DESIGN FOR RECYCLING KNITWEAR

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This research has been conducted across the realms of academia and industry and brings together three roles: industry-designer, academic-researcher and industry-based-expert. The methodological contribution of this thesis offers a way of steering the researcher through academic and industry collaboration. Using this approach, the study investigates the mechanical wool recycling system in which acrylic fibres are the main contaminant. Knitted acrylic textile waste falls straight into recycling sorting grades, without any re-use market, and are regarded as the lowest value fibres. Using this type of waste, the research explores the role of blending, sorting and cascading (reframed as spiralling) to enable designers to use recycled fibres and ensure their onward recyclability. Spanning the recovery and manufacture stages of the product's life cycle, the 'Design for Recycling Knitwear Framework' proposes a way of extending the life of textile resources in the transition to a circular economy.

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DESIGN FOR RECYCLING KNITWEAR

a framework for sorting, blending and cascading in the mechanical textile recycling industry

CATHRYN ANNEKA HALL

COVER IMAGE: Practice 3, close up image of the carding machine processing recycled acrylic fibres

IMAGES: All photographs are by Cathryn Anneka Hall unless otherwise noted.

WORD COUNT: 84,382

DESIGN FOR RECYCLING KNITWEAR

a framework for sorting, blending and cascading in the mechanical textile recycling industry

Thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy (PhD)

University of the Arts London

Chelsea College of Arts

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CATHRYN ANNEKA HALL

ABSTRACT

The problem of difficult-to-recycle textile waste is usually laid at the designer's door. However, the strategy 'Design for Recycling' is not only underexplored in the field of textile design, but the solutions offered are oversimplified and impractical for the complex materials that we have been producing. At the other end of the spectrum, much of the fashion industry has committed to using recycled fibres in their products. However, good intentions are not translating into actions. This is due to a seemingly unresolvable tension between the designers, recyclers and sorters. The circular economy demands ever-increasing quality of recycled fibres. Any decreasing quality is condemned to downcycling or cascading. The quality of fibres is allegedly overcome by accurate sorting. However, the many different methods of blending used by textile designers makes this difficult.

This research has been conducted across the realms of academia and industry and brings together three roles: industry-designer, academic-researcher and industry-based-expert. The methodological contribution of this thesis offers a way of steering the researcher through academic and industry collaboration. Using this approach, the study investigates the mechanical wool recycling system in which acrylic fibres are the main contaminant. Knitted acrylic textile waste falls straight into recycling sorting grades, without any re-use market, and are regarded as the lowest value fibres. Using this type of waste, the research explores the role of blending, sorting and cascading (reframed as spiralling) to enable designers to use recycled fibres and ensure their onward recyclability. Spanning the recovery and manufacture stages of the product's life cycle, the 'Design for Recycling Knitwear Framework' proposes a way of extending the life of textile resources in the transition to a circular economy.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my supervisors Kate Goldsworthy and Becky Earley without whom this research journey, from a tiny spec of an idea to full thesis, would not have been possible. Thank you for being so generous with your time and knowledge as I have transitioned from research assistant to PhD researcher and now the next steps of my career.

This research would not have been possible without the funding received from both University of the Arts London scholarship and the Cotton Textile Research Trust which provided me with the time and funds to explore the mechanical recycling industry across Europe and test ideas on an industrial scale. To this end, I would also like to thank all of the experts who gave me their time to either talk to me online or in person. Special thanks must go to Recycler X and Hasnain Lilani for answering my endless questions and for patiently explaining how I had misunderstood the way sorting and recycling works in practice.

An exceptionally big thank you must be given to Laetitia Forst who became my PhD 'partner in crime' providing advice and brainstorming ideas. Thank you, also for collaborating with me to create the 'Circular Design Lab' discussion group and annual 'There and Back Again' symposium which we both admit was a slight distraction. Nevertheless, it was a rich and unforgettable experience.

Thank you also to my research family at Centre for Circular Design for their non-stop encouragement. They were always willing to share their experience when the path ahead was unclear. From across UAL, I would like to thank Veronika Kapsali who gave some me much needed additional feedback at the halfway point and Stella Klein for the many hours of support sessions that provided the clarity, writing structure and generally un-muddling of the research as a whole.

To my Mum, Dad and Step-Mum thank you for your unrelenting encouragement even when it did seem like I would remain a student eternally. Special thanks to my Grandad whose disbelief that the process could take this long kept me laughing in the final stages. Thank you to my Father-in-law for the hours spent proof-reading and Auntie Jo for seemingly never ending use of your spare room. Finally, the greatest thanks are reserved to my husband, Ed. Thank you for the constant love, support and many distractions (buying a flat, getting married and relocating abroad) that you provided throughout this experience. I, truly, could not have done it without you.

PREFACE

The journey before and leading up to this PhD was very much like being on a train that gets diverted, ending somewhere completely unintended. There are so few places in academia that provide the opportunity to give your reader the context for why you are doing research on a certain topic or why you conduct research in the way that you do. So, for this small segment of my thesis I will explain the background and circumstances which has led me to this point.

As it turns out, my mother was a very influential in my journey into research. A designer, maker and collector of 'things that might be useful'; make do and mend. In a time before recycling became the norm and zero waste influencers existed, you would be lucky to escape with your life if you placed an item in the wrong recycling bin. We even cleaned and collected the juice cartons which were not collected in our local area. These would be lovingly driven over the county border creating the best excuse to visit old friends and fill their recycling bins sky high.

My background is wholly in textile design. After being scared away from fashion, 'the devil wears Prada' style by my mother who told terrible tales of the villains of the commercial rag trade, I decided to take my Batchelors degree in textiles, yet I still managed to end up in fashion. The slog of unpaid internships finally saw me land my dream job as a knitwear designer in a high-street supplier. I worked with buyers, designers, technicians and produced trends, colour palettes, mood boards, new designs, move-on designs and core garment design with factories in both China and Bangladesh. I was a small cog it a well-oiled machine. For the Far East production the possibilities were endless, but it was the boundaries set by the hand-knitting machines in Bangladesh which became my favourite challenge. Most jumpers I designed were 100% acrylic and produced on mass for the British high-street. All design choices were made on the condition that the yarn and the time it took to produce came within that vital price point. Sometimes the knits would fail to meet the performance requirements but could be justified with a 'get out of jail free' swing tag. This would inform the customer why the jumper might pill quicker than usual, or the colour may transfer to other surfaces. No-one cared and there wasn't time for me to care either.

It was throughout my career in the industry that I concede my mother may have been right, never mind Prada - the devil may in fact wear Primark. I lost my job and felt lost. My education, up until this crossroad, had far from schooled me in sustainability. One tutor during my bachelors, Dr Katie Beverly, to whom I will be eternally grateful provided an optional module which covered a few of the basics. At this point, I had little concept of a circular economy let alone some of the complexities that are discussed in this thesis. Disillusioned by the fashion industry and woefully uninformed, I wanted to make a difference rather than continue to be part the problem. I set about establishing my own business and rather last minute applied to do a Master's degree in sustainable textiles.

Textile recycling from the outset was a great disappointment in many respects. But because of this it grew to be my passion and now my PhD. During my masters I read, and I questioned. If I couldn't find the answers in books I visited, and I learned. I have lost count of how many textile recycling plants I have visited. I have always learnt far more from speaking to the people on the factory floor than from the hidden knowledge found in the pages of a book. In particular, it has always frustrated me that you can't ask a book a question. The textile recycling (not re-use but the physical recycling) I was trying to discover didn't exist in the pages of a single text nor was it summarised by a single factory visit. It was a complex system and one, that in my mind, was just not good enough and was the driving force behind both my Master's and my PhD.

A year of study at Master's level was far too short to first educate oneself and find the solutions. That busy year was the prequal to this research. It is where I first understood the categories of waste textiles by visiting sorting facilities and reading about the circles, pyramids and staircase models that the academics suggested these garments should flow within. I needed more time. It wasn't until I met my (now) supervisors, my head buzzing with ideas, that they asked if I could draw the system that I, admittedly, was having trouble explaining. As someone who is unashamedly dyslexic, I have never been brilliant with words and this new freedom to draw pictures to explain myself was joy and a challenge. I filled physical and virtual notebooks drawing and redrawing the connections I had made. I had been drawing all my life as a designer and it had never occurred to me that drawing diagrams could be even more useful.

My next stop was working for Centre for Circular Design for a year. The influence of this year on my work was profound. It was an exciting time watching practice research happen before my very eyes. I was most fascinated by the work on the Mistra Future Fashion project in which the research ideas from the 'circular speeds project' were applied by Swedish fashion brand, Filippa K. More than just words on a page the ideas came to life and in a context where they could have impact.

It was the combination of all these circumstances that has led me to this very moment. None of them planned. This document is filled with the experiences and thinking that have grown out of my background to make this research project what it is. From the first time I entered a sorting facility, to producing my first recycled yarns, I am now reimagining systems and ways of working. I am even more excited to see where the next station stop will be.

CONTENTS

FIGURE & TABLES

FIGURES

*Pink text denotes figures & tables which appear in the practice sections of this thesis.

TABLES

1

PART 1 – OVERVIEW

This part gives a full overview of the thesis and details the research methods used. It is formed of two chapters: the first is the introduction which summarises the research and the structure of this thesis, outlines the aims and objectives and defines the contributions to knowledge.

The second chapter provides a comprehensive review of the methods used in this research. It explains the bricolage of nine different methods required to undertake the study which are organised across four stages. This chapter explores the differences in ways of working between academia and industry which provide context for the methodological contribution to knowledge found later in the thesis. The chapter and Part 1 ends with a methods framework, mapping how the insights across the thesis flowed through the stages to the original contributions to knowledge.

1 INTRODUCTION

1.1 PROJECT OVERVIEW

THE PROBLEM

We are in a state of environmental crisis. We are being warned of the rapidly shrinking window of time to avoid catastrophic consequences of human impacts on the environment (Laybourn-Langton, Rankin and Baxter, 2019). While the planetary boundaries, the environmental limits within which we can safely operate, are being breached (Steffen et al., 2015) it seems humanity is unable or unwilling to make the vital changes to reverse our impacts fast enough.

Hailed as one of the world's most polluting industries, fashion is criticised as still adhering to the old linear model. One which takes resources from the earth, in order to make things and then waste them, throwing the resources away to landfill or burning them so they can no longer be used. The solution, it is suggested, can found using a circular model, in which resources can circulate around and around forever (EMF, 2017).

Today, it is estimated by both the Ellen MacArthur Foundation (EMF, 2017) and Circle Economy (2019) that approximately 70% of textiles are lost to landfill or incineration. And according to the Fibersort report (2018b) the quality of our textiles is declining. This means that un-wearable textiles that are difficult to be recycled are on the increase and solutions for this growing segment of textile waste need to be established.

WHO'S PROBLEM IS IT?

The problem of difficult-to-recycle textile waste is usually laid at the designer's door. However, the strategy 'Design for Recycling' is not only underexplored in the textile and fashion field, but the solutions offered are oversimplified and impractical for the complex products that are produced in the textile industry. Chemical recycling might be considered by some as the saving solution to the problem, but this is not yet commercialised and while everyone waits the waste problem grows. Mechanical recycling technology, previously condemned as outdated (Allwood et al., 2006), has recently become more favoured as a potential solution that works together with the future chemical technology (Sandin and Peters, 2018; Hall, 2020a). Therefore, mechanical methods, for which this research is focused, must be developed alongside the newer chemical ones.

At the other end of the spectrum, the fashion industry and the designers which work within it, are committing to using recycled fibres in their products. However, good intentions are not translating into actions (GFA, 2019). This is due to a seemingly unresolvable tension between the designers, recyclers and sorters. First, the designers demand pure and high quality recycled materials, and these demands fall to the recyclers that have to create them. However, the recyclers cannot produce the materials required by the designers if the waste textiles are not sorted first. Sorters, in turn, complain that the discarded garments they receive are difficult to sort because of the many blended materials used. This of course is the fault of the designers. The vicious circle continues (Elander and Ljungkvist 2016).

WHY HAS THE PROBLEM NOT BE SOLVED?

Within this vicious circle of blame, the two main barriers for this problem are outlined. First the lack of quality of fibres, and second the blends being used (Elander and Ljungkvist 2016). Blending is consistently condemned in the circular economy and it is often suggested that it should be avoided all together (Braungart and McDonough, 2002). Yet it continues to be prolifically used across the textile industry to create materials that are functional, aesthetically pleasing, and sold at the right price point. In the recycling industry blending is used as a tool to increase quality and functionality of the shorter fibres produced in the process. It can also be used to extend the lives of the textiles (Beton et al., 2014). This highlights the tension between the need for longevity/durability of our textiles for the circular economy and the recyclability to avoid the waste of resources. A balance needs to be struck between these two strategies (Tanttu, Kohtala and Niinimäki, 2016).

One method used to obtain quality fibres is through accurate sorting. However, this can be difficult as most sorting is done by hand and clothing labels are often inaccurate (Botticello, 2012; Circle Economy, 2020). While automated sorting technology is developing, the end-markets for which sorters grade textile waste need to be expanded (Fibersort, 2018b). Niinimäki and Karell (2020) even go so far as to suggest that we should 'Design for Sorting' as a separate strategy to 'Design for Recycling'.

The ever-increasing quality of recycled fibres is also demanded by the circular economy and this leaves little room for materials to fall short of expectations (EMF, 2017). The undesirable depletion of quality is often referred to as downcycling or cascading. Ironically, downcycling, an area underexplored across the literature, is only condemned in the field of recycling. For re-use, the act of downcycling garments into 'hand-me-downs' is actively encouraged. Similarly, cascading theory (Sirkin and ten Houten, 1994) is commonly miss-represented as solely a downcycling approach. Cascading, or spiralling as it has been coined in this research, allows materials and products to move both up and down in value. The field of cascading and circular economy have only recently been combined and have not been considered as an approach for textile recycling.

FINDING THE SOLUTIONS

The challenge this research presents synthesises each of the following areas: sorting, blending and cascading/spiralling, exploring each aspect towards a Design for Recycling Knitwear framework. This, crucially, combines a re-active design approach through designing with recycled fibre and a pro-active design approach designing for their onward recyclability. In doing this, insights are found not only for the specific challenges of designing using recycled fibres in the manufacture of yarns, materials and products, but also in understanding how design choices cause resource value at the recovery stage to move up or down and dramatically affect the longevity of the resources as they flow in and out of products across time.

This research, specifically, investigates the wool recycling system in which acrylic fibres are the main contaminant. Knitted acrylic textile waste takes the focus of the research as these textiles fall straight into recycling sorting grades, without any re-use market, and are regarded as the lowest value fibres. In order for this design research to be successful an investigation of blending (Chapter 7, page 151) and sorting methods (Chapter 8, page 193) were conducted and tested through practice (Chapter 10, page 225). Starting from the most difficult to recycle fibres in the wool recycling industry, design was used to incrementally increase the value of these fibres in recovery (at the sorting stage) and ensure the longevity of these fibres across many products' lives (Chapter 9, page 211).

1.2 AIMS AND OBJECTIVES

AIM A

To understand both the fields of design for mechanical recycling and design for cascading in the context of post-consumer wool and acrylic textiles.

OBJECTIVES

A1. Conduct a review of the current mechanical recycling industry of wool and acrylic textiles.
A2. To understand the role of design in current textile recycling industrial systems.
A3. Conduct a review of the current cascading literature in relation to textile design.

AIM B

To establish a Design for Recycling wool/acrylic textile model for designing longevity of resources through recycling and bringing together cascading, blending and sorting.

OBJECTIVES

B1. To understand how the field of cascading intersects with design for recycling of post-consumer textile waste.
B2. Identify the role of blending within virgin and recycled textile production.
B3. Investigate the methods of sorting for mechanical recycling of wool and acrylic textiles.
B4. Propose how cascading, blending and sorting might be used together to ensure resource longevity of post-consumer wool/acrylic textiles.

AIM C

To test, through practice, the ideas generated in the previous aims to produce the Design for Recycling Knitwear framework and to establish how the methods have been used across research and industry.

OBJECTIVES

C1. Investigate, and where necessary collaborate with, industrial partners to test the realities of Designing for Recycling Knitwear from yarn to product.

C2. Draw insights from opportunities and challenges of Designing for Recycling Knitwear in industry to establish how design decisions bridge the recovery and manufacture of textile resources.

C3. Draw insights from Designing for Recycling Knitwear in industry to establish a model of how researching between academia and industry can be conducted.

1.3 THESIS STRUCTURE

The thesis has been structured to reflect the aims and objectives set out in section 1.2 (page 6). This means each part of the thesis has been constructed to accomplish a specific aim. In addition, each chapter is written to achieve the objectives of the aims. This has been illustrated in Figure 1 (page 9), and is followed by a description outlining each part and chapter.

PART ONE of the thesis offers an overview of this PhD thesis and provides details of the methods used. This part is formed of two chapters.

Chapter one is the introduction which summarises the research and the structure of this thesis. It will outline the aims and objectives and define the contributions to knowledge.

Chapter two provides a comprehensive review of the methods used for this research and provides a map for how the methods were repeatedly used across four stages: Think, Explore, Test and Reflect.

PART TWO of the thesis has been created to complete the first aim outlined in this introduction; to understand the fields of design for mechanical recycling and cascading in the context of post-consumer wool and acrylic textiles. This has been outlined across three objectives which form the structure of the three chapters in this part.

Chapter three addresses the first objective, reviewing the current mechanical recycling industry of wool and acrylic textiles. This not only provides the context of the post-consumer textile recycling system within the circular economy but will outline the context for using knitted wool and acrylic textiles.

Chapter four looks at the second objective, to understand the role of design in the current textile recycling industrial system. It outlines the problems with the current Design for Recycling approaches and establishes the role the designer might play in finding solutions.

Chapter five tackles the final objective, providing a review of the current cascading literature in relation to textile design. This chapter outlines how design for cascading can be combined with the circular economy model.

PART THREE of the thesis has been constructed to address the second aim of this research. This is to establish a framework for designing longevity of resources through recycling bringing together cascading, blending and sorting to enable Design for Recycling Knitwear. It will specifically address the research question posed in the second part of this thesis: can we design for the sorting and recombining of textile waste? This has been outlined across three objectives which forms the structure of the three chapters in this part.

Chapter six explores how textile design and cascading intersect. It specifically considers the differences between product and resources cascades and considers how cascading has been defined as both downcycling and upcycling. This chapter provides a new spiral shaped model for combining cascading and circularity which brings together a resource flow and product loops.

Chapter seven looks at the first objective to identify the role of blending within virgin and recycled textile production. It outlines the reasons for blending in textiles and those used with the textile recycling industry. The chapter provides the designer with three levels of blending: yarn material and product. It highlights that understanding the blending ratio across these levels is vital to enable successful textile recyclability.

Chapter eight tackles the second objective, to investigates the methods of sorting for mechanical recycling of wool and acrylic textiles. It outlines how sorting is generally conducted in the textile recycling industry. In addition, it provides an analysis on the generic sorting grades used for wool/acrylic textiles.

Chapter nine addresses the final objective, to propose how cascading blending and sorting might be used together to ensure resource longevity of post-consumer wool/acrylic textiles. It outlines how the spiralling model (Chapter 6) can incorporate both blending and sorting (Chapter 7 and 8) to extend the lifetimes of textile fibres

PART FOUR of this thesis addresses the final aim of this research to test, through practice, the ideas generated in the previous aims to produce the Design for Recycling Knitwear framework and to establish how the methods have been used across research and industry. This final part is structured to deliver the final three objectives (Chapter 10 and 11) and draw final conclusions (Chapter 12).

Chapter ten looks at the first objective of the final aim of this research. This is to investigate and, where necessary, collaborate with industrial partners to Design for Recycling Knitwear. The chapter describes the final practice research (practice 10) and how this was conducted with industrial partners to test the model proposed in Chapter 9..

Chapter eleven addresses the second and third objective; to draw insights from the opportunities and challenges of Designing for Recycling Knitwear in industry to establish how design decisions can bridge recovery and manufacture. These insights are then used to establish a model of how researching between academia and industry can be conducted. This chapter provides discussion of the research as a whole and outlines the Design for Recycling Knitwear framework. In addition, it reflects on the research process and forms a methodological framework for working between academia and industry. This chapter forms the two original contributions to knowledge.

Chapter twelve the final chapter of this thesis, draws together the research as a whole to provide conclusions and further research opportunities.

PART 1			INTRODUCTION
			METHODS
PART 2 AIM A To understand both the fields of design for mechanical recycling and design for cascading in the context of post-consumer wool and acrylic textiles.	A 1	Conduct a review of the current mechanical recycling industry of wool and acrylic textiles.	TEXTILE RECYCLING SYSTEMS
	A 2	To understand the role of design in current textile recycling industrial systems.	DESIGN FOR TEXTILE RECYCLING
	A 3	Conduct a review of the current cascading literature in relation to textile design.	CASCADING
PART 3 AIM B To establish a Design for Recycling wool/acrylic textile model for designing longevity of resources through recycling and bringing together cascading, blending and sorting.	B 1	To understand how the field of cascading intersects with design for recycling of post-consumer textile waste.	DESIGNING TEXTILE CASCADES FOR LONGEVITY
	B 2	Identify the role of blending within virgin and recycled textile production.	DESIGN FOR RECYCLING BLENDS
	B 3	Investigate the methods of sorting for mechanical recycling of wool and acrylic textiles.	DESIGN FOR TEXTILE SORTING
	B 4	Propose how cascading, blending and sorting might be used together to ensure resource longevity of post-consumer wool/acrylic textiles.	DESIGN FOR RECYCLING KNITWEAR
PART 4 AIM C To test, through practice, the ideas generated in the previous aims to produce the Design for Recycling Knitwear framework and to establish how the methods have been used across research and industry.	C1	Investigate, and where necessary collaborate with, industrial partners to test the realities of Designing for Recycling Knitwear from yarn to product.	DESIGN AND TESTING
	C2	Draw insights from opportunities and challenges of Designing for Recycling Knitwear in industry to establish how design decisions bridge the recovery and manufacture of textile resources.	DISCUSSION AND INSIGHTS
	C3	Draw insights from Designing for Recycling Knitwear in industry to establish a model of how researching between academia and industry can be conducted.	DISCUSSION AND INSIGHTS

Figure 1. Demonstrating how the aims and objectives of the research are addressed in the thesis chapters

PRACTICE 0

AIM

Figure 2. Practice 0 separated in the thesis by appearance, using an alternative colour and font

1.3.1 PRACTICE RESEARCH

This document presents both the contextual literature and the practice research which together forms the thesis. Both the literature and the practice cannot be neatly separated. It would have been impossible to pull together the literature without the influence of the practice. The practice in its many forms (see also Chapter 2, page 19) allowed the researcher to explore ideas both generated in practice itself and through the reading of literature. Retrospectively it was understood that this approach enabled the researcher to cut through the complexity of the topic.

However, during the writing of the thesis the literature and argument was written first. It was only later understood that the missing text about the bodies of practice were the architecture supporting the argument, which at the time was not visible in the text. To overcome this, the nine bodies of practice were brought to the forefront and written into the thesis as series of texts separated by their appearance (colour and font). They are included, not to distract from the flow of writing, but to enrich the supporting literature. They are not presented in chronological order but included at relevant moments to aid the development of the text. In some cases, it may be extremely obvious why the practice has been placed in a specific location. In others, the insights are broader and have been positioned to aid the reader's understanding. The insights themselves often were understood after the whole body of practice had been completed.

The practice came together in a more meshed approach, common amongst textile design researchers (Igoe, 2013). For clarity of writing the insights from each practice are presented alone, without the complication of describing the connections between them, thus aiding the researcher's understanding. Short descriptions of each practice have been included overleaf.

The structure of each practice text has been deliberately created to demonstrate both the aims and insights of each exploration or experiment. Each section starts with the practice aim as it was for the researcher before the practice took place. At the end of the description there is a short text describing how the practice achieved the aim, plus any additional insights that were made which were more unexpectedly established. More often than not, the insight is more relevant to the research than the achieved aim. This reveals the division between the research's intended purpose and the learnings which occurred when exploring a complex topic.

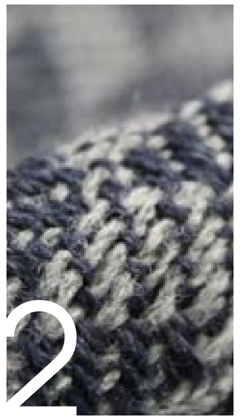
Each body of practice has been given a number (0-9) and these placed within the first three parts of the thesis. The first practice (0) is the researcher's Master's work and provides the context for the PhD research. The final piece of practice (10) is conducted in response to the ideas developed through the research which are collectively presented in Chapter 9. Chapter 10, therefore, forms the tenth body of practice but is not separated by colour or font. The insights from this final chapter are drawn together in the final discussion and are produced not only from Practice 10 but the collection of insights created in the whole thesis.

0

Master's Degree research. This practice provides the context for the PhD research ahead. Here, a range of mixed fibre navy and grey jumpers were collected and hand sorted by the researcher and pulled back to fibre in collaboration with a recycler. The recycled fibres were then designed into two non-woven materials and two yarns. Prototype products were produced to test the materials for commercial applications.

