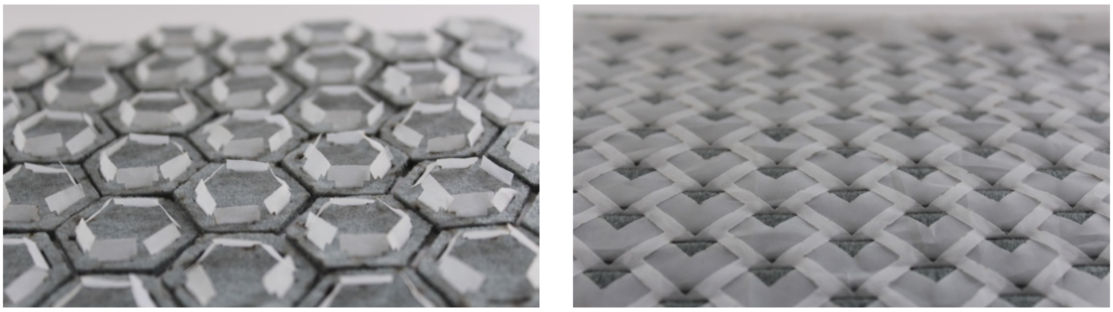

Figure 4. Examples of laser cut samples

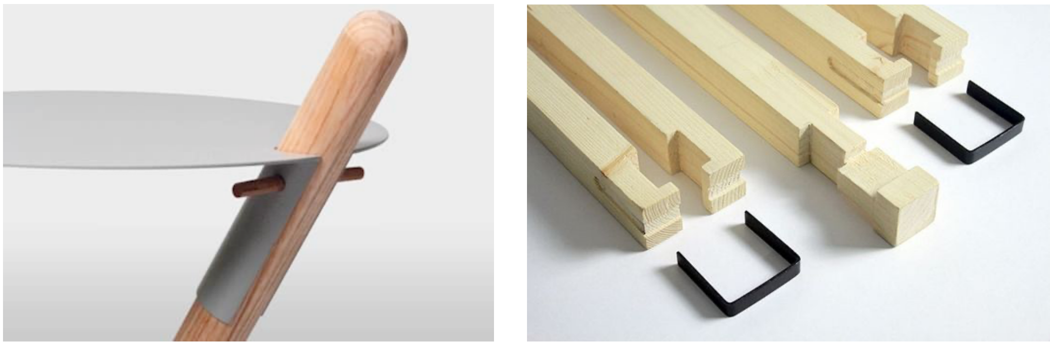

Figure 5. Inspiration from minimalist wood assembly systems: OOS Collection by Studio248 (left), and Nomadic Chair by Jorge Penades (right)

The laser cutting suggested the use of a form of dovetail assembly, directly derived from larger scale DfD approaches in product design such as with woodwork. *Indeed, minimalist assembly systems are often used in this field to put forward the intrinsic qualities of the materials. Ingenious ways of assembling different textiles 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 the products of application.

5. Discussion

5.1. Prototyping textiles for disassembly

While design for disassembly is fairly established in product design, 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 et al., 2015) and the Climatex's Duacycle (http://www.climatex.com/en/sustainability/textile-lock/) furnishing fabric. The production of this range of 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 forwards. On the one hand, 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. On the other hand, they 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.

These sample first and foremost are used to illustrate the ways in which DfD may be applied to the scale of textiles and effectively testing 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.

5.2. Tracing the thought process

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. 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 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). 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 to thoroughly examine the components of the design process without interfering with the flow of the activity in the making.