1

Field visits to multiple wool recycling companies in Prato, Italy. This practice explored all the stages of the post-consumer recycling system from point of disposal, sorting, pulling, garnetting, blending, spinning and weaving. Four hotspots in the system were established for design innovation.

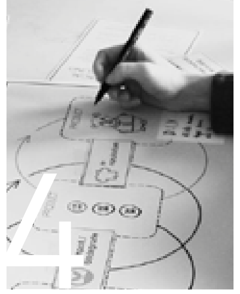


2

Weaving a commercial fabric from recycled yarns. The yarns from Practice 0 were used to explore how recycled yarns can be designed and made into commercial woven textiles, as well as going through a finishing process so they are ready to use.

3

Non-woven and yarn experiments exploring the impacts of the recycling process. Post-consumer waste white jumpers were collected and then sent to a non-woven facility to be pulled back to fibre. These were then double carded to emulate the garnetting process before being turned into non-woven materials and sample yarns.

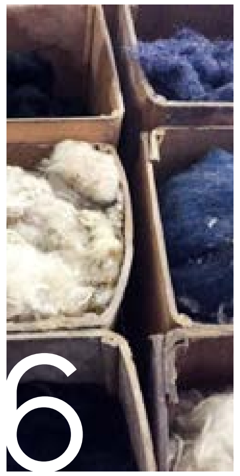


4

Workshops with students and industry exploring design for cascading. Three iterations of the same workshop was conducted with students and industry designers. The workshop was formed of three tasks. First to outline the key features of a sample garment. Second this was then re-designed for a specific end of use such as mechanical recycling. Finally, a story board was produced explaining how the product moved through multiple recycling systems so the resources could have two additional lives as products.

5

Yarn experiments exploring blend choices for recycled fibres. In collaboration with a spinning company the recycled fibres from Practice 0 were used to explore the reasons for, and benefits to, blending. The blends used by the spinning company for their production were drawn on to establish conclusions.

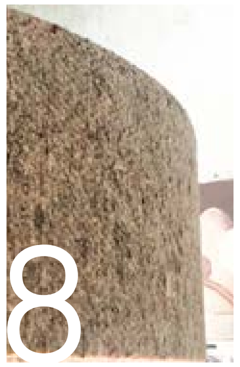


6

Field visit to a historic recycling company in UK. This practice took the form of a situated conversation with Charles Day, owner of the now closed shoddy manufacturer Henry Day & Sons. Exploring the archive of recycled textile fibres blending in the recycling industry were explored.

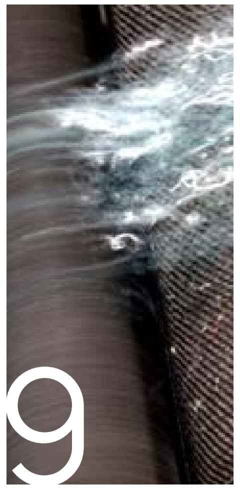
7

Yarn experiments exploring impacts of repetitive blending. In collaboration with a yarn spinner the fibre from Practice 0 was blended and carded across three iterations to explore the concept of incremental blending. In addition a small range of yarns were produced using different textile fibres as blending agents to create commercial sample yarns.



8

Field visit to an innovative recycling company in the Netherlands. This practice explored the most creative ways low value recycled fibres are being used and marketed. Exploring the different methods the company had overcome barriers to the issues associated with low-value waste.



9

Yarn experiments exploring blending choices for onward recyclability. This practice was conducted with the recycled fibre from Practice 3 and was used to design yarn for either chemical recycling or mechanical recycling technologies.

10

Commercial yarn production across six different blends. This final practice test (embedded within Chapter 10) brings together all the insights formed from the previous practices. This practice was specifically testing the models created throughout the thesis. Recycled fibre was sourced from the industry to create a yarn. The blends were designed specifically to re-enter recycling system at a high value at the point of disposal (sorting) for its onward longevity.

1.4 ORIGINAL CONTRIBUTIONS TO KNOWLEDGE

This thesis argues for two original contributions to knowledge through the articulation of new frameworks. The first is a methodological framework for conducting textile design practice research between academia and industry. The second is Design for Recycling Knitwear framework that brings together three smaller contributions that provide a new perspective on existing work in this field, namely cascading, blending and sorting for the design of recycled textiles. It is specifically in the field of mechanical wool/acrylic textiles recycling that these new perspectives have been developed and together they enable the overarching original contributions to knowledge to unfurl.

1.4.1 METHODOLOGICAL FRAMEWORK

This research outlines a new methodological framework which has developed directly from the practice research in this thesis. Presented in the shape of a steering wheel, it offers researchers a way to 'steer' design research across academia and industry (Section 11.2.5, page 308). In particular it offers a method for one person to take on both roles of academic designer-researcher and industry designer, or individuals to take on these roles, in collaboration with industry-based experts working commercially.

The framework follows four stages which continually cycle: Think, Explore, Test, Reflect. These four stages contain methods (nine different methods were used in this particular research). The actors within the research are divided into three roles: industry specifier, academic designer-researcher and expert situated in context. Through collaborative working the roles come together and provides a different perspective across now, near and far timeframes. It is the combination of the circulating methods and collaboration of the roles in-putting their varied perspectives, which leads to the generation of new knowledge.

1.4.2 DESIGN FOR RECYCLING KNITWEAR FRAMEWORK

This research outlines the Design for Recycling Knitwear framework which has materialised from the practice research in this study. Specifically, exploring design for mechanical recycling of wool/acrylic waste textiles. The framework synthesises three smaller contributions that provide a new perspective on existing work in the fields of cascading, blending and sorting waste acrylic/wool knitted textile waste.

NEW PERSPECTIVE ON CASCADING – THE SPIRAL

This research builds on cascading theory (Sirkin and ten Houten, 1994) and how it has more recently been connected to the circular economy (Campbell-Johnston et al., 2020). The research explores and differentiates between the two types of cascading approach, namely product cascading and resource cascading (section 5.4, page 121). These are synthesised with upcycling and downcycling concepts (section 6.3, page 139). Specifically, taking the perspective of textile recycling in the transition to a circular economy, a new spiral shaped model is created. This spiral is comprised of both resource flow and product loops. The designer uses this model to look beyond a single product and assess how textile resource value changes as it moves in and out of products during the recycling process (section 6.5, page 143).

A NEW PERSPECTIVE ON TEXTILE BLENDING FOR RECYCLING

This research provides a new perspective for textile blending specifically for the recycling of textile wastes. The research explores how blending is used within the recycling industry itself. These five methods: recycled and virgin, pre- and post-consumer wastes, structure, fibre type and colour, provide the wider context for blending within the mechanical recycling system (Section 7.4, page 160). In addition, the research builds on existing work in the field articulating how textile combinations can hinder recyclability (Gulich, 2006; Forst, 2021) by re-organising textile blending typologies for the context of mechanical textile recycling. This resulted in the three levels of blending: yarn, material and product (section 7.7, page 181). These levels can be used by the designer to recognise where blending occurs during the design stages. This is translated for the field of Design for Recycling considering the blending ratios between the levels which directly impact a textile's onward recyclability (section 7.7.1, page 183).

A NEW PERSPECTIVE ON DESIGN FOR TEXTILE SORTING – GRADES AND THRESHOLDS

This research establishes that the value of waste textiles is decided at the sorting stage, therefore Design for Sorting strategy (Niinimäki and Karell, 2020) can be harnessed to design value in and out of textiles (Chapter 8, page 193). This has been explored from the perspective of knitted wool and acrylic textile waste. Following Niinimäki and Karell's three steps this research establishes: the elements of textiles that sorters are concerned with, the grades the industry place the textile into and the limitations and possibilities of textile-to-textile recycling technologies. In the context of wool and acrylic textiles the complex methods of sorting and combining wastes were unpicked to create four generic sorting grades (section 8.4.1, page 203). Further still, to account for the complex waste entering the textile recycling system, the wider thresholds which surround these four core grades were explored (section 8.4.3, page 208). .

SYNTHESISING THE FRAMEWORK

The original contribution to knowledge is in combining all three of these new perspectives to form the Design for Recycling Knitwear framework (section 11.1.5, page 280). The resource spiral forms the wider context for how we can design textile fibres in and out of products. As the textile fibres reach the point of disposal, their value is determined at the sorting stage. For the designer, understanding the sorting grades and thresholds for design can utilise new or existing pathways for maximum longevity in the fibre's next life. To design recycled fibres for specific sorting pathways, blending knowledge from across the recycling and the wider textile industry should be applied. It is either by incrementally designing blends into our already complex waste textiles or incrementally designing them out that we can Design for Recycling Knitwear. The framework's original contribution specifically bridges sorting and blending knowledges by acknowledging the links between fibre quality, fibre type and fibre colour. This can then be used by the designer to design longevity into our textile resources and not only products.

2 METHODS

This chapter details how the methods, used in this thesis, have been combined to create knowledge. It explores, first, how a bricolage of methods has been used (2.1), across four stages (2.2) to problem solve (2.2.1) in a non-linear linear trajectory (2.2.2). The specific textile approach is positioned within transition design for an industrial context (2.3). This is followed by an in-depth look at the specific nine methods used in the research (2.4). As the nine methods demonstrate, the research has been conducted between academic and industrial spheres. Working between these sectors is explored (2.5), before finally analysing and mapping the methodology from methods to insights to original contributions to knowledge (2.6).

2.1 A BRICOLAGE OF METHODS

The nine methods used in this research (section 2.4, page 27) combine to form part of the overarching research methodology. These nine represent a bricolage of methods which is described as a “critical, multi-perspectival, multi-theoretical and multi-methodological approach to inquiry” (Rogers, 2012:1). The name bricolage comes from the French and describes a skilled person that undertakes any task or odd job. Lévi-Strauss (1962) uses this metaphor in explaining how knowledge is acquired.

> The 'bricoleur' is adept at performing a large number of diverse tasks; but, unlike the engineer, he does not subordinate each of them to the availability of raw materials and tools conceived and procured for the purpose of the project. His universe of instruments is closed and the rules of his game are always to make do with 'whatever is at hand' (Lévi-Strauss, 1962:22)

For practice research in design this approach is often adopted. The practice researcher, according to Yee and Bremner (2011:4), views methods actively rather than passively. This allows them to construct “methods with tools at hand rather than accepting and using pre-existing methodologies”. Yee and Bremner, highlight that this method of re-appropriating and combining elements closely reflects the activities of designers, so is therefore suited to the discipline. This has been frequently adopted as an approach in doctoral textiles research studies such as those of Igoe (2013); Vuletich, (2015) and Forst (2020).

The most relevant methods 'at hand' used for this study are outlined in Table 1 below and are shown to directly relate to the aims of the research. Like tools in a toolbox, methods were not used in sequence but repeatedly drawn upon in conjunction with others to reach the objectives of the study.

Table 1. Methods mapped against the aims of the research

AIM	OBJECTIVES	METHODS
A. To understand both the fields of design for mechanical recycling and design for cascading in the context of post-consumer wool and acrylic textiles.	Conduct a review of the current mechanical recycling industry of wool and acrylic textiles.	Literature Field Practice Exploration
	Understand the role of design in current textile recycling industrial systems.	Field Practice Tests Design Synthesis Visual Thinking
	Conduct a review of the current cascading literature in relation to textile design.	Literature
B. To establish a Design for Recycling wool/acrylic textile model for designing longevity of resources through recycling and bringing together cascading, blending and sorting.	To understand how the field of cascading intersects with design for recycling of post-consumer textile waste.	Literature Workshop Design Synthesis
	Identify the role of blending within virgin and recycled textile production.	Literature Field Practice Explorations Field Practice Tests Annotated Portfolio Design Synthesis
	Investigate the methods of sorting for mechanical recycling of wool and acrylic textiles.	Literature Interviews
	Propose how cascading blending and sorting might be used together to ensure resource longevity of post-consumer wool/acrylic textiles.	Annotated Portfolio Design Synthesis Visual Thinking
C. To test, through practice, the ideas generated in the previous aims to produce the Design for Recycling Knitwear framework and to establish how the methods have been used across research and industry.	Investigate, and where necessary collaborate with, industrial partners to test the realities of Designing for Recycling Knitwear from yarn to product.	Creative Design Brief Field Practice Test
	Draw insights from opportunities and challenges of Designing for Recycling Knitwear in industry to establish how design decisions bridge the recovery and manufacture of textile resources.	Design Synthesis
	Draw insights from Designing for Recycling Knitwear in industry to establish a model of how researching between academia and industry can be conducted.	Annotated Portfolio Design Synthesis

2.2 FOUR STAGES – THINK, EXPLORE, TEST AND REFLECT

To create a full methodological framework a more holistic understanding of how the research had been conducted was needed. Four keys words were highlighted to express the four stages that took place: Think, Explore, Test, Reflect.

For the field of sustainable textile design research, Goldsworthy (2012) and Forst (2020) offer examples of a four-stage framework: 'Think, Make, Share, Insight' and 'Scope, Make, Map, Reflect' respectively. Collaborating with industry, Goldsworthy applied her approach to create finishing techniques through laser technology for recyclable polyester textiles. This is based on what she describes as 'productive problem solving'. Whereas Forst used a creative craft-based approach to investigate disassembly to enable textile recyclability towards a circular economy.

There are many similarities between the 'Think, Explore, Test and Reflect' stages in this research and those used by Goldsworthy and Forst. First, Goldsworthy places an emphasis on thinking by understanding through enquiry, whereas Forst advocates for a scoping phase using literature and case studies in which to think about the problem to be addressed. Goldsworthy and Forst both promote exploring through practice which they refer to as 'making'. However, it is the 'sharing' and 'mapping' component of Goldsworthy's and Forst's methodology that sets this research approach apart. In this research 'mapping' is akin to visual thinking which falls within the 'Think' stage and while 'sharing' methods were used by writing research papers and setting up events they were not formalised as methods themselves. Rather the act of sharing, at workshops for example, allowed other methods to emerge. These were conducted during events that provided a platform to explore the research ideas with others. Finally, reflection is common to all the research approaches and is described aptly by Goldsworthy as 'analysis leading to insight'.

In this research, as in Goldsworthy's and Forst's PhDs, a mixture of methods has been used to solve a design problem. The choice of methods, across the four stages, therefore, specifically aims to understand the problem and establish possible solutions.

2.2.1 PROBLEM SOLVING

The concept of the design problem has been discussed in detail in the field of 'design thinking' (Cross, 2011; Brown, 2008; Rowe, 1987). Here, the problem needs to be defined before solutions can be found. However, as Cross (2011) explains, many design problems are often ill-defined which, he suggests, calls for that creation of a 'problem frame' to explore solutions. Similarly, in textile design James Moxey describes this as a 'problem space' which can be searched to gather information. For ill-defined problems, he argues, designers are required to "import information into the problem space" (Moxey, 2000:53).

However, as Igoe (2013) reveals, textile designers are often not solving problems. She even suggests that they may sometimes create their own problems for their own satisfaction in their work. This might be true of one kind of textile designer but is not necessarily true for all. The textile researcher, in contrast, views textile design problems through alternative lenses. For example, in this research and the PhD research by Goldsworthy and Forst 'the problem' is born out of a concern for sustainability.

Design for sustainability is described by Bhamra, Hernandez and Mawle (2017:130) as "design with the intention to achieve sustainable outputs". This incorporates environmental, social and economic concerns within the design (Bhamra and Lofthouse, 2007). However, in this research and Goldsworthy's and Forst's it goes beyond this, defining the problem within 'circular' design. This, Earley and Goldsworthy (2019b:176) explain, "should not be confused with 'sustainable design', although they undoubtedly overlap in ethos and approach. Circularity aims to be sustainable by default but sustainable intentions are not always circular".

Circular design encompasses the whole lifecycle of a product and can work at both micro and macro levels (materials, products and systems) and attempts to avoid the unintended consequences which come from only looking at one part of the lifecycle rather than the whole (Ibid, 2019). In order to solve a specific 'circular textile design problem' the problem space needs to be understood and explored (Moxey, 2000). Therefore, the first two stages (think and explore) of the methods framework reflect the enquiry into the problem in which solutions can then be tested and reflected on.

2.2.2 NON-LINEAR WAYS OF WORKING

In order to accomplish problem solving it was vital that movement could be made, back and forth, between the stages. The fluidity in methods is representative of the research process, which in reality does not always follow such a regimented linear trajectory from one stage to the next. This form of fluidity is often highlighted in design frameworks. Most notably in the newest version of the Design Council's (2019) double diamond model (Figure 3 overleaf). Not only does the diamond shape accommodate the widening and narrowing of an enquiry, it also illustrates a non-linear trajectory with circulating arrows to represent the way designers move back and forth between the stages.

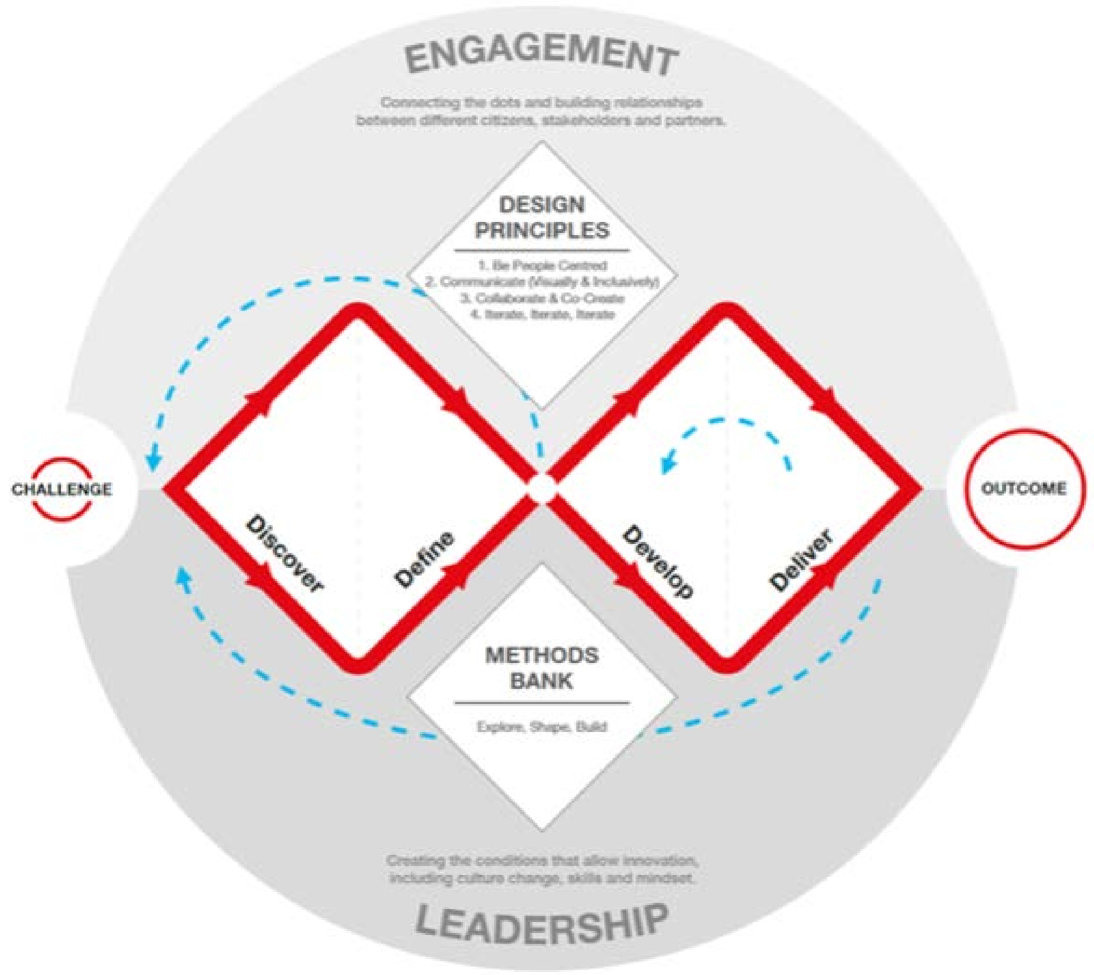


Figure 3. Design Council's framework for innovation, (Design Council, 2019)

This understanding of non-linear movement within textile design research has been explored by Mcquillan (2019). The methodology she used for her Licentiate thesis also employs the Design Council's double diamond shape but renames the stages with her own four headings to reflect her research in zero waste design: 'Experience, Conceptualise, Experiment, Proposition'. Since the nature of conducting PhD research in Sweden necessitates publishing a Licentiate thesis at the halfway point, only the first two stages of her framework had been applied. However, Mcquillan does emphasise the non-linear trajectory of her research in industry. In a similar way to the Design Council, she highlights the fluidity and circular movements between her first two stages 'experiencing the field' and 'conceptualising'. As both Mcquillan's research and this study are concerned with practice research in industry, unsurprisingly her terms 'conceptualise' and 'experience' correspond closely to 'think' and 'explore' respectively.

The prevalence of non-linear ways of working is evident in other textile studies such as that of Cleveland (2018) who includes a 'cyclic mode of enquiry', moving multiple times through four stages: planning, acting, observing and reflecting. Cleveland's research, as in this study, has been conducted in collaboration with the textile recycling industry. This involved her actively embedding herself within the recycling processes to observe and create new practice. Both Cleveland and Mcquillan's studies highlight the importance of fluidly exploring, testing and reflecting when researching in the industrial setting. Working within industry has been the key approach used in this research (section 2.5, page 47).

2.3 A TEXTILE APPROACH

Practice research is a relatively young method of conducting academic study and its value is becoming better understood. Practice research in the field of textile design is abundant with examples in which practice and making are the central methods for generating insights and knowledge. Examples include the doctoral work of Philpott (2011), Goldsworthy (2012), Paine (2015) and Forst (2020), and each of these describe their practice as craft-based making.

Craft practice is described by Pöllänen (2013:217) as an "emotional, intellectual, and physical processes in the sensory act of making, manipulating, articulating, and experiencing materials and self-made products". For the textile designer, the 'self-made products might refer to a yarn being woven or knitted into a material or a printer transferring inks onto cloth. For the academic researcher, these 'emotional, intellectual and physical' craft methods are used to investigate a specific enquiry. Examples of this include Philpott's (2011) study into the folding and fusing of cloth to create design objects towards understanding design methods, and Forst's (2020) research into assembling and disassembling textile materials to explore sustainable design solutions.

Other researchers have used a craft-making approach by transferring the making from the studio into an industrial context. Craft-making, in this sense, is conducted using industrial machinery. Examples of this include exploring the use of industrial laser technology to create different finishing and shaping techniques (Goldsworthy, 2012; Paine, 2015) and re-valuing textile waste in a micro industrial recycling system (Cleveland, 2018). In each of these examples the researcher actively participated in the making. Goldsworthy and Paine adapted the laser machinery to test different ways of creating aethetics and functions, while Cleveland used a craft-based approach at the centre of the recycling process to experience the materials, re-value them and produce new products.

As expanded on in the next section, in contrast to the studies mentioned above, it is argued that this current research is not strictly craft-based practice. It is rather conducted directly within the industry where the designer specifies combinations of materials to enable their transformation.

2.3.1 THE TEXTILE DESIGNER'S ROLE

Hornbuckle (2018) divides the many types of designers into two main categories. The first of these, 'specifiers', are 'function-led' industry-based designers who specify materials. The second, 'makers', are the 'material-led' craft-based designers. While for both types of designer materials are central to their work, it is the way in which they interact with them that sets them apart from one another. As Hornbuckle explains, the material knowledge of 'function-led' designers is often provided by third parties. In contrast, the 'material-led' designers are able to "logically think, learn, and understand through sensing and [the] immediate experience of materials" (Karana et al., 2015:38).

In this research, however, the designer-researcher's role was situated halfway between that of the function-led 'specifier' and the material-led 'maker. This was put down to the embedded nature of the research within an industrial context. The Royal Society of Arts' 2016 report explains that sometimes reading reports and academic texts is not enough. Being able to see, touch and experiment in context is vital, they argue, to change industrial practices (RSA, 2016). In line with their recommendations, the field practice exploration (section 2.4.4, page 35) and the field practice testing (section 2.4.5, page 37) in this study provided the crucial material experience in industry. which, as Karana et al. (2015) describe it, allow the researcher to fully 'think, learn and understand'.

The physical processing was not conducted by the hands interacting with the materials, neither was the machine adapted by the researcher. The designer's role in this case was to understand the types of materials entering the processes and the material outcomes after production. Here the materials were only touched before and immediately after manufacture. This type of practice research, therefore, represents a hybrid practice that might best be situated in the field of Design for Manufacturability. This is defined as fostering the "simultaneous involvement of product design and process design" (Venkatachalam, Mellichamp and Miller, 1993:355).

This research almost fulfils Pöllänen's definition of craft practice, as a sensory act of making and experimentation. However, it falls short of being a 'self-made' product. The physical making was removed from the practice, but what might be considered lost from the experience of making is transferred into the material knowledge and experience for manufacturability. As Kane and Philpott (2013) explain, this type of textile practice provides textile researchers with an implicit understanding of material behaviours and an intuitive tacit knowledge, generating new outcomes from 'inherently dynamic materials systems'.