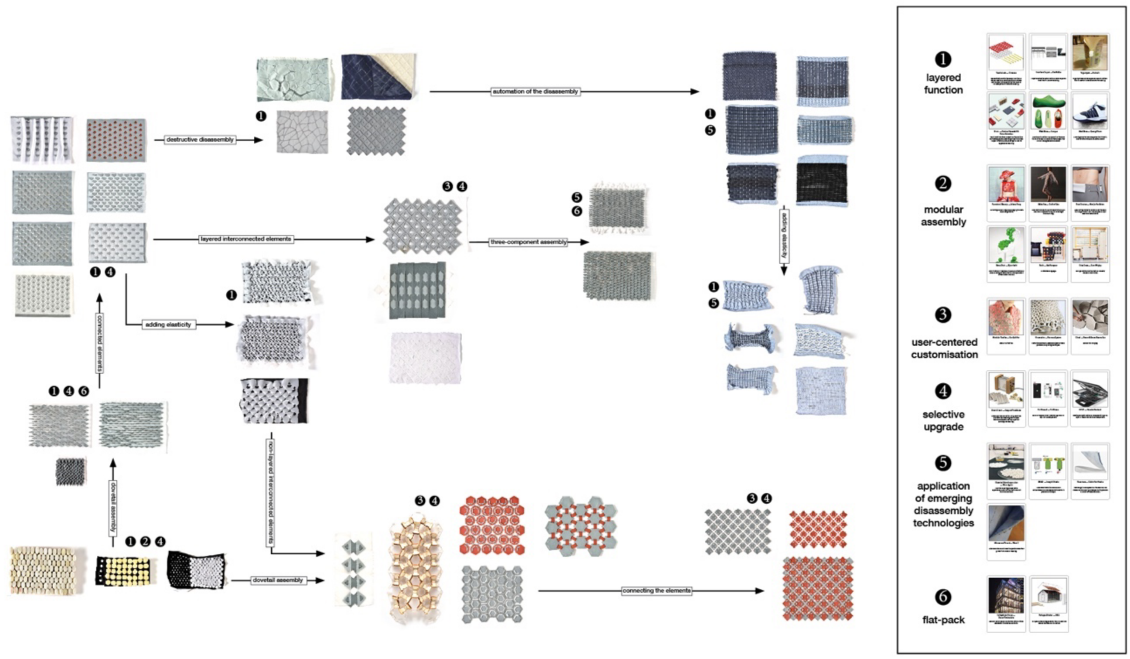

Figure 6. Sample mapping

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 this figure, 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. Additionally, each group of samples is connected to the concepts that emerged through the initial case studies, highlighting their influence as an inspiration.

This exemplifies 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 defines by Tufte (1990), visualisation assists in the recognition of patterns and generalisations, already an inherent quality 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.