The textile designer's role in this current study thus provides the experiential material knowledge needed to specify the materials appropriate to the research goal. Here, the textile designer can engage with professionals, learn from their technical competencies and work in collaboration. Their value, argues Lerpiniere (2020:92), lies in "their ability to develop models and concepts of consumption, to design new solutions and approaches in the industry".

2.3.2 TRANSITIONAL TEXTILE DESIGN

Taking this position, one in which the textile designer can create change in industry, the research in this thesis can be described as a form of 'transition design'. This is firstly because the very nature of textile design involves changing objects from one thing to another, turning yarn into fabric and fabric into products (Lerpiniere, 2020). Secondly, as Irwin, Kossoff and Tonkinwise explain:

> Transition Design acknowledges that we are living in 'transitional times' and takes as its central premise the need for societal transitions to more sustainable futures and the belief that design has a key role to play in these transitions (Irwin, Kossoff and Tonkinwise, 2015:2)

For the textile designer to fill this 'key role' in the transition, they must bring together "disparate approaches, competencies and skills" to tackle the changes required in the industry and consider the entire lifecycle of a product (Lerpiniere, 2020:93). Textile designers, as Lerpiniere suggests, are well equipped to engage with both the micro (fibre level) and the macro (supply chains). It is therefore in this context that this Design for Recycling Knitwear research began.

Figure 4. Interacting with the materials prior to production

2.4 NINE METHODS

A collection of nine different research methods have been used to produce the practice research presented in this thesis. These will each be discussed in following nine sections. The methods comprise, literature review (2.4.1), design synthesis (2.4.2), visual thinking (2.4.3), field practice research (2.4.4), field practice experimentation (2.4.5), workshops (2.4.6), interviews (2.4.7), creative design brief (2.4.8) and annotated portfolio (2.4.9).

2.4.1 LITERATURE REVIEW

The first and most traditional method used in research was the completion of a literature review. In accordance with Vernon Trafford and Shosh Leshem's description of doctoral research, the literature review "is founded on scholarship and this, in turn, depends on candidates being intimately engaged and conversant, with certain theories" (2008:67). Here in this thesis the literature review is split across the themes of design for recycling, cascading, blending and sorting. While the understanding and critiquing of these themes is vital for the success of this PhD research, it is the designerly methods used (design synthesis and visual thinking) that underpin how the literature has been brought together. These are both discussed in the next two sections.

2.4.2 DESIGN SYNTHESIS

Designers use 'design synthesis' as a method, especially in a professional setting, as a means of finding order in chaos and organising complexity. The driver for design synthesis is described by Kolko (2010) as an 'abductive sensemaking process'. As he explains, there is something 'magical' and invisible about synthesis in professional practice. He sums up this process more precisely as follows:

> Synthesis is frequently performed privately ("in the head" or "on scratch paper"), the outcome is all that is observed, and this only after the designer has explicitly begun the form-making portion of the design process. While other aspects of the design process are visible to non-designers (such as drawing, which can be observed and generally grasped even by a naive and detached audience), synthesis is often a more insular activity, one that is less obviously understood, or even completely hidden from view (Kolko, 2010:15)

The thinking stage of design, as Kolko points out can be difficult to substantiate. He explains that in professional design, clients cannot always see the value in the design synthesis stage before ideas and artefacts are produced. It is a common perception that design institutions only teach designers to design, whereas academics in design studies do the opposite (thinking only). This perception, however, is overly simplistic, "as if questioning and rethinking were not ever part of the practice of designing" (Tonkinwise 2014:198).

As Tonkinwise suggests, design synthesis is a method used by all designers and it is a natural part of the design process. However, design synthesis has been purposely included to discuss the various ways the researcher has approached the research problem.

SYSTEMS ORIENTED DESIGN

As this thesis unfolds it will become more evident that systems thinking has played a role in the way the research has been synthesised. However, it is a Systems Oriented Design approach which describes the methods most appropriately. Founded by Birger Sevaldson, this form of design is situated at the cross-section of two dichotomies: the fields of design thinking and design practice, and systems thinking and systems practice. Sevaldson (2009) indicates that the approach sits slightly closer to design practice than any of the other fields. As he explains, it builds "the designer's own interpretation and implementation of systems thinking so that systems thinking can fully benefit from design thinking and practice and vice versa".

Sevaldson, (2013:3) further explains, "the systems-oriented designer is initially less concerned about hierarchies and boundaries of systems and more interested in looking at vast fields of relations and patterns of interactions". This is demonstrated in the research by bringing together the fields of design for textile recycling and cascading. The unpacking of information in these two fields revealed the importance of blending and sorting, although this was by no means a simple task. It was only through investigating those complex patterns and connections between blending and sorting that the Design for Recycling Knitwear Framework finally emerged.

2.4.3 VISUAL THINKING

While 'design synthesis' represents a more insular method there is no rule which dictates that this cannot be combined with more outward methods of research. Therefore, to compliment the design synthesis method, a more outwardly discernible range of visual thinking methods were employed.

Traditionally, visual methodologies focus on understanding the visual works created by others (Rose, 2013). However, in this research visual thinking is used as tool in itself. For designers, visual thinking is explained by Fred Collopy in the Fast Company magazine:

> If thinking is at the centre of the activity that we want to encourage, it is not the kind of thinking that doctors and lawyers, professors and business people already do. It is not a feet up, data spread across the desk to be absorbed kind of thinking. It is a pencil in hand, scribbling on the board sort of thinking. (Collopy, 2009)

Ruholf Arnheim's (1969) book 'Visual Thinking' discusses the merits of this visual method. He explains that 'cognitive operations', which he refers to as 'thinking', are not only a mental process but an essential part of perception. There is no difference, he points out, between what happens mentally when someone looks at the world and when they close their eyes and 'think'. The operations to which Arnheim refers to are multiple: "active exploration, selection, grasping of essentials, simplification, abstraction, analysis and synthesis, completion, correction, comparison, problem solving, as well as combining, separating, [and] putting in context" (Arnheim, 1969:13). This vast list of cognitive operations reflects the complexity of visual information. In the words of Kolko (2010) the designer addresses this complexity as follows:

> The designer will frequently turn to a large sheet of paper and a blank wall in order to "map it all out." Several hours later, the sheet of paper will be covered with what to a newcomer appears to be a mess—yet the designer has made substantial progress, and the mess actually represents the deep and meaningful sensemaking that drives innovation (Kolko, 2010:16)

It is important to note, however, that visualisation in design is most often associated with communication (as in the field of Graphic and Communication Design). While the visuals in this thesis are used as a means of communication, they have essentially been developed through a variety of visual thinking methods. In line with Tufte (1990), they have been used to reason, communicate and preserve knowledge throughout the research journey. These include permanently filling notebooks with doodles and pictures (Figure 6); temporal mapping on whiteboards to draw and re-draw connections (Figure 8) and using post-it notes across a desk to clarify relationships between ideas (Figure 5). These techniques have been collectively used in order to understand the literature, practice and processes of the research.

During the research the visual methods changed and adapted with the thinking that was taking place. At times a notebook was preferred whereas at others a large sheet of paper on the studio floor was necessary (Figure 7). This visual thinking methods also crossed from these analogue realms to digital realms using illustrator and PowerPoint to explore ideas (Figure 9).

Figure 5. Post-it note mapping and notebook visualising the structure of the thesis

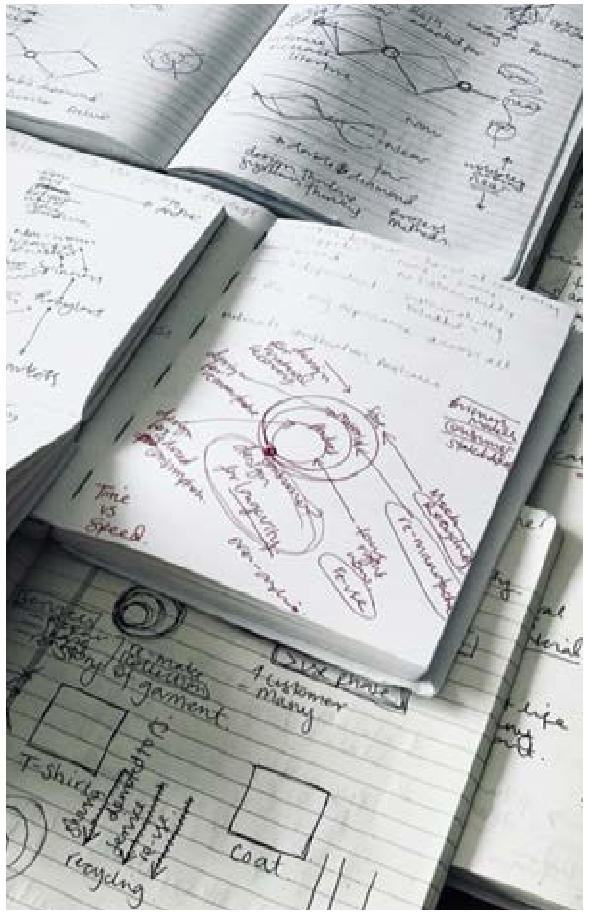


Figure 6. Notebook Diagrams as a visual thinking method

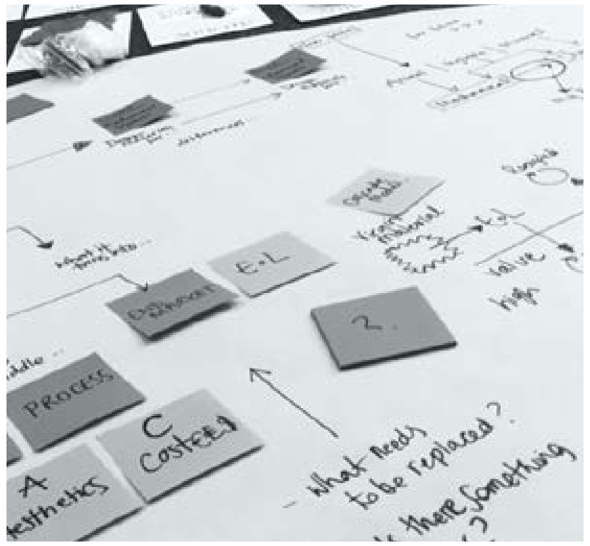


Figure 7. Mapping on a large sheet of paper on the floor of the studio as a visual thinking method

Figure 8. Photographic Scan of whiteboard mapping used as visual thinking tool

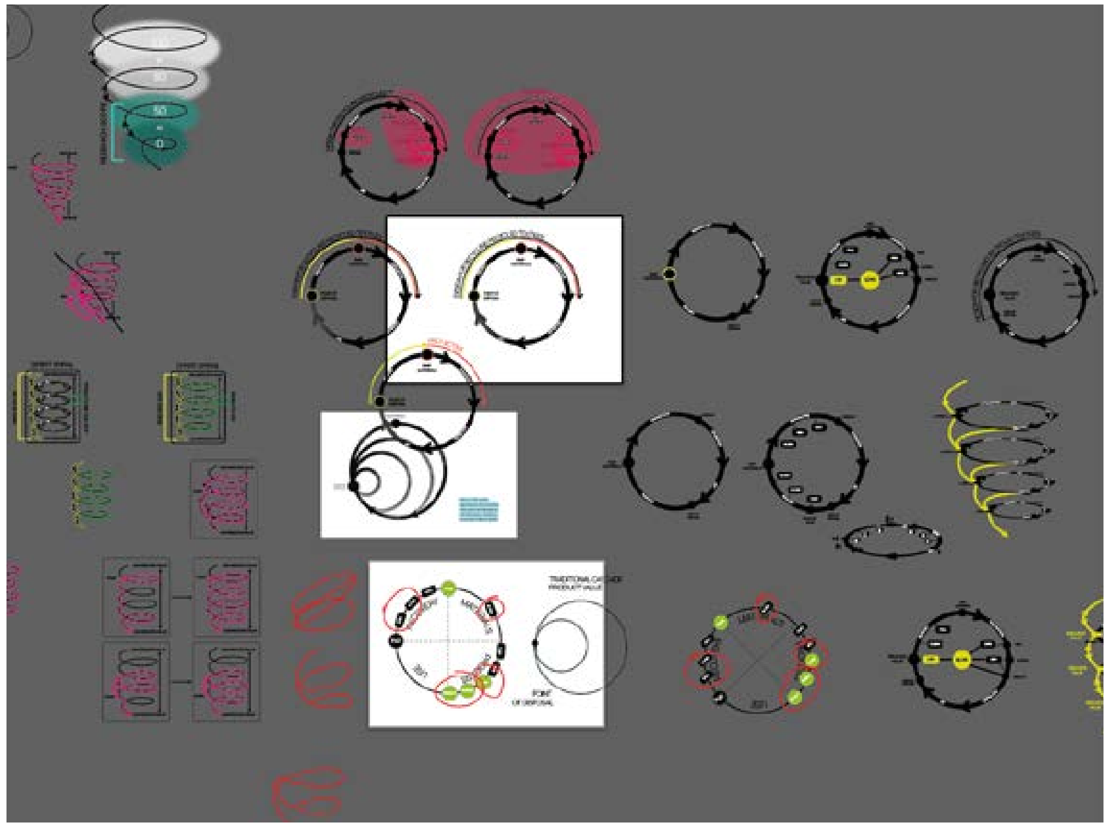


Figure 9. Digital Diagramming as a visual thinking method

DIAGRAMS

One of the visual methods employed by the researcher was the use of diagrams, not simply to display data in the form of charts and graphs, but as "a set of relations that emerge through events and processes" that are fluid and ever-evolving (Barry, 2017:331). Figure 10 illustrates the extended process of visual thinking in the development of the methodological framework, from notebook documentation to more formalised digital media formats.

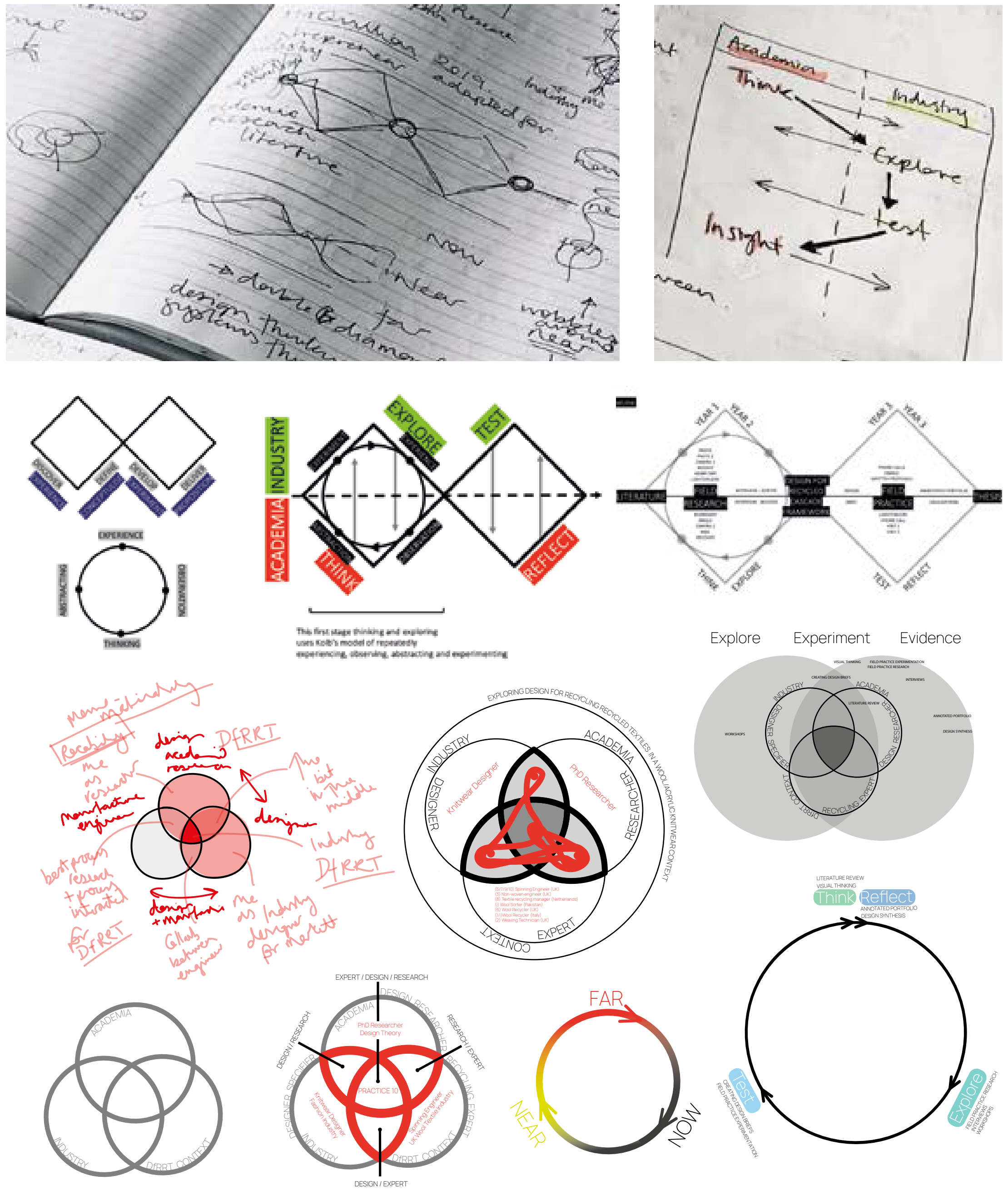


Figure 10. Collection of methodological diagrams which evolved across the research

MAPPING AND GIGA-MAPPING

Diagrams, as individual tools, was only one approach of many visual thinking employed during this research. Diagrams were also brought together to generate maps, illustrating the richer interactions of ideas and relationships (Figure 11).

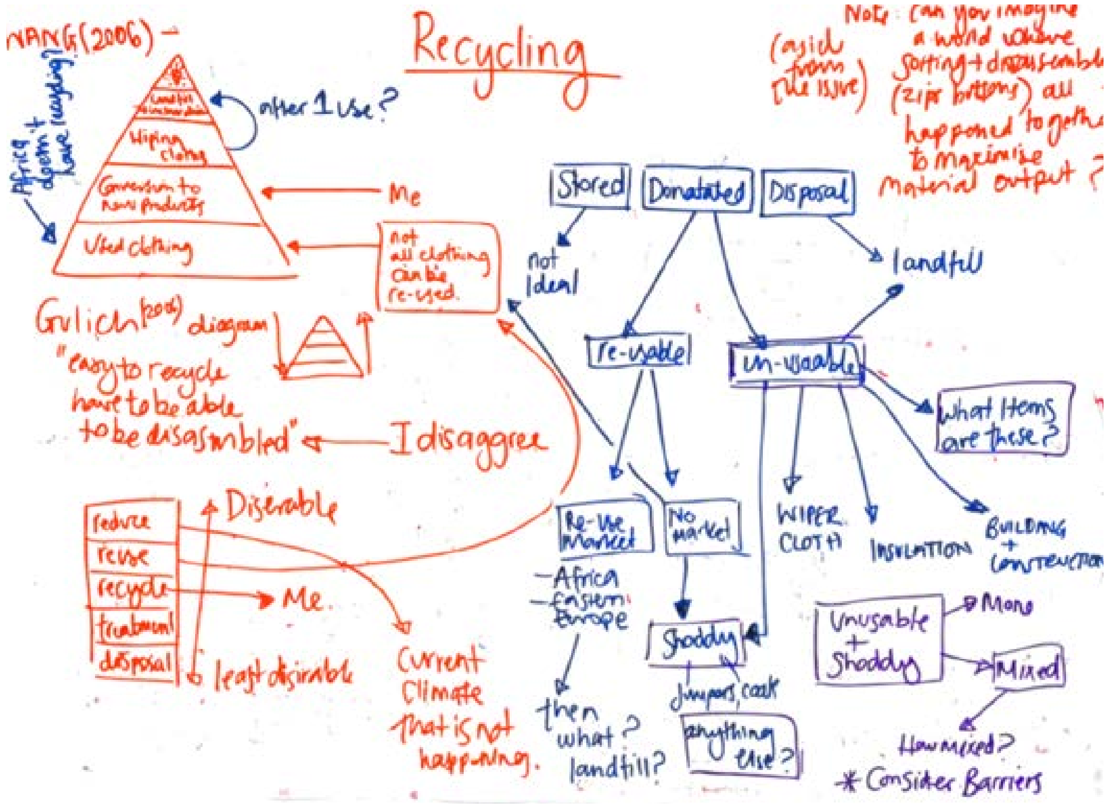


Figure 11. Visual thinking in the form of a map

Mapping in this way brings together the diagrams layering them together. These maps bring together images (diagrams) and are connected with annotations. This methods of envisioning information is described by Tufte (1990) as a method to isolate details and place them into context. Colour was also often used to separate academic ideas from the industrial systems being represented. Tufte explains that colour can be used in four ways "to label (colour as noun), to measure (colour as quantity), to represent or imitate reality (colour as representation), and to enliven or decorate (colour as beauty)" (Tufte, 1990:81). In this case colour has been used to both label and measure, in order to aid the researcher's design synthesis of the problems and identify possible solutions to be investigated.

From a more simplistic mapping of ideas and relations, the next level up is the formation of a GIGA-map. This is a central method in Systems Oriented Design and is the creation of multi-layered map for the purpose of capturing and understanding complexity. Unlike diagrams, which Sevaldson (2011) claims, often oversimplify complex problems, he argues that GIGA-maps allow for structures and processes to be fully drawn out and explored, spanning many scales from global to small details. Unlike its predesessor 'rich pictures' (Checkland, 2000), the first stages of GIGA-mapping are not used to communicate with others but enable the creator to document thoughts and ideas even when still not 'sure of what they are doing'. The richness of GIGA-mapping highlights the importance of resisting the urge to simplify too early. The mapping will never be complete, but it is only once the map expands beyond what seems relevant that clear boundaries of the research can be drawn (Sevaldson, 2013).

While many elements of the GIGA-map have been used to capture visual thinking in this research, it has never been exercised as a formal method in itself. GIGA-mapping is used to incorporate all elements of a research project as a whole. However, a single GIGA-map was never reached. Rather, an adaptation of this approach was used. This was achieved through the creation of a series of smaller maps. These were used as a tool to reprocess, build upon and bring forward ideas over time. Each time a new sheet of paper or a new digital file was started, sections of previous maps or individual diagrams were redrawn/copied and pasted to start a-fresh, all the while still building on these previous ideas. Though this approach lacks the holistic nature of a GIGA-map, this sequential method enabled the designer to revisit the visual thinking process if needed. Individually, none of these maps represented the research in full, but together they portrayed sections of an overlapping GIGA-map (which never fully existed). An example provided below (Figure 12) shows a variety of diagrams and maps which provide a snapshot of what the GIGA-map might have contained if one had been made. In reality, the whole map remained in the mind's eye of the researcher as the precise details in each smaller map progressed.

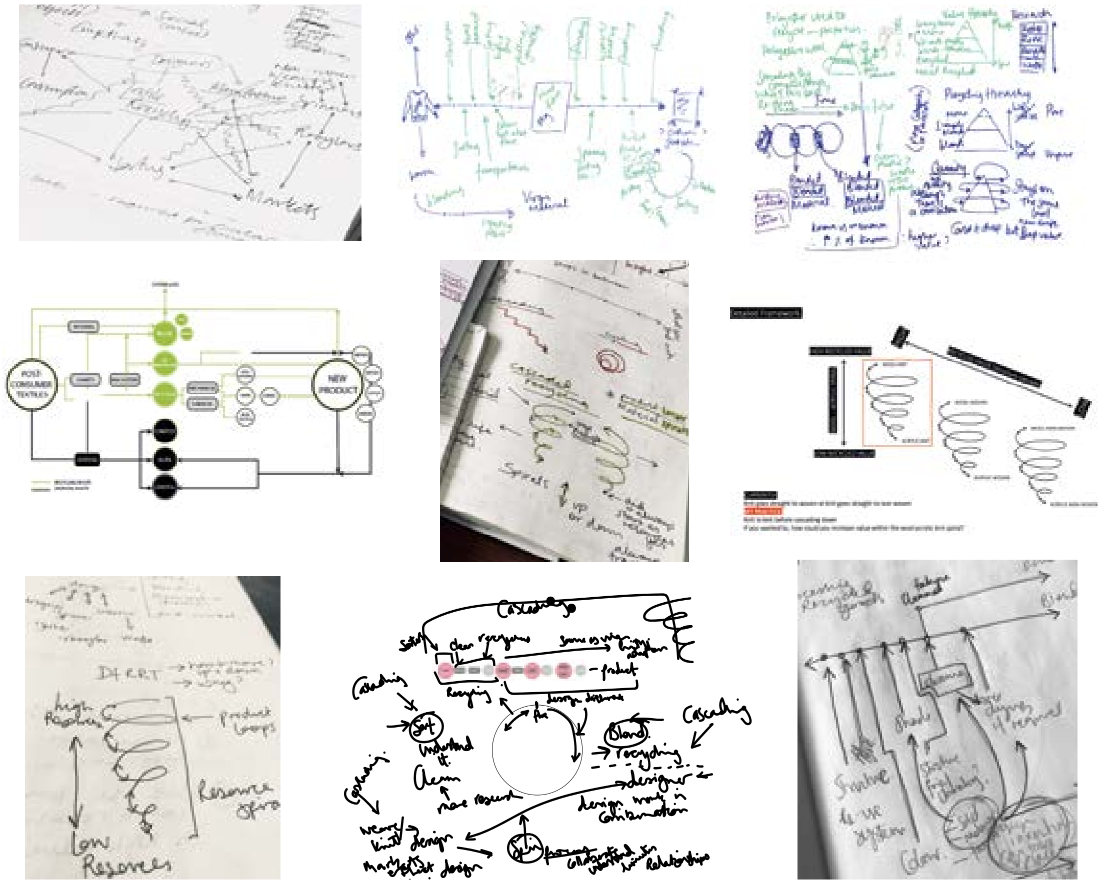


Figure 12. Multi-media maps portraying sections of an overlapping GIGA-map which never existed as a whole

Figure 13. In the field a picture of machinery on a factory visit

2.4.4 FIELD PRACTICE EXPLORATION

Field research is a well-documented method which originates in the social sciences. This, Koskinen et al. (2011) explain, is one of three approaches for designers to integrate design-specific work methods into research: Lab, Field and Gallery. Using a field approach allows the design object to be understood in context rather than through extracted data. It was applied in this study through the investigation of recycled materials (the design object) within the textile recycling system (context). The methods themselves include questioning (conversation and semi-structured interviews), observing, note-taking and photography.

This phenomenological approach makes it almost impossible to distance oneself from the research. While it has many benefits, as Bonner and Tolhurst (2002) explain, being an 'insider' in research has the advantage of increased understanding of a situation, in turn fostering greater communication and higher levels of accuracy. At the other end of the spectrum, unconscious bias cannot always be avoided (Hewitt-Taylor, 2002). However, many other research fields such as clinical medicine and law build their knowledge in a related way by assessing case studies as the context for new ideas. Similarly, as Koskinen et al (2011) point out, the field approach allows designers to study existing designs and processes to learn their logic and thus address problems in context. In this research, the field approach was not utilised alone, but combined with other methods to maximise knowledge and understanding.

In order to enter into the field a number of experts were identified. Their expert status was based upon their level of experience in the textile recycling industry. Initial contact was made via telephone or through online channels to gain further information and to establish the relevance of a visit. A vast number of conversations with experts in the UK, Italy, Pakistan, the Netherlands and Sweden were carried out. However, a relatively small number translated into a physical visit. Even if an initial conversation did not transfer into the field, each one provided a deeper understanding of the textile recycling process and system.

The field visits themselves had an unstructured approach. Much like a semi-structured interview (Brinkmann, 2014) questions were roughly outlined before any visit. However, new questions were often formed by standing in front of the machinery and watching the process unfold. This responsive approach was a vital part of the method. If the research has been solely conducted over the telephone without seeing the process first-hand, many of these enquiries would never have formed.

NOTE-TAKING

Note-taking is a vital part of any field research. However, in this type of field 'experience' it was not always practical. A typical visit would last only an hour or two. This was especially relevant as most tours were provided by busy professionals who often could only spare a set amount of time. The conversations were most often conducted on the move, with much shouting over the thunder of loud machinery. It was, therefore, difficult to use written text as a method to record findings when moving around quickly and carefully in an active environment. However, note-taking was not disregarded entirely. While the majority of a visit was conducted on the move, a notebook was always at hand to jot down important thoughts and became essential on returning to the host's office to raise further questions and discussion.

Figure 14. Notes from the field scribbled in a notebook

PHOTOGRAPHY

In order to overcome the difficulty of conducting research in this manner, other methods of recording information were required. As used across the fields of ethnography and anthropology (Gottlieb, 2006; Collier and Collier, 1986) photographs were taken alongside notebook jottings as a means of prompting visual recollections but also to reduce misunderstandings at the analysis stage. A zoomed-in technique (Figure 15) as a focused activity avoided what Henkel (2014) describes as a photo-taking-impairment effect that occurs when the whole rather than the relevant part of an image is captured. Using this method, the experience was embodied within the photographs thus allowing for analysis after the event.

2.4.5 FIELD PRACTICE TESTING

Field practice testing took the field practice exploration one step further in which active experimentation was completed in the industrial context. The testing itself was on two distinct scales. Earlier on in the research, smaller scale experiments were conducted to test initial research ideas (Practice 2, 4, 6 and 8). This was achieved using industrial machinery used by the companies for R&D (research and development) and therefore was suitable for experiments on a smaller scale. This form of practice was used to explore and understand elements of the enquiry, such as blending and cascading. It involved using recycled fibres, blending them and test spinning to create small sample yarns. This type of quick experimentation enabled quick reactions to new ideas and the scale meant more risky ideas could be attempted.

The experiments themselves were set up after the initial field visits had taken place. A number of textile production companies, such as spinners, were approached. Rather than solely conducting field practice research by asking questions, the act of physically bringing recycled fibres into the factory to be used on the machinery raised many questions and challenged normal practices, demonstrating the necessity of this method.

Following this, the final practice test (Practice 10) was conducted on a larger scale, designed to test the ideas in full. This meant that not only would yarns be produced but also a 'proof of concept' could be created, namely, knitting the yarns into swatches and producing prototype garments. These final stages were important to assess the manufacturability of the material design for which conclusions could be drawn.

Figure 15. An example of a zoomed-in photograph as part of the field research

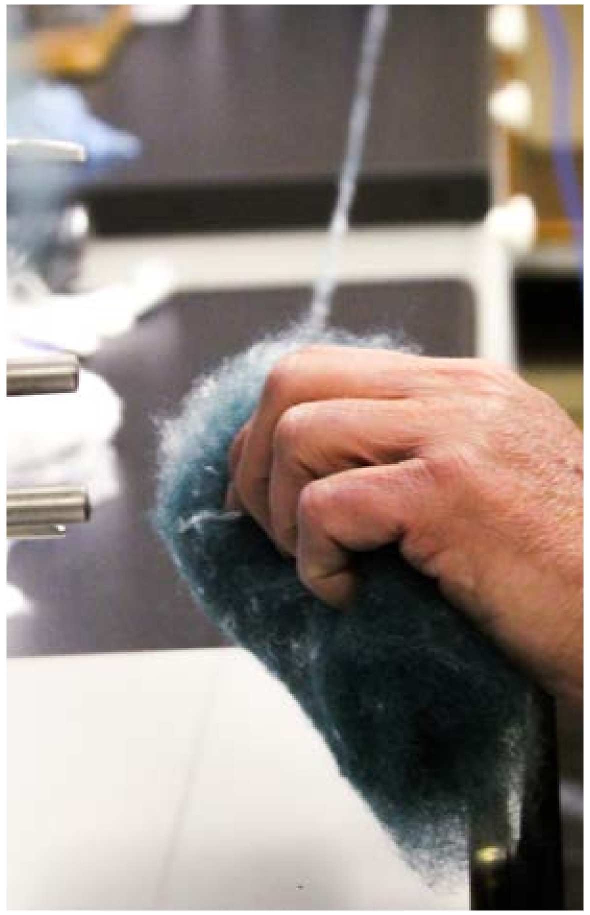


Figure 16. An example of quick and small experiments

Figure 17. The yarns produced during the large-scale experiments

Figure 18. Workshop at Weißensee Kunsthochschule Berlin

2.4.6 WORKSHOPS

Workshops were used as an investigative tool across the first two years of the research. This was an explorative phase in which the researcher was synthesising her research ideas. Three iterations of a single workshop were conducted (Practice 4). The workshops were conducted as part of three larger events, two editions of the 'There and Back Again' symposium held at UAL: Chelsea College of Arts and 'GreenLab' project at Weißensee Kunsthochschule Berlin. The former was an event co-created by the researcher aiming to bring together students, researchers, industry and the wider public to discuss the sustainable design theme for each year (Forst and Hall, 2018). The workshops in this case brought together a range of different participants from these areas. The latter workshop was conducted as part of a larger series of events introducing students from across product, textile and fashion design at Weißensee to different sustainable design strategies (GreenLab, 2020). For each workshop groups of 3-5 participants worked around a single worksheet (Figure 18).

The workshop itself consisted of three tasks. First the participants mapped all the elements of the garments they had been given and decided the easiest end-of-use option in its current state. The garments were specifically chosen for the participants due to their material complexity. For example, they were made up of many components of different materials or made from a blend of materials meaning they would not easily flow into an end-of-use strategy. These end-of-use strategies, such as mechanical recycling, remanufacture or biodegradability were explained during the introduction to the session and basic information was provided in the form of cards for participants to refer to. The second task was a redesign challenge. The participants had to select an alternative end-of-use strategy and redesign the garment for this specifically. The third and final challenge was to create a story board. The redesigned garment would be used at the beginning of the storyboard to flow into the desired end-of-use strategy and turn into a new product. This had to flow into another (different) end-of-use strategy and end as a final product. After the first iteration of this workshop an additional worksheet was also provided for participants to consider 'how it would work?' to explore the realities of the systems they had designed.

The insights from the workshops themselves where not fully understood until much later in the research process and were brought together with the results from other methods to be synthesised. For example, the concept of design for repeated cyclability was combined with cascading literature to understand this as a design strategy in full. Initially the workshops had been designed only as a means for participants to engage with design for cyclability. However, as the research developed it was only then that the workshops were appreciated as a key method of exploration in these initial stages.

The use of workshops as a methodological tool is commonly used by researchers. In the field of textile design, workshops have been used as training and consultancy (Earley et al., 2016), as method to develop interdisciplinary dialogue (Tubito et al., 2019), and participatory making to investigate well-being (Twigger-Holroyd, 2013) amongst others. Ørngreen and Levinsen (2017:70) explain that workshops as a research approach can be described as "an explicit method choice that allows us to iterate, and thus refine and moderate, our research design over time and in different contexts". They have explored how workshops are used as method from three different perspectives: 'workshops as means', 'workshop as practice' and 'workshop as research methodology'. 'Workshop as means', they expound, are authentic and create the means to achieve a goal, whilst, 'workshops as practice' often have a developmental element (creating something material or immaterial) and focus on the relationships between the workshop and its form and outcomes. Finally, using a 'workshops as research' methodology is specifically designed to fulfil a research purpose.

The workshops in this case fit into Ørngreen and Levinsen's (2017) 'workshop as practice' definition. This, they suggest, either investigates the workshop format itself or the outcomes from the participants. This can result in the generation of guidelines on "how to innovate and incorporate workshop frameworks into future situations" (ibid, 2017:72). This aptly describes the series of workshops undertaken used as a research probe into the topic of design for repeated cyclability (later to be understood as cascading and coined spiralling). This, in conjunction with other methods, led to the development of the Design for Recycling Knitwear Framework.

2.4.7 INTERVIEWS

The final explorative method is the more formalised interviewing of experts (Field-Springer, 2017). This method was used to discover specific information unable to be established fully through literature or the field research itself. In this research, interviews were conducted to understand the sorting categories of wool and acrylic textiles, a line of enquiry that developed during the field research. When the researcher returned to the literature the gap in knowledge was exposed thus requiring specific questions to be answered.

The experts, like in the field research, were selected due to their experience and knowledge pertaining to the sorting categories of wool and acrylic textiles. The interviewees were, firstly, Hasnain Lilani who owns a wool sorting company 'Recycle Wool' (who requested not be kept anonymous). He was selected for his experience of industrial hand sorting in Pakistan. Hasnain was contacted during the first explorative stage prior to the field research and re-contacted for two subsequent interviews. Secondly, the owner of a spinning company in Prato, Italy (kept anonymous) producing recycled yarns from wool and acrylic fibres was contacted. This spinner had been previously visited during the field research and was selected for interview as his company purchased both pre-sorted textiles as well as unsorted textiles. A combination of pre- and self-sorted garments were used to create the recycled fibre for his yarn production.

The first interview with Hasnain Lilani was conducted over the phone. However, all subsequent interviews with both Lilani and Recycler X were conducted over WhatsApp, a quick messaging platform for written, spoken and visual communications. This was the medium of choice for both interviewees and enabled fast communication that could be made at any time during the day. This was particularly relevant as both subjects were based over-seas and had busy work lives. The interviews were formed of a mixture of short written communications, longer voice messages and photographs. In particular, voice messages proved to be a particularly useful tool when answers could not be simply explained in written form. They also overcame any language barriers as concepts could be explained in less formal language. Visuals were also helpful as it enabled the researcher to explain her questions more clearly. In this way, the interviews became more akin to a conversation (as in field practice exploration) conducted face-to-face in an industrial context, where it is easy to discuss complex topics, pointing to and picking up physical objects as a form of reference.

The decision to use only two interviews could be considered a small sample size, however, this was deemed appropriate to accomplish the research aims. The researcher had considered conducting further interviews but doing this was unnecessary due to the shifting nature of sorting categories depending on the market and customer's needs (discovered during the field research phase), making exact categories very challenging to find. Therefore, extensive interviewing and investigation was discounted. For the purposes of this research, only generic sorting categories were required, and this data could be obtained using a small sample. The selection of the two 'experts' was deliberate, spanning both supply and demand within the textile sorting industry: a company supplying sorted wool textiles and a company buying the sorted and unsorted waste for recycled production.

It is important to note that these interviews do not stand alone in this research. The qualitative information regarding the sorting categories gained from the interviews was compared and contrasted with information found in the literature on hand sorting of wool and acrylic textile waste (Botticello, 2012; Thompson, Willis and Morley, 2012; Norris, 2005; Norris, 2012c). This was supplemented with recent research on automated sorting of textiles (Circle Economy, 2019). Thus, comparisons could be made between categories in hand sorted, automated sorting and those categories used by the producers of recycled materials in the current industry to establish the generic categories required for the research.

2.4.8 CREATING DESIGN BRIEFS

The use of a creative design brief as a method was used for the final practice experimentation and has been inspired by the commercial textile and fashion design process. In industry when starting a design project, a design brief is often established and is described by Marchant (2016:340) as "a form of discourse…that design context and design intentions for the proposed project need to be conveyed". For this research project, the design brief was provided in part by the research aims themselves and to enable the Design for Recycling Knitwear Framework to be tested (section 9.3, page 217). In essence this required the textile to be made from recycled fibres which can then be recycled without losing value at the sorting stage. This provided the basis of a design brief to work towards.

The next steps in a commercial design process is described by Sinclair (2014) as ensuring the appropriate price points and market for which the design is intended. She continues that the fashion designer will research into silhouettes, trend predictions for style, cut and colour. Inspirational research, visiting museums and 'watching people on the street', is combined with market research to come up with a 'concept' for the design in question (Figure 19).

This research which Sinclair describes was conducted and resulted in a series of mood boards. A mood board is defined by Cassidy (2011:227) as "tools used by designers to bring together apparently incongruent visual data to promote inspirations to develop suitable end products". The images selected were arranged in what Cassidy describes as a meaningful manner to enable a flow of thoughts and inspirations towards an outcome. Three mood boards were created, the first collection of images and text exploring the current blends and price points of knitwear containing acrylic and wool. The second an inspirational board of images exploring silhouette, yarn texture and design details. The final board summarised the key trend research found on the WGSN website. The three activities, market, trend and inspirational research, were brought together to create the 'concept' for the design of both the yarn and the garment.

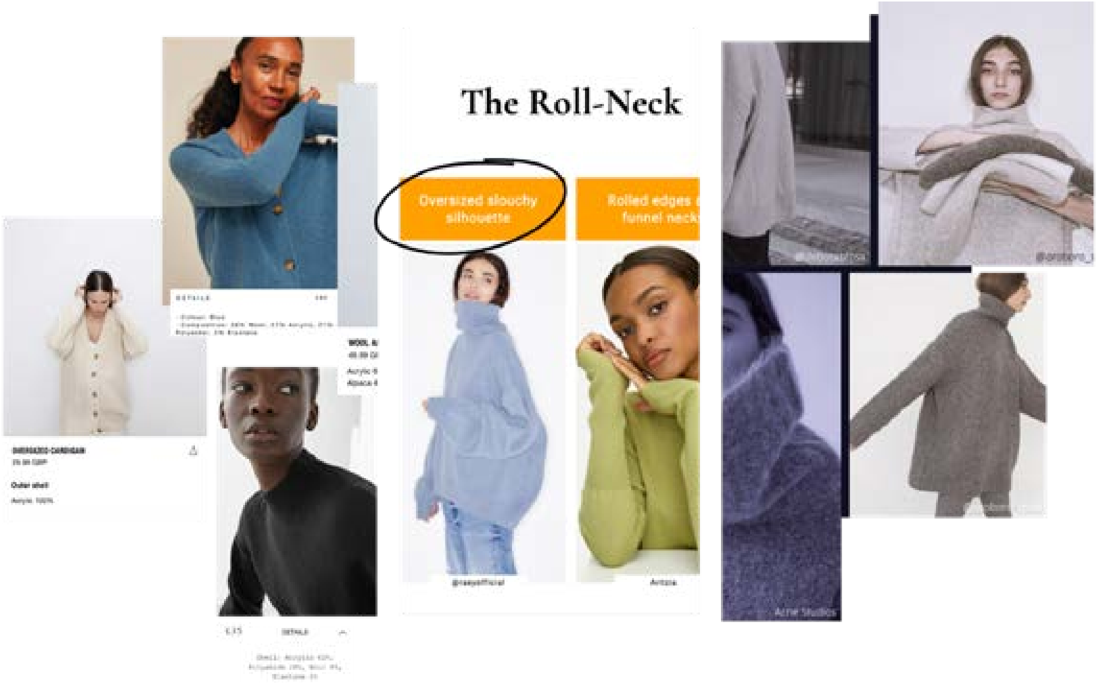


Figure 19. An amalgamation of trend, Inspirational and Market Research boards used in the research

2.4.9 ANNOTATED PORTFOLIO

The final method used in the research was a reflection tool to analyse the research and produce insights. This was achieved using an experiential annotated portfolio approach (Hall, 2020b). The original annotated portfolio approach was first brought to the field of research-through-design by Gaver and Bowers (2012) to address the issue that works of design do not speak for themselves. They argue that a design object embodies the decisions and processes made by the designer, but this is not always immediately obvious (Gaver, 2012). To best encapsulate these design decisions, annotations (written notes) can be placed around the image of a design object as a method to explain and validate the design process. When combined with other annotated images they become a portfolio which can help to bridge larger research issues. This approach takes a form of reflection to help designers establish what works and why. This is described by Löwgren (2013) as a form of intermediate-level knowledge to bridge the gap between practice and academic research (new knowledge).

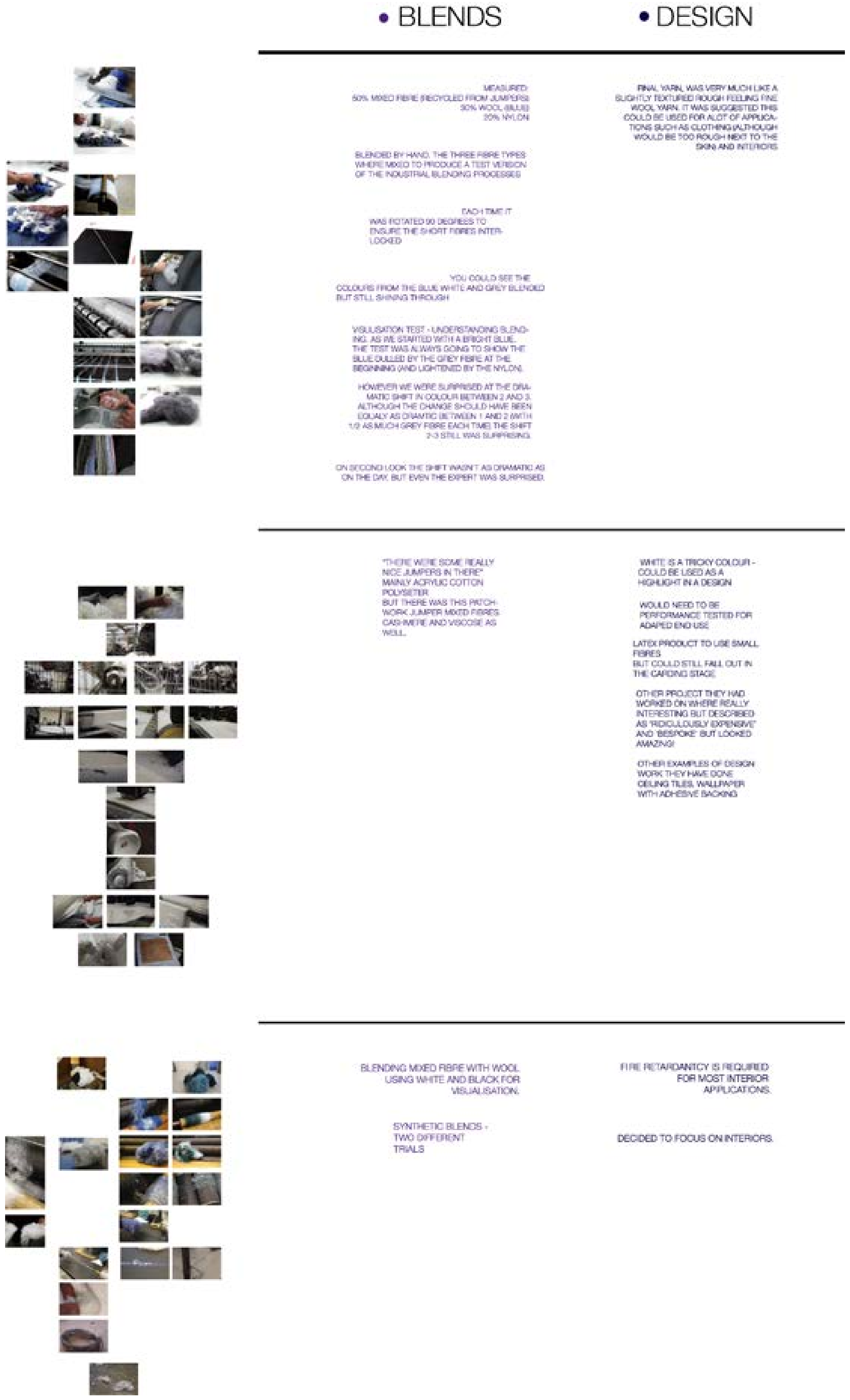
Gaver and Bowers (2012) stress that there is no one way of doing an annotated portfolio and there are many examples, such as aiding the anyalsis of design interviews (Sauerwein, Bakker and Balkenende, 2018) and insights from material samples for the development of business model concepts (Pedersen, Earley and Andersen, 2019). In this research, the annotated portfolio method was developed specifically to create designerly insights from experience and has been published in the Journal of Textile Design Research and Practice (Hall, 2020b - Appendix 14.8.3, page 440).

The 'taking note' annotated portfolio approach for design experience is split into three stages: reflective, thematic and holistic.

Table 2. Three approaches for experience-based annotated portfolio, (Hall, 2020b:10)

THREE STAGES	
REFLECTIVE	Self-reflective information about what happened and why
THEMATIC	Themed insights from zoomed-in experiments
HOLISTIC	Over-arching conclusions (systems)

The method uses photographs taken during a design experience, such as a field visit (section 2.4.4, page 35), to create a form of design object. Photographs are selected based on their relevance which are then laid out in a vertical timeline format; beginning to end. Additional images can then be added horizontally to form clusters of detail. The annotations are then added as forms of reflection (the first stage). These are recommended to be added under three catagories: investigative questions, data (such as the observed insights and understandings) and reflective thoughts and comments relating to the experience. The annotations are colour coded into themes (stage two) and organised into a table format. This new visual diagram can be analysed like a bar chart emphasising the themes that have more weighting than others. Finally, the visual is then combined to be holistically analysed (stage three) which creates the portfolio (Figure 20).



MEASURED:
50% MIXED FIBRE (RECYCLED FROM JUMPERS)
30% WOOL (BLUE)
20% NYLON

BLENDED BY HAND. THE THREE FIBRE TYPES WHERE MIXED TO PRODUCE A TEST VERSION OF THE INDUSTRIAL BLENDING PROCESSES

EACH TIME IT WAS ROTATED 90 DEGREES TO ENSURE THE SHORT FIBRES INTERLOCKED

YOU COULD SEE THE COLOURS FROM THE BLUE WHITE AND GREY BLENDED BUT STILL SHINING THROUGH

VISULISATION TEST - UNDERSTANDING BLENDING. AS WE STARTED WITH A BRIGHT BLUE. THE TEST WAS ALWAYS GOING TO SHOW THE BLUE DULLED BY THE GREY FIBRE AT THE BEGINNING (AND LIGHTENED BY THE NYLON).

HOWEVER WE WERE SURPRISED AT THE DRAMATIC SHIFT IN COLOUR BETWEEN 2 AND 3. ALTHOUGH THE CHANGE SHOULD HAVE BEEN EQUALY AS DRAMTIC BETWEEN 1 AND 2 (WITH 1/2 AS MUCH GREY FIBRE EACH TIME) THE SHIFT 2-3 STILL WAS SURPRISING.