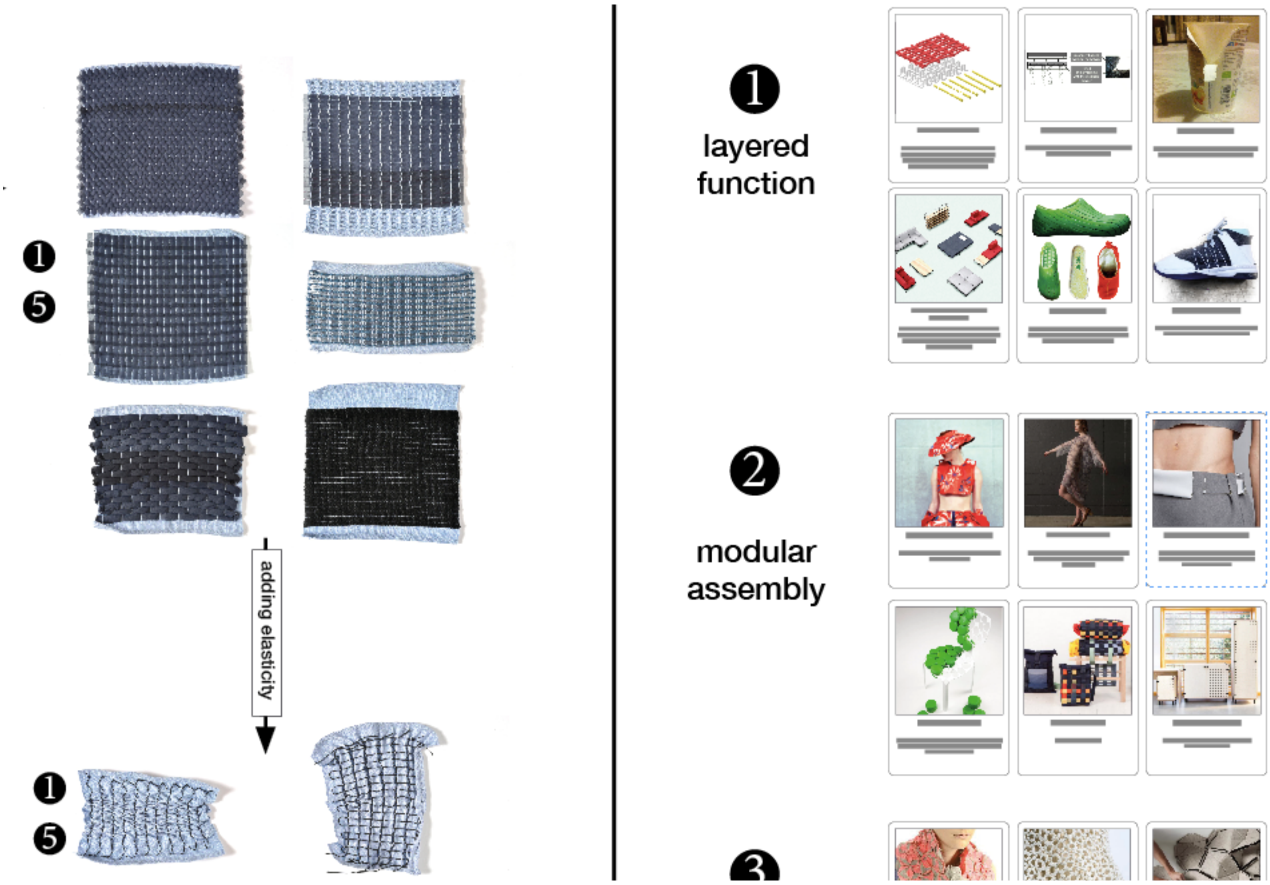

Figure 7. Close-up of the correlation between samples and the case studies

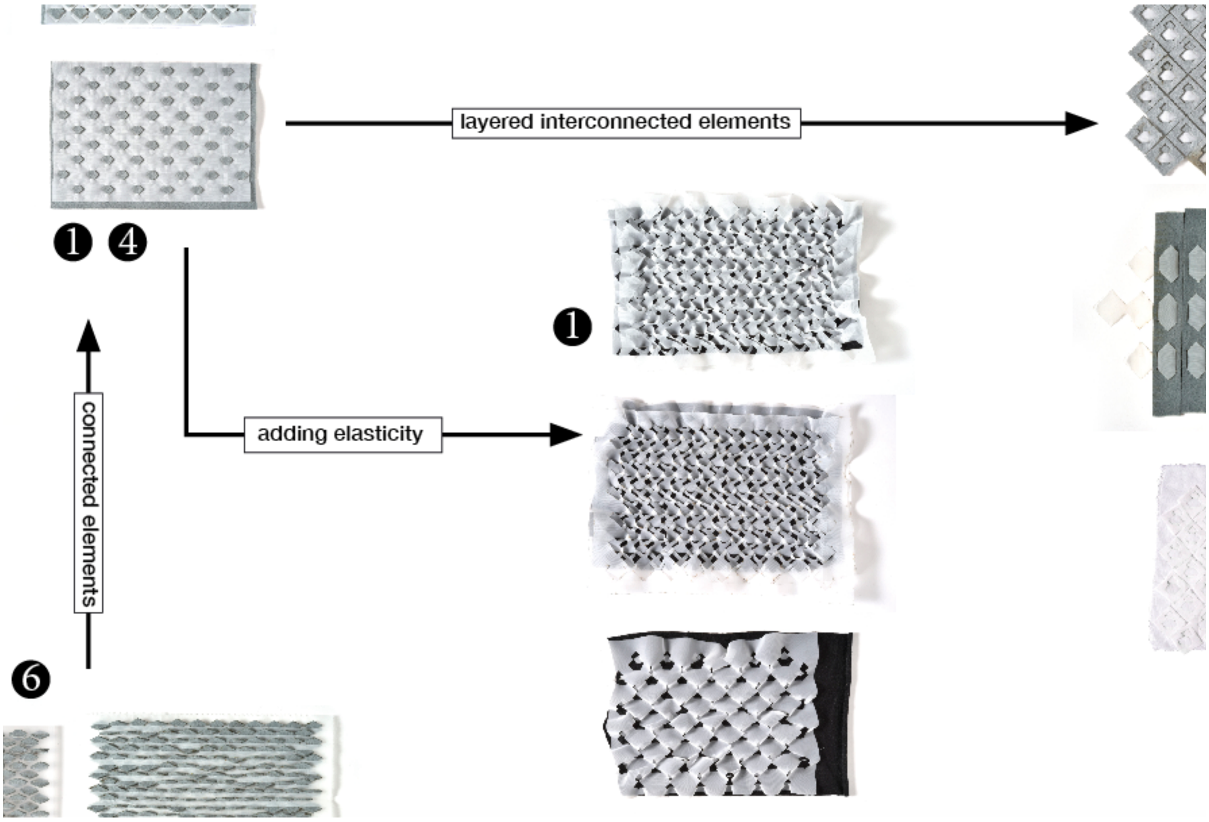

Figure 8. Close-up of the tracing of the evolution of concepts in the samples

5.3. 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 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 starts 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 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. Indeed, 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. DfD in this case, 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 interesting 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 to create a blueprint for the integration of DfD within creative textile design practice, and these DfD strategies allow to create a new impulse to solving blend-related problems within product design.

6. 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 "bissociative" 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. Using these samples in further research has also shown their value as boundary objects, a let them become, in their own turn, triggers for innovation at a product design level.

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