ON SECOND LOOK THE SHIFT WASN'T AS DRAMATIC AS ON THE DAY. BUT EVEN THE EXPERT WAS SURPRISED.

FINAL YARN, WAS VERY MUCH LIKE A SLIGHTLY TEXTURED ROUGH FEELING FINE WOOL YARN. IT WAS SUGGESTED THIS COULD BE USED FOR ALOT OF APPLICATIONS SUCH AS CLOTHING (ALTHOUGH WOULD BE TOO ROUGH NEXT TO THE SKIN) AND INTERIORS

"THERE WERE SOME REALLY NICE JUMPERS IN THERE"
MAINLY ACRYLIC COTTON POLYSETER
BUT THERE WAS THIS PATCH-WORK JUMPER MIXED FIBRES. CASHMERE AND VISCOSE AS WELL.

WHITE IS A TRICKY COLOUR - COULD BE USED AS A HIGHLIGHT IN A DESIGN

WOULD NEED TO BE PERFORMANCE TESTED FOR ADAPED END USE

LATEX PRODUCT TO USE SMALL FIBRES
BUT COULD STILL FALL OUT IN THE CARDING STAGE

OTHER PROJECT THEY HAD WORKED ON WHERE REALLY INTERESTING BUT DESCRIBED AS 'RIDICULOUSLY EXPENSIVE' AND 'BESPOKE' BUT LOOKED AMAZING!

OTHER EXAMPLES OF DESIGN WORK THEY HAVE DONE CEILING TILES, WALLPAPER WITH ADHESIVE BACKING

BLENDING MIXED FIBRE WITH WOOL USING WHITE AND BLACK FOR VISUALISATION.

SYNTHETIC BLENDS - TWO DIFFERENT TRIALS

FIRE RETARDANTCY IS REQUIRED FOR MOST INTERIOR APPLICATIONS.

DECIDED TO FOCUS ON INTERIORS.

Figure 20. Holistic annotated portfolio of an experience in a table/bar chart format, (Hall, 2020b:17)

2.5 INDUSTRY AND ACADEMIC METHODS

The research itself and the methods selected to accomplish it were influenced by a body of prior knowledge brought to the enquiry by the researcher. This could also be described as the researcher's 'tacit knowledge' a term coined by Micheal Polanyi starting from the notion that "we can know more than we can tell" (Polanyi, 2009:4). In the case of this study, this knowledge can be divided into two parts. First, the experience of working as a commercial knitwear designer in industry (see preface,page iv) and second, the practice-based content of the researchers Master's degree investigating textile recycling (see Practice 0, page 59). These comprised two different types of knowledge from industry and academia respectively.

The tacit knowledge gained from industry experience of the design process has influenced the methods chosen. Using a 'creative design brief' through mood boards is a clear example of the researcher using the tools 'to hand' to achieve her aims. On the other end of the spectrum, tacit knowledge gained from her Master's degree provided visual thinking tools to explain complex ideas in an academic context. While a large part of this PhD research has been conducted through exploration in an industrial setting, the researcher continually returned to the university to think and conceptualise the knowledge gained. This divide between industry methods and academic ones enabled the discovery of rich and applicable insights.

Lucy Kimbell (2011) stresses the unwanted division between ways of working in academia and industry, she suggests that academics need to understand more about the role of the professional designer, particularly at a time when practitioners are working in "challenging new contexts". She argues further that the focus should be placed on the creation of materials and objects (practice) by the 'situated' professional designer. This is opposed to focussing solely on 'design thinking', the problem-solving design method employed for innovation in other fields such as business (Brown, 2008).

Accordingly, the choice of methods used in this PhD research illustrates the importance of practice by using field practice exploration and field practice testing in industry throughout the research. In her follow-up text, 'Rethinking Design Thinking: Part II' Kimbell explains:

> Using a practice approach re-conceives of design activity as linking both what designers do, know, and say, with what end-users and other stakeholders do, know, and say, acknowledging the materials and objects that are part of these activities (Kimbell 2012:144).

At the heart of Kimbell's argument is the value of industry stakeholders working with designers using materials and objects. These industry methods are distinct from craft-based practice research, in which the textile designer looks down and works on a small square of fabric (Igoe, 2013). The industry practice research in this PhD study allows for collaboration with a variety of industrial stakeholders where the materials and objects must be designed using pre-existing systems within the limits of the machinery and scales of production.

Rodgers, Innella and Bremner (2017:S4450) go so far as to suggest that "in the hands of most practitioners, design is useful and research is useless". This would imply that the practices in industry and academia are entirely discrete. Bonsiepe, (1999 cited in Rodgers, Innella and Bremner, 2017:S4455) would disgree, however, claiming that design theory (academia) is vital for the education of future professional designers (industry). This, he reasons, is because every form of professional practice takes place within a theorical framework. Here Bonsiepe acknowledges the clear connection between industry and academia. However, in reality, when conducting academic research within industry, the lines between the two are more blurred.

2.5.1 INDUSTRY METHODS IN RESEARCH

It has been pointed out by Vuletich (2015) that there no methodological frameworks in the field of sustianble textile design to conduct research in the industry setting. We can see that over the last couple of decades there has been a rise in textile research being conducted with industry. For example using industry workshops to develop and test research ideas (Earley and Goldsworthy, 2019a), and textile design PhD Textile design research (Farrer, 2000; Paine, 2015; Cleveland, 2018; Mcquillan, 2019). However, understanding the methods of acheiveing this successfully is still being establsihed.

On a larger scale funding bodies such as the EU Commission and Arts and Humanities Research Council (AHRC) are actively encouraging proposals working directly with industry partners. For example, EU Horizon 2020 Trash-2-Cash (2018) project that produced a design-driven material innovation methodology to work with 18 partners across academia and industry. Similarly, the AHRC Creative Clusters project (2019) brings together academic researchers and industry partners to create nine cluster projects. Each 'cluster' is hosted by a higher education institution working with the industry to drive innovation.

This type of research and industry collaboration has been driven by the imperative to understand the impact of research projects which is often created through Knowledge Exchange (KE). KE is defined generally by Cruickshank, Whitham and Morris (2012:481) as "a key component of any collaborative, productive or creative process involving more than one person". Rather than using KE to teach the industry directly, KE methods can be utilised so that both business and design can learn from each other (Follett and Marra, 2012). However, Cruickshank, Whitham and Morris (2012) emphasis that we need to design KE approaches, tools and mechanisms. Often, they explain, academics do not engage with the projects that use these tools.

2.5.2 COMBINED INDUSTRY AND ACADEMIC METHODS

Understanding how to work and interact across both academia and industrial spaces is complex. In the field of interaction design, Fallman (2008) has explored how these two approaches combine. In his model, he describes 'design practice' as an industry endeavour that is close or even identical to the activities outside of academia, such as working for a commercial design organization, consultancy or in-house design department. This industry-based design practice, as Fallman (2008:12) points out "needs to be real, in that it must pay attention to and often adhere to commercial aspects, cost, time to market, sales figures, other products in the market". In contrast, he explains, 'design studies' is an academic endeavour which has an "overall goal is to build an intellectual tradition within the discipline, and to contribute to an accumulated body of knowledge" (ibid, 2008:9). These contrasting activities form two points on a trianglular shaped model (Figure 21).

Fallman explains that it is most interesting and rewarding to move between these two positions (design practice and design studies) and that doing so offers a change in perspective, or has he puts it, the opportunity of "using a different set of goggles" (2008:10). What Fallman refers to as the changing of goggles broadly corresponds to this researcher's use of the 'changing hats' metaphor. This has been explored in her co-written journal article "Divide, Switch, Blend: exploring two hats for industry entrepreneurship and academic practice-based textile design research" (Hall and Earley, 2019). The article, written after completing Practice 3 in this research (page 131), explores not just the experience and value of shifting in perspective but also the complexities arising out of this.

Fallman (2008:11) suggests that the "two activities [industry and academia] often transpire and feed into each other, rendering them almost inseparable". He further explains that explicitly thinking and understanding when and which perspective is most needed in any given moment is vital to planning and explaining interactive design research. Hall and Earley's article support and refine this idea in the context of textile design, making a clear distinction between the various ways in which the designer and researcher hats interact, dividing, switching and blending. 'Divide' entails wearing both hats separately on different occasions; 'Switch' is having both hats to hand ready for swift interchange on the same occasion; and 'Blend' refers to the wearing of both hats simultaneously. They conclude that recognising the dominant hat in a given situation is vital for fluidity and greater awareness leading to broader and deeper insights (Hall and Earley, 2019, see Appendix 14.8.2, page 423).

The third element in Fallman's (2008) triangle shaped model (Figure 21) is described as 'design exploration'. This is the process through which the researcher brings forth a product or a service. This, he admits, is very similar to what he calls 'design practice' but does not have the clients, customers or final market in mind. However, the main difference, he explains, is that the researcher within the exploration asks the question: 'what if?', in an attempt to identify what might be possible and to challenge the status quo. Fallam suggests that creative problem-solving methods are employed within the process, such as those offered by Cross (2011) and Moxey (2000) to provide a problem frame or space in which to carry out the design exploration. However, unlike design practice (designing in industry) design exploration, Fallman (2008) argues, is self-initiated and concerned only with the researcher's agenda.

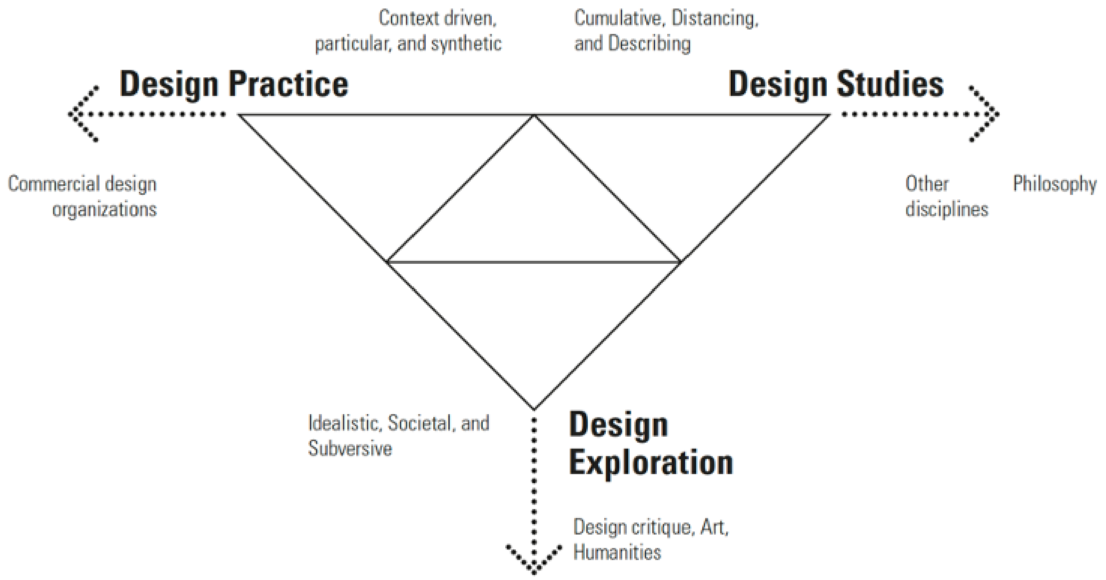


Figure 21. The model of interaction design research in its most basic form (Fallman, 2008)

2.5.3 DIVIDED INDUSTRY AND ACADEMIC METHODS

While Fallman's model has crucially highlighted the complexity of working between industry and academia, to start to understand the complexity in this research between industry and academic spheres, a visual thinking method was employed by the researcher. First each method has been colour coded to suggest which are common to industry design or more associated with academic research. These are mapped onto a quadrant graph in Figure 22 (overleaf) which vertically ranges between academia and industry and horizontally between Think-Reflect and Test-Explore stages.

The graph demonstrates that methods flowed diagonally between the bottom left corner of the quadrant to the top right quadrant. This highlighted for the researcher the dominance of thinking and reflecting are academic methods and testing and exploring are akin to industry methods. The relative positioning of the different methods within their respective quadrants represents the extent to which they interrelate with the opposing field. Engaging with literature, for example, is a highly academic activity while the use of creative design briefs is a distinctly industry-based method.

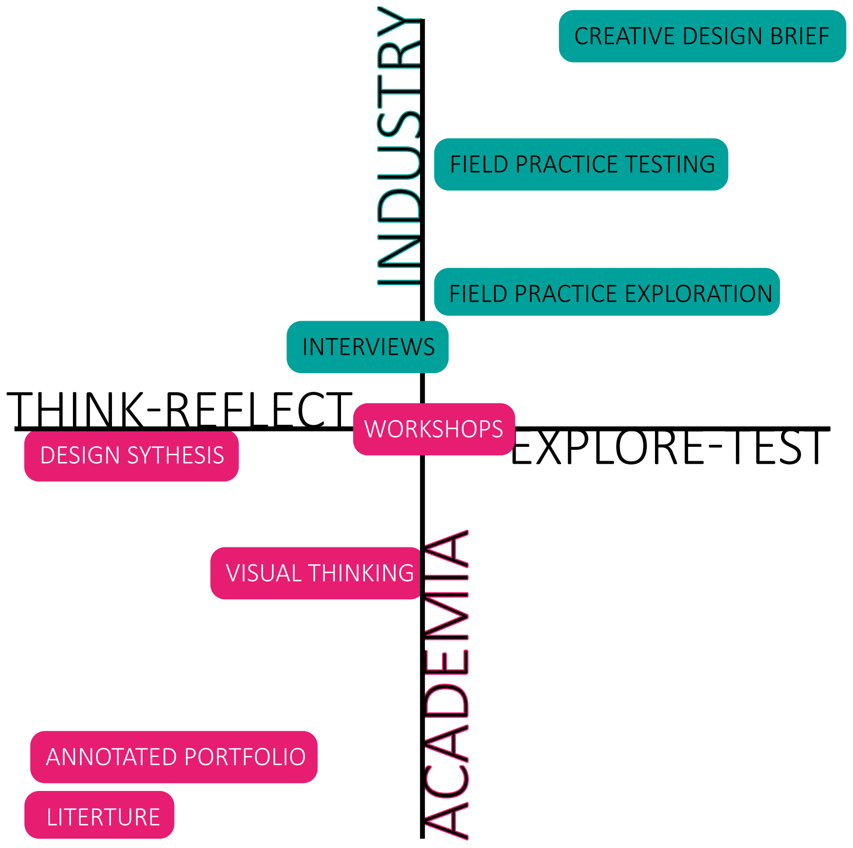


Figure 22. Quadrant graph mapping the nine methods of this research within academic and industry methods which achieve thinking and exploring.

While the majority of methods on the graph sit within the top-right and bottom-right quadrants, there are examples which edge into the opposing top-left and bottom-right quadrants. The most obvious example is the conducting of workshops which is a form of academic exploration that is explored with students and industry designers. However, the divide of methods between those used in academia and those used in industry is not so clear-cut. In reality, there is far greater 'osmosis' across the two fields than any theory might suggests. Vitally, it is by working across the two domains and understanding how they interact that the researcher can generate new knowledge and insights (Hall and Earley, 2019). Further discussion of how this dual approach between research and industry is used and the framework that was generated can be found in Chapter 11, in a reflection and discussion of the research conducted in this thesis (section 11.2, page 295).

2.6 BUILDING METHODLOGICAL FRAMEWORK

To understand how the nine methods together form a methodology, Table 3 (re-produced from section 2.1, page 19) maps each aim to individual methods and has been colour coded. These colours demonstrate the assigned stage that each method belongs to, namely Think, Explore, Test and Reflect. As colour has been added to the methods, a cyclic pattern has emerged in which the research moved from first thinking, to exploring and/or testing, to reflecting. From there the cycle repeats (Table 3).

Table 3. Thinking, Exploring, Testing & Reflecting methods

AIM	OBJECTIVES	METHODS
A. To understand both the fields of design for mechanical recycling and design for cascading in the context of post-consumer wool and acrylic textiles.	Conduct a review of the current mechanical recycling industry of wool and acrylic textiles.	Literature Field Practice Exploration
	Understand the role of design in current textile recycling industrial systems.	Field Practice Tests Design Synthesis Visual Thinking
	Conduct a review of the current cascading literature in relation to textile design.	Literature
B. To establish a Design for Recycling wool/acrylic textile model for designing longevity of resources through recycling and bringing together cascading, blending and sorting.	To understand how the field of cascading intersects with design for recycling of post-consumer textile waste.	Literature Workshop Design Synthesis
	Identify the role of blending within virgin and recycled textile production.	Literature Field Practice Explorations Field Practice Tests Annotated Portfolio Design Synthesis
	Investigate the methods of sorting for mechanical recycling of wool and acrylic textiles.	Literature Interviews
	Propose how cascading blending and sorting might be used together to ensure resource longevity of post-consumer wool/acrylic textiles.	Annotated Portfolio Design Synthesis Visual Thinking
C. To test, through practice, the ideas generated in the previous aims to produce the Design for Recycling Knitwear framework and to establish how the methods have been used across research and industry.	Investigate, and where necessary collaborate with, industrial partners to test the realities of Designing for Recycling Knitwear from yarn to product.	Creative Design Brief
	Draw insights from opportunities and challenges of Designing for Recycling Knitwear in industry to establish how design decisions bridge the recovery and manufacture of textile resources.	Field Practice Test Design Synthesis
	Draw insights from Designing for Recycling Knitwear in industry to establish a model of how researching between academia and industry can be conducted.	Annotated Portfolio Design Synthesis

The next stage was to explore further the relationship between the methods, the four stages, insights and ultimately contributions to knowledge that this research has produced. To make the jump from aims to methods to insights, informed by Forst's (2020) methodological framework, a mapping exercise was conducted (Figure 23 overleaf). Forst, specifically uses mapping to move from a set of disjointed actions, creating links in the form of a flow to interpret them. These connections and flows have been adopted and are presented in Figure 23.

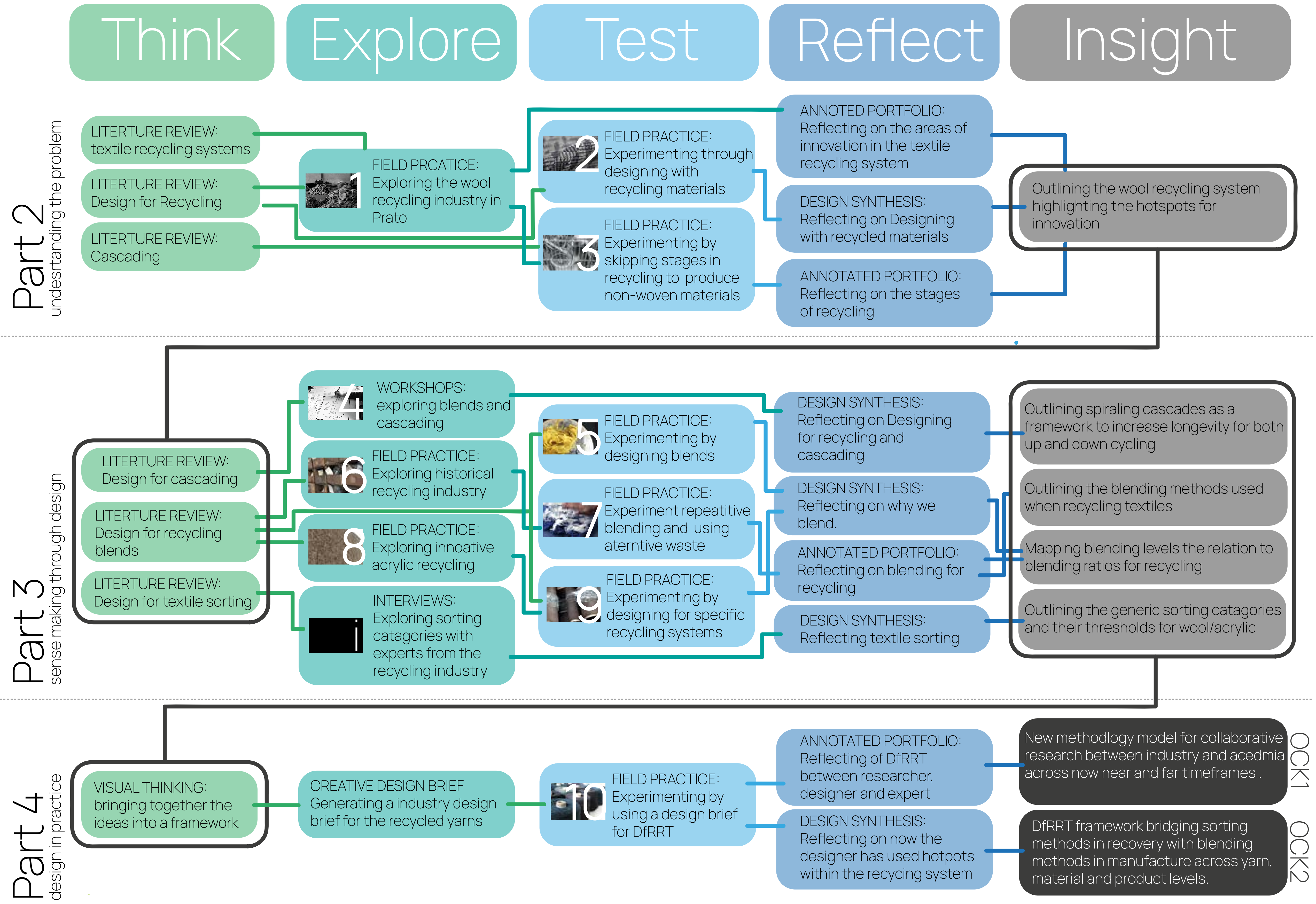
While Forst's original contributions to knowledge seem to emerge at various points throughout her research, here the circular motion of method across the four stages enabled the generation of insights which, in turn, were used to inform the next part of the research. In particular the connection between the final reflecting stage and returning to the thinking stage, is captured in Moon's (2004:80) definition of the reflective process. She suggests reflection is "a process, [that] seems to lie somewhere around the notion of learning and thinking". Reflection in this case is not the established method designers employ called 'reflective practice', introduced by Schön in 1983, whereby reflection occurs during the design process. Although this form of reflection undoubtably occurred during the field practice testing. Here the formal reflection stage takes place afterwards in the form of an annotated portfolio method and design synthesis.

As demonstrated in Figure 23 each part of the research (Part 2-4 of this thesis) moves through the four stages and in doing so each of the three aims and their objectives are addressed (as in Table 3). The mapping draws out the more complex connections between the methods which work together towards insights. These ultimately lead to the two final contributions to knowledge – a methodological and a practice framework - presented at the end of the thesis. The methodological framework, which emerges directly from the practice research itself, seeks to understand how research conducted between the realms of academia and industry can be harnessed for the generation of insights and new knowledge. Further discussion can be found in section 11.2 (page 295).

2.7 METHODS SUMMARY

The methods used in this research represent the more messy and experimental nature of discipline of design. They are brought together using a bricolage approach, in which methods available 'to hand' were drawn on in any given situation from reading literature in academic setting to taking pictures in industry field visits. As a textile designer-researcher craft practice is often drawn on to conduct doctoral research. However, drawing on previous experience as a function-led designer-specifier in industry (see preface, page iv) the research is described as a hybrid practice between function-led industry designers and material-led designer-makers. Here the designer interacted (as a material-led designer) with the recycled fibres, yarns and materials before and after specifying (as a function-led designer) how they should be made on industrial machinery. Conducting research in this manner, between the realms of industry and academia, provides context for the later methodological model which emerges from this thesis as an original contribution to knowledge. This research, it is argued, is a form of transition design towards a more sustainable future for which this research is enabling Design for Recycling Knitwear. Here the textile design is able to move between the micro, experiencing the recycled fibres and macro, understanding the recycling system in order to make change.

The research itself was undertaken in four district stages: Think, Explore, Test and Reflect. The nine methods explored in this chapter, namely, literature, design synthesis, visual thinking, field practice exploration, field practice testing, workshops, interviews, creative design briefs and an annotated portfolio, can be divided between these four stages. Across the research a pattern has emerged in which the methods are selected so that the researcher circulates between the four stages. Mapped across the thesis structure, this cyclic structure is evident as each part of the thesis was conducted across each stage, producing insights. This is repeated until eventually the thesis results in two contributions to knowledge.



Think

Explore

Test

Reflect

Insight

Part 2
understanding the problem

LITERTURE REVIEW:
textile recycling systems

LITERTURE REVIEW:
Design for Recycling

LITERTURE REVIEW:
Cascading

1
FIELD PRCATICE:
Exploring the wool recycling industry in Prato

2
FIELD PRACTICE:
Experimenting through designing with recycling materials

3
FIELD PRACTICE:
Experimenting by skipping stages in recycling to produce non-woven materials

ANNOTED PORTFOLIO:
Reflecting on the areas of innovation in the textile recycling system

DESIGN SYNTHESIS:
Reflecting on Designing with recycled materials

ANNOTATED PORTFOLIO:
Reflecting on the stages of recycling

Outlining the wool recycling system highlighting the hotspots for innovation

Part 3
sense making through design

LITERTURE REVIEW:
Design for cascading

LITERTURE REVIEW:
Design for recycling blends

LITERTURE REVIEW:
Design for textile sorting

4
WORKSHOPS:
exploring blends and cascading

6
FIELD PRACTICE:
Exploring historical recycling industry

8
FIELD PRACTICE:
Exploring innoative acrylic recycling

i
INTERVIEWS:
Exploring sorting catagories with experts from the recycling industry

5
FIELD PRACTICE:
Experimenting by designing blends

7
FIELD PRACTICE:
Experiment repeatitive blending and using aterntive waste

9
FIELD PRACTICE:
Experimenting by designing for specific recycling systems

DESIGN SYNTHESIS:
Reflecting on Designing for recycling and cascading

DESIGN SYNTHESIS:
Reflecting on why we blend.

ANNOTATED PORTFOLIO:
Reflecting on blending for recycling

DESIGN SYNTHESIS:
Reflecting textile sorting

Outlining spiraling cascades as a framework to increase longevity for both up and down cycling

Outlining the blending methods used when recycling textiles

Mapping blending levels the relation to blending ratios for recycling

Outlining the generic sorting catagories and their thresholds for wool/acrylic

Part 4
design in practice

VISUAL THINKING:
bringing together the ideas into a framework

CREATIVE DESIGN BRIEF
Generating a industry design brief for the recycled yarns

10
FIELD PRACTICE:
Experimenting by using a design brief for DfRRT

ANNOTATED PORTFOLIO:
Reflecting of DfRRT between researcher, designer and expert

DESIGN SYNTHESIS:
Reflecting on how the designer has used hotpots within the recycing system

New methodlogy model for collaborative research between industry and acedmia across now near and far timeframes .

OCK1

DfRRT framework bridging sorting methods in recovery with blending methods in manufacture across yarn, material and product levels.

OCK2

Figure 23. Mapping how each method led to insights and onto original contributions to knowledge (OCK) throughout the thesis

PART 1 SUMMARY

This part of the thesis has provided both an overview of the thesis and an in-depth look at the methods used. This is split into two chapters.

Firstly, the introduction outlines the context of the research presented across the thesis and a review of the methods used. The aims and objectives are presented as a list of items to be achieved within the study and link directly to the structure in which the thesis is written. Finally, the two contributions to knowledge that this thesis is leading towards are articulated.

Secondly, the methods chapter outlines the nine methods used in this thesis. It highlights the way this practice research has been split between academic and industry methods. This combination of the two realms is also reflected in the way the researcher has created practice, using a hybrid approach between function-led designer specifying and material-led designer-maker. The methods themselves are completed in four stages; Think, Explore, Test and Reflect in which the nine methods are categorised within. To accomplish the aims and objectives the methods circulate through the four stages multiple times leading to the original contributions to knowledge.

PRACTICE 0

AIM

To establish if recycled mixed fibre, originating from discarded jumpers, could be used to create yarns and non-woven materials suitable for commercial interior products

Practice 0 describes the author's Master's degree research. This represents the prior knowledge which was brought to this research. This has acted as a springboard for the investigation and inquiry and provides a vital context for the rest of the practice presented in this study. The practice involved sourcing and recycling waste textiles (discarded grey and navy jumpers) into new knitted and non-woven materials. The researcher sorted each jumper, touching every item by hand which allowed her to roughly estimate the composition of the material. While other fibres such as wool were also found, the majority of jumpers were largely synthetic in content (acrylic). The batch of discarded jumpers was thus classified as low value acrylic-mix fibre. These were then shredded and garneted resulting in a recycled fibre which was used to create both a recycled yarn and a non-woven fabric across two colour ways (grey and navy).

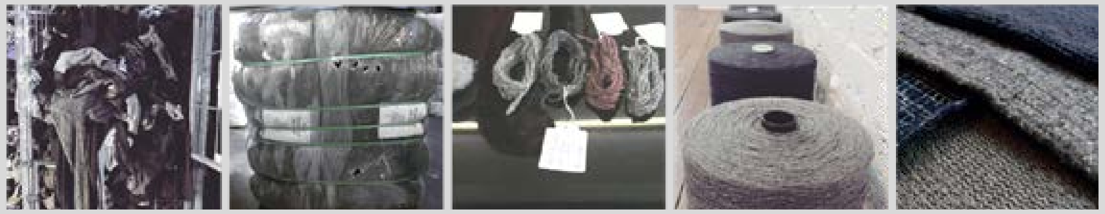


Figure 24. Five stages of Practice 0: sorting process, final bale ready for recycling, blending experiment samples, final recycled yarns and final non-woven and knitted materials

The first aim of the project was to create a yarn that gave priority to aesthetics and hand-feel, followed by function and cost considerations. Carlsson et al. (2017) describe these as the conditions of the design process. While recycling was inherent in the process, design for onward recyclability was not one of the conditions of the project. Instead, design from recycling, incorporating recycled content into products, was the driving approach (Veelaert et al., 2017).

Two different blends were created to fit the conditions of the brief and were used comparatively.

Yarn 1. 50% grey recycled fibre / 50% white virgin wool

Yarn 2. 70% navy recycled fibre / 30% white virgin nylon

The yarns were used to create a number of knitted interior products. This was achieved across two stages: first the creation of products for the Master's degree show (Figure 26), and second the redevelopment of these products into a commercial collection for the researcher's start-up Anneka Textiles (Figure 25).

The second aim was to create two non-woven materials using a needle punching process. Usually, needle punched non-woven fabrics are used for hidden applications such as insulation and mattress pads (Hawley, 2006). Here, however, sorting the waste by colour (grey and navy) created materials that could be used in alternative applications, such as interiors. As part of the process a backing material is required in order to punch the fibres into a fabric. Two different types of backing material were trialled. For the grey fibre a non-woven polyester 'scrim' was used and for the navy a polypropylene mesh-like grid structure was tried. When transferring these materials into an interior context the grey material was too weak and fell apart. In contrast, the mesh backing for the navy fabric was strong and could be used visibly as a design feature (Figure 27).

Both tests, yarn and non-woven, highlighted the need for the designer to be present in the process. This was important to encourage the use of low value recycled fibres in new applications. While the aims of the project were fulfilled, resulting in a 'proof-of-concept' final collection, it also opened up new lines of investigation for the PhD. Unexpected discoveries emerged during the process. For example, when designing using recycled content the researcher found it significantly affected the blend decisions. Blending with Yarn 1, for example, produced an aesthetically pleasing yarn and knitted textile, but with its 50% wool content this resulted in a rougher hand-feel compared with the smoothness of Yarn 2's synthetic blend. Furthermore, Yarn 2, with a higher ratio of recycled material (70%), produced a lower yield (amount of yarn produced). This was due to the reduced amount of longer fibres to carry the shorter recycled ones through the manufacturing process. This highlighted the dual importance of blending for the yarn design and manufacture.

Figure 25. Anneka Textiles Commercial collection

Figure 26. Master's Degree Collection and Anneka Textiles Commercial collection

Figure 27. Two cushion designs using both the front and the back of the non-woven fabric

ACHIEVED AIM

The aim was achieved by collecting, recycling, blending and spinning and needle-punching recycled mixed fibre to create 'proof-of-concept' commercial interior products.

INSIGHT

Practice 0 highlighted the importance of the role of the designer in the interaction with all stages in the recycling process. Additionally, it was found that blending with recycled fibre is used to meet both the design and manufacturing conditions. This opened up new questions that underpin this current PhD research.

2

PART 2 - UNDERSTANDING THE PROBLEM

This part of the thesis has been created to address the first aim outlined in the introduction: to understand the fields of ‘design for mechanical recycling’ and cascading in the context of post-consumer wool and acrylic textiles. This has been outlined across three objectives which form the structure of the three chapters in this part.

Chapter 3 addresses the first objective, reviewing the current mechanical recycling industry of wool and acrylic textiles. This not only provides the context of the post-consumer textile recycling system within the circular economy but will outline the context for using knitted wool and acrylic textiles.

Chapter 4 looks at the second objective, to understand the role of design in the current textile recycling industrial system. It outlines the problems with the current Design for Recycling approaches and establishes the role the designer might play in finding solutions.

Chapter 5 tackles the final objective, providing a review of the current cascading literature. This chapter outlines how design for cascading can be combined with the circular economy model.

3 TEXTILE RECYCLING SYSTEMS

This chapter reviews the field of mechanical textile recycling. Starting with a brief overview of the system as a whole, it then examines the current and historical methods of dealing with post-consumer textile waste with a focus on wool. The circular economy is presented and critiqued as a reference model with an emphasis on the role of recycling. The chapter continues to consider both the current challenges and the opportunities within the post-consumer textile recycling system. The chapter closes by presenting the intersections between wool and acrylic fibre for textile recycling; it argues why these materials should be the focus for the research going forward.

3.1 THE POST-CONSUMER TEXTILE RECYCLING SYSTEM

Textile recycling is broadly split into two systems: pre- and post-consumer. In this thesis, the focus is on the post-consumer recycling system. Post-consumer textile recycling is a misleading name for a system that includes far more than just the 'recycling' of discarded textiles. The system, which was first comprehensively outlined by Hawley (2006), extends beyond recycling to incorporate approaches such as re-use and re-manufacture of the clothing we discard (Figure 28). Hawley's systems approach demonstrates the 'textile recycling' industry's adherence to the waste hierarchy, defined by the Department for Environment, Food & Rural Affairs (DEFRA, 2011), as a way of ranking the waste management options according to what is best for the environment. This starts with re-use, the most desirable approach. The hierarchy then continues moving from re-manufacture, to recycling, to incineration and ending with the least desirable outcome: landfill.

Hawley's research, as in this thesis, is limited to the post-consumer textiles produced by households. Yet textile waste comes in many shapes and sizes and the definitions of the different categories vary across the literature (Hawley, 2006; Sakthivel et al., 2012). To avoid confusion, this research will follow the definitions offered by International Organisation for Standardization (ISO), as presented in Table 1.

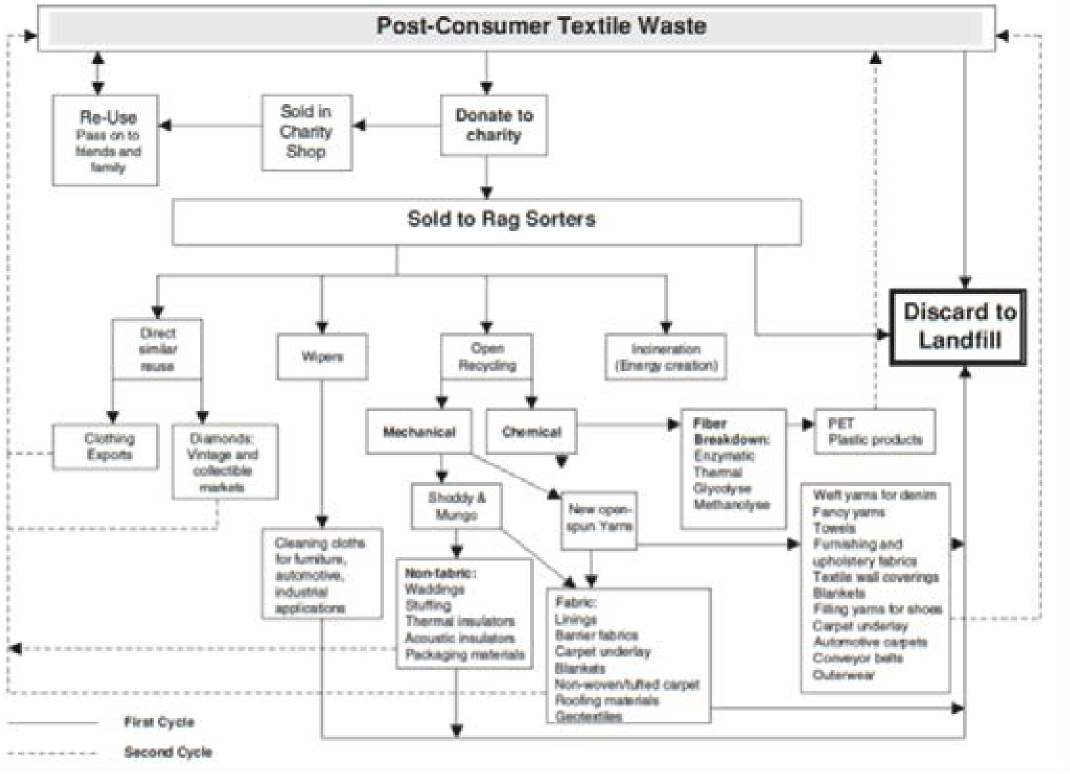


Figure 28. General Life Cycle Schematic for Postconsumer Textiles, (Hawley,2006:267)

Table 4. Recycling Definitions, Source: ISO (2016:15)

RECOVERED [RECLAIMED] MATERIAL	Material that would have otherwise been disposed of as waste or used for energy recovery, but has instead been collected and recovered [reclaimed] as a material Input, in lieu of new primary material, for a recycling or a manufacturing process.
RECYCLED MATERIAL	Material that has been reprocessed from recovered (reclaimed] material by means of a manufacturing process and made into a final product or into a component for Incorporation into a product.
POST-CONSUMER MATERIAL	Material generated by households or by commercial, Industrial and institutional facilities in their role as end-users of the product which can no longer be used for Its intended purpose. This Includes returns of material from the distribution chain.
PRE-CONSUMER MATERIALS	Material diverted from the waste stream during a manufacturing process. Excluded is reutilization of materials such as rework, regrind or scrap generated In a process and capable of being reclaimed within the same process that generated it.

Since Hawley created her system outline, further research has explored certain processes in more detail, as well as end markets and quantities of textiles (Thompson, Willis and Morley, 2012; Muthu, 2014; Pokkyarath and Biddie, 2014; EcoTLC, 2019). Three particular aspects of the system, re-use, re-manufacture and recycling, are examined here.

3.1.1 RE-USE

Re-use, as Hawley (2006) originally suggested, still accounts for the majority of the clothing currently processed. This is supported by the Fibersort study (2018b) which found 64% of their sample of discarded textiles was wearable and suitable for re-use. Muthu (2014) identifies three forms of re-use: formally through charity donations, semi formally via second-hand sales platforms such as Depop or eBay, and informally, by sharing with friends. The highest prices are afforded to branded, vintage and retro clothing. These are known as 'diamonds' (Hawley, 2006) or the 'cream' (Ljungkvist, Watson and Elander, 2018). Unlike the majority of re-usable clothing, which is shipped to overseas second-hand markets, these diamonds are sold into local markets. Other high-quality clothing, from countries such as the UK, is increasingly being sent to eastern Europe as there is a market for the highest quality re-wearable clothing (Oakdene Hollins, 2006). The rest are sorted and exported again to second-hand markets often in Africa (Ljungkvist, Watson and Elander, 2018).

WEARABLE AND UNWEARABLE FLOWS

While the majority of wearable garments successfully flow into re-use markets, some wearable garments with limited re-use options 'leak' into the recycling streams. If these garments are not classified as diamonds they will not be sold back into the local markets. As Norris (2012c) highlights, the remaining re-use markets are largely located in countries with typically warmer climates. Here, knitted garments and overcoats are unsurprisingly low in demand. And as Norris (2012a:394) points out, unlike the perceived 'torn, tatty and stained goods' that should fall into recycling grades, many of the woollen and acrylic jumpers "may be of good enough quality to be re-used but [there is] no market for them". Therefore, without re-use as an option, it is vital that recycling of these garment types is effective.

There is also concern over the stability of the re-use markets commonly found in Africa. While Morley, Bartlett and McGill (2009) point out how little we know about the textiles we export, Hawley (2015) goes so far as to suggest that we are using these territories as our dumping ground. Penny Marshall (2020), the UK's ITV African news correspondent, has highlighted how low-quality second-hand clothing with no market is filling the landfills in Ghana. This is supported by the 'Dead White Man's Clothes' research conducted in Accra, Ghana by Ricketts and Skinner, (2016), the title being a literal translation of the Akan expression 'Obroni Wawu' used to describe second-hand clothing.

> Our surveys, interviews and observations indicate that 40% of the clothing traded at Kantamanto [Accra, Ghana] ends up in landfill almost immediately. This amounts to at least one million pounds of clothing going to the landfills surrounding Accra on a weekly basis in addition to the unmeasured (but large) number of items that are dumped or burned informally, often in socially and environmentally sensitive areas.
> (Ricketts and Skinner, 2016)

Roos et al. (2019b) echo this concern. They explain that if this waste is being filtered into countries with less developed waste treatment systems, there is a "risk that the benefits of using the material for a longer time are offset by poor waste treatment at its end-of-life" (Roos et al., 2019b:36). And while Baden and Barber (2005) highlight this flow of re-wearable textiles does provide the social benefit of affordable clothing to developing nations, for the circular economy it means these resources could be lost.

3.1.2 RE-MANUFACTURE

Unlike re-use concerned with the reapplication of the same product, re-manufacture entails converting waste materials and giving them new life (Sung, 2015). Often, as Hawley (2006) describes, the waste textiles are converted into small squares, called wiper cloths, for the purpose of mopping up oil spills or testing for washing machine functionality. Sadly, these are generally single use only and once discarded the squares are destined for incineration or landfill. Another re-manufacture approach, commonly known as upcycling, is where the designer transforms waste clothing into new products (Earley, 2010), often in the form of patchwork. Upcycling, however, is labour-intensive and poses difficulties such as how to guarantee material type, size and quality. It is, therefore, very challenging to produce at scale (Child, 2016).

3.1.3 RECYCLING

Recycling is concerned with returning fabrics to their constituent materials such as fibres. Since profits mainly derive from re-wearable textiles this has been given more attention, whereas the unwearable contingent appears less across the literature. This is supported by Norris (2012b) who points out that very little systematic analysis has been completed regarding the value and distribution of re-usable clothing and none regarding recycling. Since then a few research studies have started to address this gap (Ward, Hewitt and Russell, 2013; Dutch Clothing Mountain, 2017; Fibersort, 2018b). Currently, waste textile flows are dictated by market pull and not by sustainable goals.

The two forms of textile recycling, mechanical and chemical, can be sub-divided into three levels: fibre, polymer and monomer recycling (outlined in Table 5). Further details regarding mechanical recycling, the focus of this research, will continue to be explored throughout the rest of this chapter.

3.2 GOING AROUND IN CIRCLES - A CIRCULAR ECONOMY

The aim of this research is to aid the transition from a linear economy to one that is circular. Since the industrial revolution industries, including textiles, have profited from a linear 'take-make-waste' economy. With the rise of industrial progress came a plethora of social benefits overcoming the scarcities of shelter, food and goods. Yet, while mass production turned scarcities into plenty, this was followed by an abundance of waste (Stahel, 2019). The system, on which we have come to rely is pushing the planetary boundaries to its limits (Steffen et al., 2015). Increasingly we hear the argument being made for a complete system overhaul from the current linear system to one that is circular, replacing the end-of-life waste concept with restoration of our resources and prioritising value retention (EMF, 2013).

A circular economy, defined by the Ellen MacArthur Foundation (EMF), is an industrial system that is restorative and regenerative by design. In other words, it designs out waste and keeps materials/products at their highest utility/value at all times (EMF, 2017). This approach was born from Braungart and McDonough's (2002) cradle-to-cradle model in which resources circulate within two separate systems: biological and technical. Natural materials should cascade – a flow of sequential uses allowing materials to stay in the system longer (Sirkin and ten Houten, 1994) – so they can finally bio-degrade to provide nutrients for biological cycles. In contrast, technical materials should flow into closed-loop cycles, cycling forever. Contamination is to be avoided at all costs.

Table 5. Mechanical and Chemical Recycling Definitions, (EMF, 2017:96)

MECHANICAL	CHEMICAL
Fibre Recycling	
For fibre recycling, garments are sorted by colour and material, and then shredded and processed back into fibres. This level of recycling is often referred to as 'mechanical recycling'. The fibres are shortened through the shredding and thus deteriorate in quality. This quality loss makes it necessary to use higher-quality fibres (current solutions to this often use virgin cotton or polyester recycled from sources such as PET bottles) as a supplement for creating new yarn. By design, fibre-recycling processes cannot separate blends or filter out dyes and contaminants. This causes problems where any substances of concern are retained in the textiles, as recycling these in the fibres can lead to the continued circulation of – and therefore exposure to – these substances. Textiles that were placed on the market before current regulations can contain significantly higher amounts of certain substances of concern than virgin materials, where the use of these substances is restricted. If garments are sorted by colour, no bleaching or re-dyeing is needed, however it is possible if a different colour is wanted.	
Polymer Recycling	
Polymer recycling takes fibres back to the polymer level, destroying the fibres but keeping the chemical structure of the material intact. There are two variants that are different in terms of process and output quality:	
Mechanical polymer recycling is carried out via melting and extruding of textiles made from mono-material plastic-based fibres. By design, this process cannot filter out dyes and contaminants, such as substances of concern. As with fibre recycling, no bleaching and re-dyeing is needed, however it is possible if a different colour is wanted.	Chemical polymer recycling dissolves textiles with chemicals after the garments have been de-buttoned, de-zipped, shredded, and in some cases de-coloured. This technology can be applied to plastic- and cellulose-based fibres or a mix of both. Cellulose – the polymer that is the main component of cotton – and polyester are extracted separately for further treatment. Cellulose pulp can then be transformed into new cellulose-based fibres and plastic polymers are treated separately to bring them to back to virgin-equivalent quality. Dyes, non-target fibres in small quantities, and other contaminants can be removed during the process.
Monomer Recycling	
	Chemical monomer recycling breaks down polymers into individual monomers or other constituent materials that can then serve as feedstock to produce virgin-quality polymers. Dyes, non-target fibres in small quantities, and other contaminants can be removed during the process.

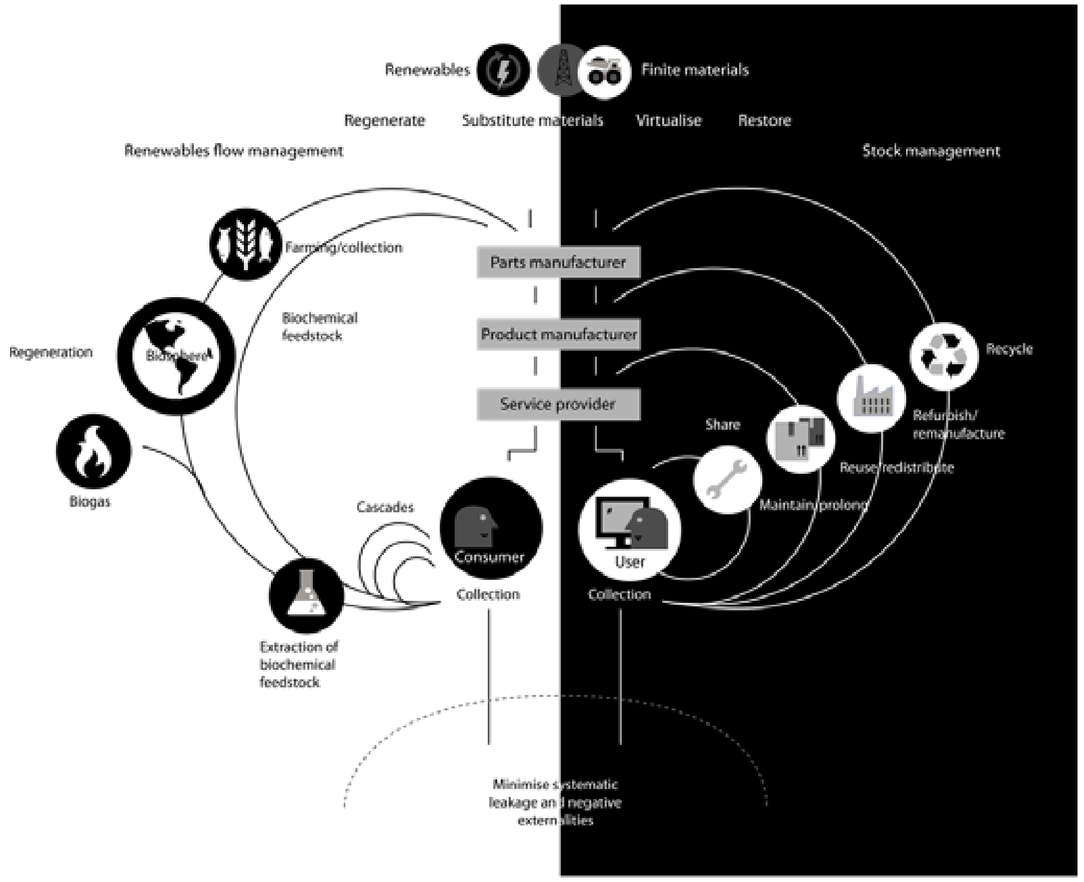


Figure 29. A Circular Economy Butterfly Diagram, (EMF, 2013)

3.2.1 RECYCLING AND THE CIRCULAR ECONOMY

A circular economy, according to a study conducted by Kirchherr, Reike and Hekkert (2017), was found to often be misunderstood and used incorrectly. Their review of the definitions concluded with their own over-arching definition of a circular economy as follows:

> an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond). [This is] with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers.
> (Kirchherr, Reike and Hekkert, 2017:229)

This definition brings together economic, environmental and societal perspectives across micro to macro levels and it moves away from the common opinion that a circular economy is solely focused on recycling. This is regularly referred to as the recycling economy and is explored by Fellner et al. (2017) as a fundamentally flawed method to solve our waste problems. Whilst recycling is almost certainly not the only answer, the industry (fashion in this instance) has been criticised by Brooks et al. (2018) for concentrating on closed-loop material systems and being blinded to the problems of 'continuing and growing cycles of consumption'. However, the circular economy, by Kirchherr, Reike and Hekkert's definition, must follow the waste hierarchy in which we first must reduce (which would appease Brooks et al.), then re-use, recycle and recover.

Reducing consumption and reusing our clothing is very important. However, as a notoriously tricky topic, that even Brooks et al. admit would involve a wide societal shift in mindset, it is thus beyond the scope of this research. As Roos et al. (2019:48) suggests "reuse and recycling are not competing strategies but rather both necessary and complimentary in a circular economy". It is important to note here, however, that the previous cycles have not been forgotten; they are simply not the focus of this thesis. Therefore, once we have reduced and re-used our materials, we can focus on recycling.

3.2.2 A CRITICAL PERSPECTIVE OF RECYCLING IN THE CIRCULAR ECONOMY

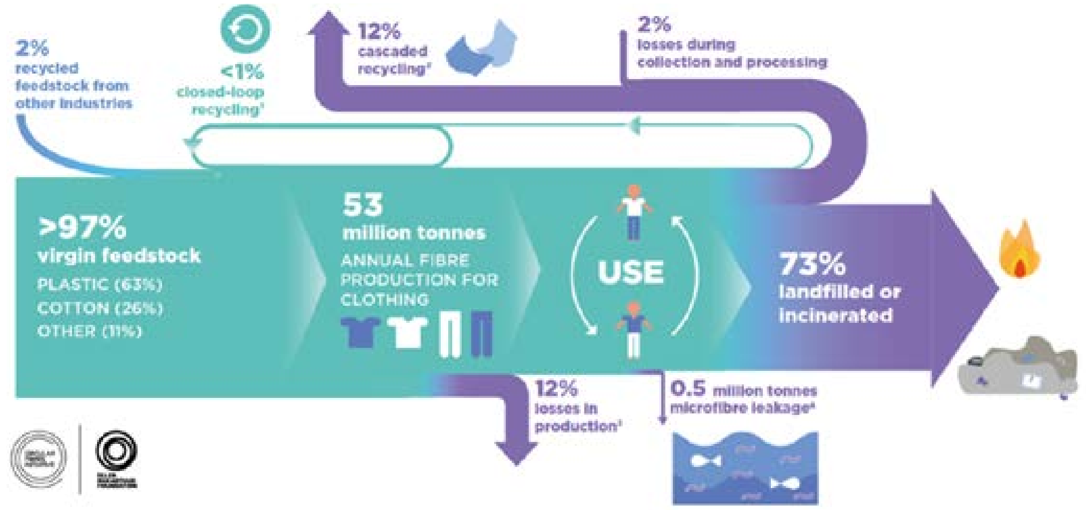
Although the circular economy model provides the context for this PhD thesis, it is not without its pitfalls. We are reminded by Naudé that "although theoretical frameworks and models on their own do not guarantee success, they provide a basis to work from" (Naudé, 2011:361). She concludes that sustainable development must not be treated as an add-on but be aligned with our industry strategies. This thinking is supported by Zink and Geyer (2017) who warn of the dangers of a 'Circular Economy Rebound'. This is when secondary materials, such as those that have been recycled, are brought into the market. If the recycled materials are of poorer quality, they may compete in price with the virgin materials. Thus, instead of directly replacing their virgin counterparts, this has the undesired effect of driving down their value and heightening levels of competition.

Alternatively, lesser quality recycled materials may enter new markets. These will not replace production but create new demand generally increasing purchase and use of both the virgin and recycled materials. In short, the unintended consequence of implementing a circular economy could in fact make the situation worse. The focus, Zink and Geyer (2017) urge, should be on creating good substitutes which displace primary production.

3.2.3 A CIRCULAR TEXTILE ECONOMY

Shifting the focus to look directly at the textile industry, EMF's (2017) 'A New Textiles Economy: Redesigning Fashion's Future' report outlines the challenges we are still facing to reach true textile circularity. As the textile industry exponentially grows this is putting pressure on the earth's finite resources. Clothing production has doubled in the last fifteen years and prices keep falling. This is accounted for by a growing middle-class population combined with the 'fast-fashion' phenomenon promoting increased numbers of smaller collections with quicker production times leading to higher sales. The problem is, as the EMF (2017) report suggests, only escalating.

With consumption at an all-time high the demand for raw material is equally as great. Morley et al. (2006) points out, as reuse declines due to the trend for buying cheaper lower quality clothing this means recycling volumes are increasing. However, as Morley et al. explain, this is coupled with a lack of value-added markets for these recycling grades of clothing. The EMF report (2017) paints an even bleaker picture, explaining that as much as 73% of the material flowing into the clothing system is being lost to landfill or incineration. They estimate that less than 13% of our clothing is recycled in any form. Of this 12% are cascaded into other low-value applications and less than 1% is recycled from clothing into clothing.



1 Recycling of clothing into the same or similar quality applications
2 Recycling of clothing into other, lower-value applications such as insulation material, wiping cloths, or mattress stuffing
3 Includes factory offcuts and overstock liquidation
4 Plastic microfibres shed through the washing of all textiles released into the ocean

Figure 30. Global Material Flows for Clothing in 2015, EMF(2017:20)

In addition, EMF (2017) has set out four ambitions which they assert will lead to better economic, environmental, and societal outcomes. Alongside, utilising renewable energy, phasing out substances of concern/microfibre release and increase clothing utilisation, is 'radically improve recycling'. Part of achieving this challenge, EMF ascertain, will involve aligning design with recycling processes. It is this ambition that this research has started to work towards.

3.3 TEXTILE RECYCLING THEN AND NOW

In order to meet the challenge, set out by the EMF's report to radically improve recycling, we must review the historical and current recycling industry. This will not only provide context for this research but outline the importance for selecting wool/acrylic knitwear as the waste material which is the focus.

3.3.1 HISTORY - A SHODDY PROCESS

The origins of textile recycling has been investigated in detail by Malin (1979) outlining that the recycling industry began with wool. In the late eightieth and early ninetieth century, wool used for clothing grew in popularity and therefore raw material prices increased. With such demand, Malin explains, cheaper alternatives were highly sought after which led to the birth of textile recycling.

There is much confusion over who invented the machinery to tear fibres from cloth in order to recycle wool. However, it is usually attributed to Benjamin Law in Yorkshire, England in 1813 (Jubb, 1860; Shell, 2014). From then, recycling of woollen textiles developed into a booming UK industry. Aided by the improved transportation to access discarded woollen garments, known as 'rags', it enabled the import of waste and export of finished cloth across the globe (Malin, 1979).

Textile recycling or utilising textile waste is not a new concept. Hawley (2006) explains that 2000 years ago in China used clothing was shred and hand spun into yarns. Even in Britain in the early eighteen hundreds, Day (2016a) points out, 'rag and bone' men would collect textiles to be crudely shredded and used to stuff saddles. In addition, Shell (2014) highlights that prior to industrial manufacture of paper from wood-pulp, cotton and linen rags had been used to produce writing paper and woollen rags were used as fertiliser on the land.

Within the recycled textile industry there are two forms of fibre output; shoddy and mungo. Shoddy is closely associated with knitted garments but is described by Day (2016c) to also include rags that were loosely woven. Mungo therefore describes the opposite. Usually from tightly woven, or felted rags that produce short fibres (ibid). Mungo, as a name, originated from the phrase 'it must go'. This, as Jubb, (1860) illuminates was first described by a dealer who was trying to sell this new type of rag. When doubts were cast over the ability to sell the material, he announced that 'it mun go' and the name was born.

Shoddy and mungo manufacture, as a whole, is defined by Malin (1979:201) as encompassing "mechanical or chemical conversion of woollen rags into shoddy, mungo or extract which was then marketed to manufacturers of cloth, carpets, blankets and other woollen goods". The definition extends to cover both smaller companies that shred rags on a commission basis and larger integrated manufacture that include rag-sorting. Additionally, it includes chemical recycling processes. Until the demise of the textile recycling industry in the UK it was commonplace to use acids and heat (not so far removed from today's chemical recycling) to remove vegetable fibres from the woollen clothing. For example, it was used to remove the cotton threads used to stitch garments together or to separate wool/cotton blends. This was called carbonising and as Malin (1979) identifies was a preparation stage to the mechanical recycling process to ensure pure woollen feedstocks.

Since, its heyday the shoddy industry remained relatively unchanged. The process in simple terms, Gee (1950) describes, firstly involves sorting the rags and then cleaning any contaminants such as buttons and zips. These are then mutilated or cut into smaller pieces ready to be 'shredded' or 'pulled' or 'opened' back to a fibre. The result of this first rudimentary stage is fibre with the remnants of textile material. The next process, 'garnetting', Gee (1950) clarifies is similar but is more specialised ensuring the transformation of the input to a fully fibrous state. This is followed by the same stages used to produce virgin materials: blending, carding (combing fibres) and spinning. However, each stage has to be adapted to deal with the shorter recycled fibres which are the result of this mechanical process. The blending stage, for example, might involve mixing shorter recycled fibres with longer virgin ones to increase quality, strength and ease of processing. Finally, the spun yarns are knitted or woven, while the punched fibres produce non-woven felts. These fabrics are then marketable for numerous end products across the value chain (EcoTLC, 2019). The simplified system outlined in Figure 31 is still used across the mechanical recycling industry today (Hall, 2018).

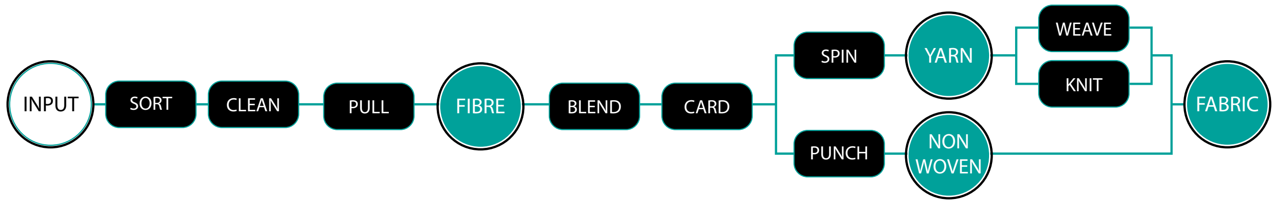


Figure 31. Simplified mechanical textile recycling process, (Hall, 2018)

3.3.2 THE TRANSITION FROM THEN TO NOW

Historically, the textile recycling industry, as described previously, was purely focused on wool. It, therefore, thrived in times of war when woollen military uniforms and blankets were in demand (Day, 2016b). From the humble beginnings in Britain in 1813 the industry peaked and troughed for over a century. This was until the introduction of synthetic fibres. As Hepworth (1954) describes these were first introduced in virgin production and added to recycled yarn to improve quality. However, once blended with wool, they were difficult to identify during rag sorting and the labour costs to remove synthetic sewing threads became too high. These difficulties, as explained by Day, (2016b) together with the switch from wool to cotton in the fabrication of military uniforms, led to the demise of Britain's wool recycling industry.

Although the industry diminished, it has not completely disappeared. Recycling in the UK and across Europe today is a small sector focused on low grade recycling for the non-woven markets (Morley, Bartlett and McGill, 2009). Wool clothing is often recycled in combination with other fibres types to benefit from its fire-retardant properties for hidden applications, such as mattress inners. More recently the various different recycled fibre types and applications has been mapped by EcoTLC (2019). Their map demonstrates that most markets have developed around the challenging array of fibre blends. The resultant products are not sorted by colour and this produces a sludgy dark-greyish material (Uchimaru, Kimura and Sato, 2013). They are typically non-woven and include automotive materials, carpet underlays, and insulation (Hawley, 2006; Morley, Bartlett and McGill, 2009; EcoTLC, 2019).

MECHANICAL VS CHEMICAL

Although the industry has adapted to the challenge of recycling these new blended inputs, it has faced much criticism. In 2006, the 'Well Dressed?' report condemned the recycling technology for not progressing in over 200 years (Allwood et al., 2006). However, since this publication the industry and academia alike have focused their efforts on developing the now more favoured chemical recycling technology. This has predominately focused on the chemical recycling of cotton, polyester and poly/cotton blends (Trash-2-Cash, 2018; Quartinello et al., 2018; Worn Again, 2020; Renecell, 2020). Over the same period, with the exception of a few studies in the design and science fields (For example, Langley, Kim and Lewis, 2000; Vettese, 2017; Lindström, Kadi and Persson, 2019), mechanical textile recycling has been overlooked. This is supported by Dahlbo et al.'s 2016 paper which calls for new policies specifically relating to the advancement of chemical processes alone.

While chemical recycling offers a way to retrieve virgin equivalent raw materials from waste textiles, the processes to date are only available at lab or pilot scale. The gap between this and commercialisation is wide and there are many challenges to bring it to market before any of these technologies can be relied upon as a recycling method (Girn, Livingstone and Calliafas, 2019). In the meantime, the mountain of textile waste continues to increase.

However, a shift in thinking is slowly emerging. During the 2016 Dutch symposium, Beyond Green: Zero Waste, Isaac Nicolson (at the time working for Recovertex, a mechanical cotton recycler) discussed a future in which both mechanical and chemical technologies might work together (Beyond Green: Zero Waste, 2016). This is now being demonstrated in large scale projects such as Interreg North-West Europe project: Fibersort (2020a) in which partners in both mechanical and chemical recycling sectors have participated. This shift contradicts previous criticism of mechanical textile recycling technology and acknowledges that it has viable future.

While the chemical recycling technology falls outside the scope of this research project the combination of these two technologies, as they have been used in the past, forms the inspiration for this research (Hall, 2020a - Appendix 14.8.4, page 463). Notably, Sandin and Peters (2018) have gone so far as to acknowledge the potential for cascading mechanical systems to flow into chemical ones. One that allows textiles to enter mechanical recycling processes and be utilised across multiple cascading loops first. Following Sandin and Peters' suggestion, this research will consider how design for mechanical textile recycling technology within a cascading system can extend the lives of textile materials. This will be further discussed in chapter 5.

3.3.3 TEXTILE RECYCLING NOW

Today the current high-value mechanical recycling systems have clustered around reclaiming specific fibres types. While the research presented here takes a focused look at the wool and acrylic recycling system this section will contextualise this within the wider textile recycling approaches. From the invention of textile recycling for wool, the industry has expanded to recycled cotton and synthetics covering polyester and nylon. As lab-scale chemical recycling technology has materialised there has been an emphasis on recycling into three main categories: proteins such as wool; cellulose such as cotton and synthetics such as polyester and nylon. These will be briefly explored below.

POLYESTER AND NYLON

The escalation of synthetics from the mid-twentieth century has seen a dramatic increase in the range of textile materials. The extensive use of PET (Polyethylene terephthalate), as Park and Kim (2014) discuss, has led to an escalating waste problem and has increased the need to develop recycling technologies for these materials. They go on to explain that the most common commercialised version of recycling PET is from plastic bottles into textiles, achieved both mechanically by melting and chemically using chemicals. The same applies to Nylon recycling, which usually comes from the collection of waste fishing nets. Whilst, both polyester and nylon fibre-to-fibre recycling is possible and can produce virgin equivalent fibres, the process requires pure feedstocks. The barriers of contamination created by blends in our clothing means that plastic-to-textile recycling is more widespread.

COTTON

Mechanical cotton recycling has developed commercially with companies such as Recovertex leading the way using pre-consumer waste. The mechanical recycling of cotton works in a very similar way to wool and faces many of the same challenges such as fibre length. Chemical technologies for cotton and all other cellulose-based textiles have advanced at lab and small-scale manufacturing levels. Although these chemical processes appear promising, the resultant regenerated cellulosic textile is different from the virgin cotton input. Whilst this can be classified as fibre-to-fibre recycling, as the Waste and Resources Action Programme report explains, it is not a direct replacement (Girn, Livingstone and Calliafas, 2019).

WOOL

As previously discussed, mechanical wool recycling was once a booming industry in the UK. However, Padovani (2017) explains, the industry continues to thrive on a small scale in Prato, Italy. Machinery was first seen in this region in 1850 and still functions to this day (Hall, 2018). In her book chapter, 'Made in Italy', Padovani (2017) describes Prato as one of the few industries which successfully recycles post-consumer waste rather than solely pre-consumer textiles. The 'Cardato Recycled' certification has been created as a method to promote the growing consumer interest in sustainability. Testa et al. (2017) detail the certification specification: the recycled wool must have at least 65% recycled content, it is to be produced in the Prato district and its environmental impact must be measured.

More recently, recycling of wool has developed in the infamous hub of Panipat, India. Norris (2012b) explains that Panipat was an old hand-weaving town but due to the coarseness of local Indian wool and the expense of importing quality virgin fibre, the recycling industry in this area boomed. By the 1980s, Norris describes, vast quantities of rags were being imported for sorting and recycling. Today, Panipat is the largest recycling hub globally (Norris, 2012b) and is largely known for the low cost blankets (global aid and local market). In addition, the industry in Panipat produces interior carpet, mattress and furnishing products. However, the majority of the exports is thought to be virgin quality which are exported all over the world (Arisa and Sympany, 2020). Other, smaller recycling hubs such as Ludhiana and Amritsar, also in India, specialise in recycled acrylic for knitting and recycled wool for woven cloth respectively (Norris, 2005).

In the last few years, there have been moves towards developing chemical recycling techniques for animal proteins in textiles. This has been explored by the EU Horizon 2020 RESYNTEX project. The result transforms woollen textiles into resins or wood-based adhesives but not textile-to-textiles applications (Bell et al., 2017; Quartinello et al., 2018).

PRACTICE 1

AIM

To understand the current industrial wool recycling systems

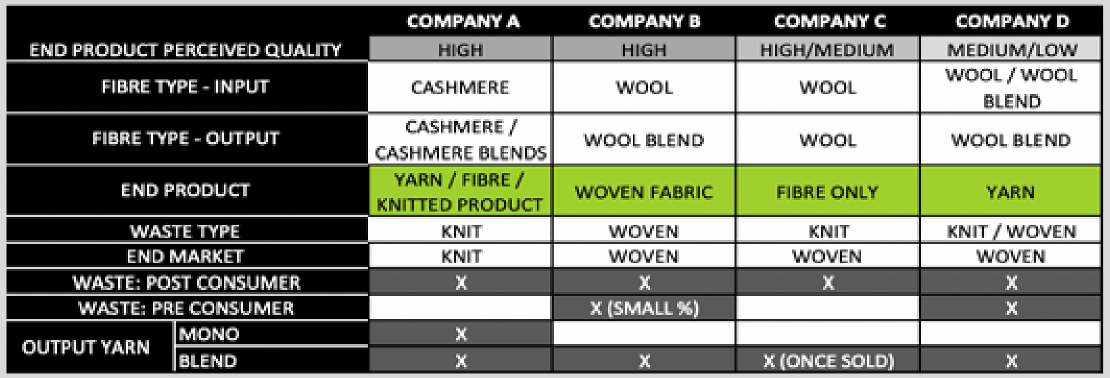
Practice 1 took the form of explorative practice visiting recycling facilities, seeing, questioning and touching the recycled textile materials. This practice was made up of many visits. On each visit photographs were taken, and material samples were collected as memory and thinking devices for the investigation. An in depth account of Practice 1 is fully discussed in conference paper ‘MIXING IT UP IN PRATO: identifying innovation hotspots within mechanical textile recycling’ (Hall, 2018, Appendix 14.8.1, page 405) and is summarised below.

This exploration took place in Prato, Italy one of the global wool recycling hubs. All stages of the mechanical recycling system were seen first-hand from sorting of waste textiles to recycling these into fibre to create new yarns, materials and products. Seven companies were visited but four specifically are focused on here. These four companies (Company A-D) demonstrate a wide range of approaches for the recycling of wool. These included using different types of feedstocks (input), producing different forms of materials (output) which are then made into different end products. The overarching findings are presented in Table 6.

The visits themselves centred around asking questions about the recycling process. This led to an understanding of the main stages: sorting, cleaning, shredding, blending, spinning and weaving. While the stages of each company’s process differed, the general elements were the same. Subtle differences were noted (as captured in Table 6) which were important for the designer.

Figure 32. Practice 1: Piles of waste knitwear waiting to be sorted and cleaned in a factory in Prato, Italy

Table 6. Simplified recycling system insights from companies A-D, Hall (2018).



		COMPANY A	COMPANY B	COMPANY C	COMPANY D
END PRODUCT PERCEIVED QUALITY		HIGH	HIGH	HIGH/MEDIUM	MEDIUM/LOW
FIBRE TYPE - INPUT		CASHMERE	WOOL	WOOL	WOOL / WOOL BLEND
FIBRE TYPE - OUTPUT		CASHMERE / CASHMERE BLENDS	WOOL BLEND	WOOL	WOOL BLEND
END PRODUCT		YARN / FIBRE / KNITTED PRODUCT	WOVEN FABRIC	FIBRE ONLY	YARN
WASTE TYPE		KNIT	WOVEN	KNIT	KNIT / WOVEN
END MARKET		KNIT	WOVEN	WOVEN	WOVEN
WASTE: POST CONSUMER		X	X	X	X
WASTE: PRE CONSUMER			X (SMALL %)		X
OUTPUT YARN	MONO	X			
	BLEND	X	X	X (ONCE SOLD)	X

For example, Company A only worked with the highest quality cashmere knitwear. In contrast Company D accepted the lowest quality wool blends made up of knit and woven materials. These two companies aptly demonstrate approaches from either end of the wool recycling spectrum. For the highest quality cashmere, the sorting and cleaning processes were vital. As with all the recycling companies in Prato, textiles would be sorted into family colours and shades. However, in the next cleaning stage they would not only remove buttons, zips and labels but seams would be cut out to avoid all types of contamination. This seam waste was then sold to other manufacturers who valued the high percentage of cashmere present and were willing to except the synthetic contamination used in the original garment production to link the seams together. Company D took a slightly different approach. They explained that for the products they produced knitwear seams would only be cut out if it was deemed necessary. The cleaning stage was an extra cost and therefore if it wasn't a benefit to the final yarn or material it became an unnecessary expense.

In a slightly different approach Company C prioritised the sorting stage. Their process incorporated an additional step, sorting knitwear into 'ordinary' (chunky gauge knits) and 'fine' (fine gauge knits). This was their unique selling point which they claimed resulted in a higher quality recycled fibre. Throughout the visits it became apparent that these first stages (sorting and cleaning) played a vital role in establishing the quality and cost implications of the output material to be created.

Next was the pulling stage, which represented the physical recycling of the textile back to fibre. This was achieved using a variety of machine types. However, most companies are fairly secretive about the machinery used and therefore could not be investigated in any depth.

Once garments have been transformed into fibre a new set of decisions had to be made. These centred around blending and combining the different fibres ready for spinning. These decisions were directly affected by the sorting and cleaning methods used and controlling composition was a vital concern. For example, Company B would only use post-consumer woven garments with a wool content of 97% or more, controlled at the sorting stage. Company D took a different approach accepting a lower wool content. They controlled the wool composition at the blending stage. They did this, they explained, by mixing different types of wastes together (post-consumer and pre-consumer as well as different qualities of post-consumer) to ensure the final yarn had the desired percentage of wool.

Furthermore, both Company B and D used virgin materials to aid the manufacture (spinning) of the fibres. The choice and percentage of virgin fibres in a blend were made based on aesthetics and function of the end product, manufacturability of the fibres in the blend and overall cost. Neither company, however, appeared to make any decisions to aid onward recyclability. For example, Company B would only except 97% wool composition at the sorting stage. In contrast their output (recycled yarns) was typically 65% or 75%. This meant, therefore, that their yarns would be unacceptable if they returned to the recycling process.

This divide between the requirements for the recycling system and end products produced was also demonstrated by the company's approach to creating colour. The complex sorting systems that occurred in Prato were often supplemented by pre-sorted garments imported from locations such as India to ensure a wide range of shades were available. Colour contamination, particularly for the highest quality output was to be avoided at all costs. Yet these carefully sorted coloured fibres are subsequently used by re-blending specific combinations to create exacting shades.

Figure 33. Sorting garments into colour categories

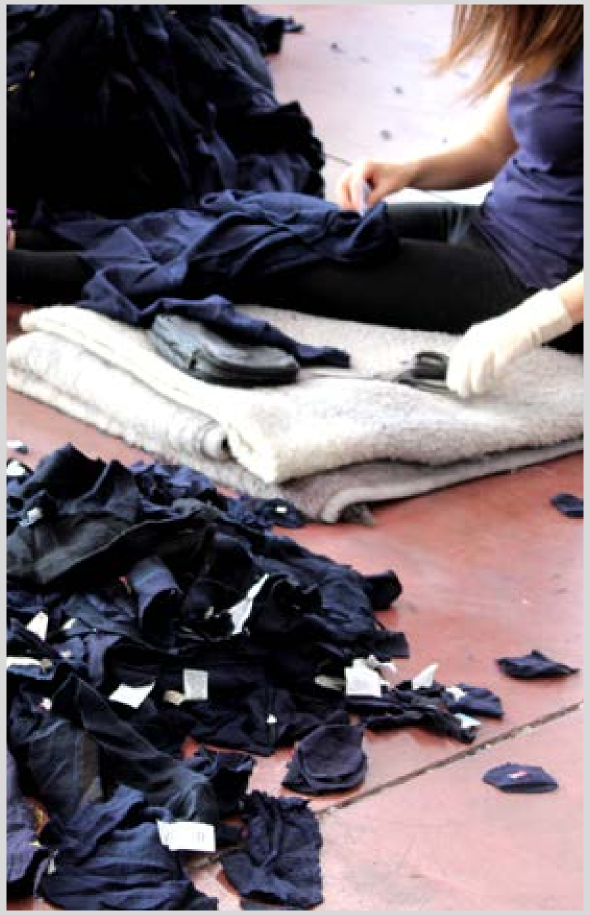


Figure 34. Cleaning garments by removing labels

Figure 35. Company B recycled fibre after shredding

The final outcome of Practice 1 resulted in a hotspots analysis of the stages of the recycling system. The four hotspots for future design research and innovation were: sorting, blending, processing and end markets/products (Hall, 2018).

More importantly, it is the more nuanced connections between the hotspots which the practice has highlighted. For example, the decisions during the sorting and blending stages have a major impact on the manufacturing and the type of end market the materials can enter into. In reverse, the end markets available will also determine the method of sorting, blending that is required. These hotspots are investigated throughout this research and are used as the basis for the discussion in Chapter 11 (page 265).

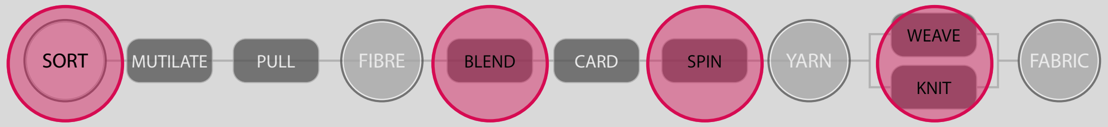


Figure 36. Hotspots for innovation within the processes of recycling textiles, (Hall, 2018)

ACHIEVED AIM

The aim was achieved, and a full understanding of the current industrial wool recycling systems was established

INSIGHT

Practice 1 additionally provided an in depth understanding of how the sorting and blending within the recycling process effects the material outcomes (spinning yarns and manufacturing materials) and vice versa.

Figure 37. Storage warehouse with bales of different colour and composition of waste garments and processed recycled fibre

Figure 38. Sorted jumpers waiting to be processed.

Figure 39. Colour blending card showing the 15 different coloured fibres (recycled and virgin) used to create the exact shade of blue required for the customer.

3.4 POST-CONSUMER TEXTILE RECYCLING CHALLENGES

There are many barriers that stand in the way of successful textile recycling. While these have been categorised in a variety of ways across the literature, they boil down to two key areas: one relating to the supply of feedstock and the other to end market demand for the recycled textiles. In the recycling industry the relationship between supply and demand is somewhat skewed. As Crang et al. (2013:10) explain, the impetus of material flows are created by "someone getting rid of existing, unwanted stuff. In other words, supply comes before demand".

3.4.1 FEEDSTOCK SUPPLY

The main challenges associated with the feedstock of post-consumer textiles can be further broken down into three categories: scale, geography and transparency. These will be explored further below.

SCALE

The issue of scale in recycling comes down to the availability or accessibility of feedstock streams. As Fletcher (2008) described in her Design for Recycling checklist, the most desirable materials are those that are mono-material and uncoloured. Supported by Roos et al. (2019b) they use the example of large-scale laundry services, such as bed sheets from hospitals and hotels which are normally white and often are made from pure cotton. While these materials can be obtained in bulk and with a known content, Roos et al. points out, these waste streams only form a small proportion of the textiles industry waste and their supply is therefore limited.

The demand by the recycling industry for pure waste steams is seen across all fibre types. Watson et al. (2017) explains

> insufficient volumes [of wool] are collected and sorted for recycling. This is in part due to the fact that many used textile collection operations, for both economic and legal reasons, do not accept or encourage households to deliver non-reusable clothing which would otherwise be available for recycling markets (Watson et al., 2017:34)

Collecting waste clothing at scale is one of the first limitations to the recycling supply chain. Here, we return to the vicious circle of supply and demand, namely, the supply being controlled by the purchases people make. As Crang et al. (2013:17) expounds this is "mediated via the stockholding in various 'national wardrobes' and the percentage of discarded clothes that are collected".

According to Fibersort (2020a) project report the success of recycled textiles is dependent on its ability to make recycled materials a 'sound business choice'. This is supported by Elander and Ljungkvist (2016:43) who argue that recycling needs to be a "cost efficient process that competes with virgin production" and in order to do this the industry must work at scale. However, alongside the benefits scaling up has on cost, barriers such as increasing sizes of minimum order quantities also appear. This, as Watson et al. (2017) points out, can be challenging for smaller brands that require smaller batches of recycled material.

GEOGRAPHY

The challenges of geography in the global textile industry are great, and this is only made worse by the ripple effect of garments being manufactured, purchased, worn and disposed of at numerous locations across the world. As Roos et al. (2019b) explain, it is only at the sourcing and manufacturing stage that materials are concentrated, such as extraction and processing of wool from sheep on a farm. In contrast, it is highly unlikely that waste textiles from the same original batch would ever be reunited at their point of collection for recycling. Currently, without brands being able to track any one of their garments after they leave the shop floor, there is no way to establish the location or timescales in which customers will discard it. The best that can be hoped for is that the garment ends up in a collection of similar materials.

Roos et al. (2019b) points out that the solution could lie in the localisation of waste-streams, as in Prato where the side-by-side production of virgin wool and its corresponding wool recycling industry thrive (Hall, 2018). However, this close proximity of recycling facilities is uncommon, and it would not necessarily be practical for all wool manufacturing areas to develop these. Localisation works effectively for pre-consumer waste created by the production of fibres, whereas the geography of post-consumer textile waste is a greater challenge. Low collection rates of post-consumer fibres, such as wool, only exacerbates the problem (Watson et al., 2017).

If recycled content has to be collected from around the world to be recycled together there are other challenges, such as differing regulations by country which need to be overcome. These might be regulations on waste treatment or regulations that limit the import of waste (Roos et al., 2019b). For a globalised system to work, it requires global cooperation. For example, the communication barrier between the producers of products, predominantly in Asia, and the feedstocks collected in Europe means that finding solutions is only made worse by distance (Elander and Ljungkvist, 2016).

TRANSPARENCY

Even once feedstocks are obtained the challenges are not over. Concerns over the chemical content of waste are great. In a report by the Swedish Chemicals Agency or KEMI (2016) it was concluded that of the 3500 chemicals examined 350 of them contained concerning hazardous properties. These were not regulated by REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) and would have the greatest impact on the producer countries and the consumer in the use phase (KEMI, 2016). KEMI (2016) also found that nearly a third of the 3500 chemicals used in the sample could not be examined due to confidentiality. This demonstrates the industry's lack of transparency but could mean the situation is significantly worse than the figures reported. This lack of information and chemical uncertainty in virgin production transfers into the waste textile streams. The challenge is compounded by changing regulation, as waste textiles could contain chemicals allowed by previous regulation. While there are few mechanical solutions to this problem, Roos et al. (2019b:40) suggests "in the case of large-scale recycling of textiles, a certain dilution effect is likely to be obtained". This, they describe, depends on whether the chemicals present are persistent or short-lived, this approach can be either a benefit or a hindrance to solve this problem.

The presence of hazardous chemicals is not only relevant to the recycling industry but a concern for the clothing that remains in the nation's wardrobes. Much research still needs to be done in this area, however, for this research it only provides a context and falls outside the scope of the practice research conducted. While this challenge is present and very real, mechanical recycling industries are today working successfully with post-consumer waste to comply with the REACH standards such as the wool recycling industry in Prato.

3.4.2 MARKET DEMAND

At the other end of the spectrum there are the markets which the recycled materials flow into. The main challenges addressed below are quality and acceptance.

QUALITY

Quality in this context refers to a number of different things: composition, colour and fibre length. Similar to the challenges of scale, the quality of recycled fibre is often determined by the desirability of the feedstocks that created them. Fletcher (2008) describes the most desirable qualities for recycled materials are mono-material fibres with no colour. Although, as Elander and Ljungkvist (2016:43) point out "it seems unlikely that a majority of future textiles will be made from single fibre materials". In addition, in their study Elander and Ljungkvist (2016) found that the main concerns of the recyclers, sorters and fashion companies interviewed were concerning contamination. This included blended fibres but also the presence of plastic prints on textiles and different materials being used in a single garment such as linings which all impacted the recycling and therefore the quality of the resulting materials.

The industry's consistent use of blends in all their forms (discussed in more detail in chapter 7, page 151) is one of the biggest challenges to the entire system. Clothing suitable for recycling, described as 'unwearable', is difficult to sort by fibre type by hand. New near infra-red (NIR) scanning technology has been developed to deal with this issue. However, as Wedin et al. (2017) demonstrates, the technology is not without its challenges. The scanner can only read one specific area and this is little help in identifying complex multi-material garments and those with low content blends such as garments with small percentages of elastane. The NIR technologies have also been developed to sort the textiles by colour. This type of sorting is easier to do by hand, but as with any labour it can be costly and margins are therefore squeezed (Ljungkvist, Watson and Elander, 2018). Sorting by colour has environmental benefits reducing the need to dye materials. This, as Norris (2005) explains, is achieved by first sorting garments into family colours and then shades. This is laboriously done to retain the colour for the final product. Ironically, colour sorted recycled fibre is often re-blended to meet the textile industry's exacting colour requirements.

The final stage before physical recycling is cleaning, in which contaminants such as buttons, zips or patterned designs have to be cut away. The cleaning stage faces the same high labour costs faced during sorting. However, unlike sorting, there is currently no alternative technology (Fibersort, 2020a). The ultimate goal is purity of materials. Virgin resources, Roos et al. (2019b:35) rationalises, are extracted in homogenous and of known content whereas recycling consistently is challenged by the comparison. This is really the sticking point for recycling, producing unknown material content for the market. Essentially, the more efficient the sorting and cleaning, whether by colour and/or by fibre, the higher the quality of the end product (Fibersort, 2020a).

Even after the sorting and cleaning, the physical process of mechanically recycling rips the fibres from the textiles. Recycling materials in this way damages the fibres and reduces length (Gupta and Saggu, 2015; Yuksekkaya et al., 2016; ECAP, 2019d). The shortening of fibres compared to their virgin counterparts has been criticised by researchers and brands alike. They are most often concerned about the performance of the recycled materials (Watson et al., 2017). To overcome this challenge, the European Clothing Action Plan (ECAP, 2019d) found it necessary to blend the recycled material with longer virgin fibres or with other high quality waste fibres. This approach is often criticised with a demand for 100% recycled content that performs, is aesthetically pleasing and cost effective.

ACCEPTANCE

Ultimately for recycled materials to make it to market this requires acceptance not just by the consumer but of the whole value chain (ECAP, 2019c). Everyone must understand the challenges involved when creating recycled products and this has been explored by Elander and Ljungkvist (2016). They have established that increased consumer awareness of the environmental impacts could help create markets for recycled materials as well as promote the collection of feedstocks. This was investigated alongside the designer knowledge. They found that even if awareness of the problems exists, designers found it most challenging converting this into action. This problem is exacerbated not just in textile recycling but other fields such as electronics (Fakhredin et al., 2013). Finally, Elander and Ljungkvist point out that more understanding of market conditions such as costs and volumes of recycled materials is needed in order to assess its feasibility.

Specifically, cost is often the main acceptance issue for recycled content. Watson et al. (2017) indicate that one of the biggest problems is that recycled fibres remain more expensive than virgin. This, they say, is due to economies of scale, limited supplies of material and lack of maturity of textile recycling technologies. As we transition towards a circular economy many of these challenges can be overcome. However, this cannot be without, as ECAP (2019a) 'Circular Textiles Ready to Market' report indicates: companies taking action, cooperation in the supply chain and harnessing marketing power to help the customer accept them.

3.4.3 CHALLENGES TO OPPORTUNITIES

Many of the challenges associated with the supply of recycled fibres and demand for recycled textiles have been outlined in the above two sections. Generally, the aims of this research are to establish how the supply of waste wool/acrylic knitwear can be successfully recycled and then utilised to create demand within the market. Importantly, these fibres must also be recyclable to recreate the supply. This practice research provides an opportunity to cover some of the issues relating to scale and quality. However, the challenges associated with 'geography', 'transparency' and 'acceptance' are such large and expansive topics that it is impossible to cover them fully here. Further research would be required and they have been included to provide the wider context only.

3.5 ACRYLIC TEXTILE FIBRE

Acrylic fibre is closely connected to the production of wool and therefore to the recycling of wool. This is due to many of its attributes mimicking wool's properties (Hatch, 1993). Super-wash finishes are often applied to wool and this coating can be made from acrylic to protect against felting (Rex, Okcabol and Roos, 2019). While the production of other synthetics, such a polyester, are replacing its use, acrylic it is still used widely for mainly knitted goods across the apparel industry (ibid). While the 2016 Information Handling Services report suggest this fibre is on a trajectory of slow decline (IHS Markit, 2016), acrylic still accounted for 1.4 million tonnes of all fibre produced (Rex, Okcabol and Roos, 2019). As its production has moved away from the US and Europe it is now predominantly produced in China and Turkey (IHS Markit, 2016).

Acrylic production is threatened by the low prices and recyclability of polyester fibre (IHS Markit, 2016). Yet, within the outdoor textile sector acrylic fabric is thriving due to the weatherability of the material outperforming its polyester competitor. The issue when recycling these outdoor fabrics is often the chemical treatments applied to the materials to enhance their properties. This is being addressed by EU Horizon 2020 project 'Recycling of Waste Acrylic Textiles' (REACT, 2019) exploring the waste treatment of these fibres, removing chemical finishes and mechanically recycling the materials.

Aside from this, one of the most prevalent uses of acrylic fibre is within the knitted apparel industry. It has gained popularity as it has the closest resemblance to wool and is It is often blended with wool to reduce cost (Sinclair, 2014). It also boasts a soft handle, good resilience and ease of care (Hatch, 1993). The process of producing acrylic fibre involves many chemicals and solvents and Fletcher (2008:18) points out that if left untreated these chemicals, including the base ingredient acrylonitrile, have a high potential to cause environmental problems. Acrylic might have a small, but still significant, presence in the market and Fletcher advocates that more sustainable material substitutions be made, such as wool. Yet, wool comes with its own environmental impacts. For example, the methane emissions given off by the animals and the chemicals used to process the fleece (Koppert et al., 2016). While wool might still be a better alternative to acrylic, the price tag attached to this luxury fibre does not encourage substitution as a strategy for mass industry appeal and might explain why acrylic is still widely used by fashion brands. Another substitute advocated by Rex, Okcabol and Roos (2019) is the polyester alternative, polylana®. While such substitutes should be encouraged, the accumulation of cheap acrylic knitwear and its blends is a mounting resource for the recycling industry. The fibre that has already been produced should not be wasted but requires considerable thought regarding its application. Landfill and incineration of these fibres that could drastically harm the environment should be avoided.

3.5.1 RECYCLING ACRYLIC

Acrylic has increasingly been used as a blending agent with wool to maintain the wool-like character in yarns (European Commission, 2003). This combination of fibres, by default, at the end-of-life contaminates wool recycling streams. Norris (2012a) explains that unlike the 'recycling grade' clothing that is stained, damaged and unwearable, acrylic knitwear is unmarketable for western re-use as well as unsuitable for the warm climates of the global second-hand re-use markets. It, therefore, becomes an accidental recycling grade. The blends between wool and acrylic are present across the global wool recycling industries including the lowest grades in Prato, Italy (Hall, 2018).

Historically, wool took centre stage in the textile recycling system. However, as Norris (2012c) explains, in the 1990s India also started importing acrylic rags, opening up a variety of new markets. At the higher quality end, Norris clarifies, acrylic yarns are produced to export to Africa or used locally for men's shawls (lohi) and school uniforms. However, the biggest market is for blankets. The better-quality versions are brightly coloured and patterned, popular with the Indian middle classes. Alternatively, grey versions, usually a combination of acrylic and wool, designed to last a few years are used for prisons, hospitals and the military. Yet, by far the biggest market is still the lowest quality blankets. These are grey, thin and are such low quality they usually would only last a single season. Described by Norris (2012a:390) as 'smelly and scratchy' these low quality materials are either sold to India's poorest citizens, while the rest are produced as relief blankets, stockpiled to be handed out in times of crisis. Norris (2012c) continues to explain that usually the yarn is specified at 50% recycled wool which is blended with cheaper fibres such as recycled acrylic knits. The warp is made of stronger synthetic materials to hold the fragile shoddy yarns together. These blankets are renowned for being very low quality. This is because during the finishing stage additives such as flour are included to create the illusion of weight. Norris uses a local joke to illuminate this point; if you unfold and refold a blanket you could easily loose half its weight in dust and if you were to wash one it could disintegrate entirely.

3.5.2 WOOL AND ACRYLIC KNITWEAR RECYCLING - WHY BOTHER?

In 2018 the European Parliament, for the first time, legislated that member states must separately collect waste textiles by 2025 (Sajn, 2019). Currently, this is achieved across most of Europe on a voluntary basis as re-wearable clothing is highly sort after. Companies rely on profits from selling re-usable textiles into the global second-hand markets to keep their businesses afloat. With this new EU legislation, increased collecting of un-wearable and lower quality textiles could cause economic instability (Dutch Clothing Mountain, 2017). This, combined with a growing waste heap with limited markets, would have a knock-on effect on the recycling industry in which there is a need for new market pull of these low quality fibres (Fibersort, 2020a). Within this context it has become vital to find recycling solutions for textiles that are unwearable and that are unsuitable for re-use. As illustrated in the previous section, wool and acrylic knitwear falls into this category (Norris, 2012a).

Currently, wool and its blends form one of the most established recycling markets, even though it only represents a small share of the textiles collected. Because of this, the purest recycled wool fibre demands the highest prices of all mechanical recycled materials (Fibersort, 2020a). While chemical recycling technology is currently at pilot scale for cotton and polyester, this does not apply to wool or acrylic. We need to avoid what Wennberg and Östlund (2019) describe as a chicken-or-egg situation in which no recycled content is used as brands wait for chemical technology to be established at scale (Watson et al., 2017). As chemical solutions textile-to-textile do not apply to wool blends and the current mechanical recycling options are regarded as low value there is an emphasis to find improved mechanical recycling solutions to turn these recycled fibres back into yarns.

The much-needed demand and willingness to use recycled fibres has started to be exhibited by the fashion industry, but progress is slow. In July 2019, only 11% of brands achieved their target to use more post-consumer recycled content in the Global Fashion Agenda's 2020 'Circular Fashion System Commitment'. The main barrier cited was quality of materials in high enough or pure enough quantities (GFA, 2019). This is supported by Elander and Ljungkvist (2016) who point out one of the greatest challenges relates to the recycling of blends. Most recycling technologies require precise input materials and therefore recycling feedstocks play a vital role to enable quality outputs (Fibersort, 2018b:2). The Dutch Clothing Mountain (2017:60) report calls for further "development of recycled fibres and fabrics with increased quality, hand feel, and technical capacity". It is this challenge, within the remit of wool/acrylic blends, that this research is concerned with. It will provide a systemic system for the use of wool/acrylic recycled fibres for clothing in a way that means they are also recyclable. This will be an approach to aid the transition towards a circular economy, one that does not negatively rebound (Zink and Geyer, 2017).

3.6 SUMMARY

This chapter completes the first objective, to review the field of mechanical textiles recycling. It has demonstrated that historically wool was the first fibre to be industrially recycled and currently the industry is based in both Italy and India. With the development of synthetic fibres used as blending agents this caused problems for recycling and has led to lower quality outputs. An example of this is wool and acrylic fibres. These are commonly used together in knitwear and therefore the recycling processes of both these fibres are closely connected. Knitwear in particular is used as a recycling grade, even when the garments are still suitable for re-use. This is because the countries that discard the knitwear have no market for them as second-hand goods and other countries which have developed markets are located within hot climates unsuitable for heavy knitwear. Therefore, this chapter concludes that wool/acrylic knitted garments should be the focus of this research.

In addition, this chapter argues that challenges of post-consumer textile recycling are centred around understanding the supply of feedstocks and creating a market demand. While the fashion industry declares it is willing to use recycled fibres there has been low take up. It is feared that the industry is waiting for chemical recycling, which is not yet developed to commercial level, to provide a solution. In the meantime, the waste heap is growing. In the context of wool, this is not a viable option. While wool fibres can be chemically recycled, the output does not return materials to the textiles industry and if the aim is first and foremost to recycle textile-to-textile, the chemical technology falls short. If we are to transition towards a circular economy, the aim laid out in this chapter, there must be a combination of approaches used. This, therefore, is why mechanical recycling solutions need to be found particularly for wool/acrylic fibres and this chapter concludes that solutions need to be found to utilise recycled fibres for new yarns. These solutions are also required to be designed for future recyclability. This will be further explored in the next chapter.

4 DESIGN FOR TEXTILE RECYCLING

This chapter defines and explores the field of 'Design for Recycling'. It provides a detailed look at the two main approaches: mono-materiality and disassembly and in particular how these have been applied to textile design. The chapter concludes investigating the role of the textile designer for recycling in industry. This includes both the designer as an individual and within wider networks.

4.1 DESIGN FOR RECYCLING APPROACHES

Design research has attempted to generate many methods to provide practitioners with ways to Design for Recycling (DfR). There are no official formalised rules, but over the years a plethora of guidelines have been produced. Generalised lists of do's and don'ts are exhibited across the literature (Xing, Abhary and Luong, 2003; Luttropp and Lagerstedt, 2006; Roos et al., 2019a). These have been developed to assist designers' awareness and decision making for the different end-of-life strategies. For example: Rose and Ishii's (1999) end-of-life design advisor tool lists the key characteristics of a product which a designer should consider. Such as: functional complexity; number of materials, modules and parts; cleanliness; hazards; size; design and technological cycles; replacement life; reason for obsolescence and wear-out life. Others have addressed the topic using broader principles, such as Maris et al. (2014) who state that the design of recyclable materials requires them to be simply sortable, transformable and economic. Alternatively, shorter lists of DfR requirements can be combined with other approaches. For example, van den Berg and Bakker's (2015) framework for the circular economy which combines DfR alongside other strategies such as 'future proofing' to 'last long' and 'use long'.

While a lot of the guidelines are very similar, they are often generalised to apply across many product categories. The literature up until recently has been focused primarily on the field of product design and has not taken into account the other design fields. One size in this case does not fit all. Peters et al. (2012) sums up the overall feeling around DfR strategies pointing out that most approaches and guidelines "lack a combination of concrete instructions, prioritization, and recyclability performance feedback" (Ibid,2012:203).

4.1.1 DESIGN FOR TEXTILE RECYCLING

Whilst the literature for DfR started in the field of product design, in recent years we have seen more and more specific research being conducted. In the field of textiles, an early pioneer was Farrer (2000) whose PhD thesis explored mechanical recycling of post-consumer wool textile waste. In her research Farrer utilised waste wool jumpers blended with post-consumer cotton from jeans and polyester from plastic bottles to create a yarn. This demonstrated the feasibility of recycling problematic post-consumer waste sources into new materials. Farrer's research advocated for design-led solutions on craft and industrial scales to address the growing waste problem. This is a challenge which this research will move a step closer to achieving. Yet, it wasn't for another six years that research, such as Gulich's (2006a) 'Designing products which are easy to recycle', would take the field of textile recycling forward. Here, Gulich explored the tensions between recyclability and functionality (further described in Chapter 7, page 151). Since then the discussion around textile recycling has remained fairly general. For example, Fletcher (2008) has simply outlined four points in her DfR checklist which enables waste textiles to enter into the most optimum markets (Table 7).

Table 7. Design for Recycling Checklist, (Fletcher, 2008:125)

DESIGN FOR RECYCLING CHECKLIST	
WHITE	for easy re-dyeing,
NATURAL	fibres that are easier to mechanically recycle
QUALITY	(long staple) fibres which can be processed on faster machines
PURE	(not blended fibres) that require less processing than fibre mixes and are less problematic in subsequent processing stages

While this checklist provides an overview of the most desirable waste streams for the recycling market, it is certainly not an exhaustive list nor practical for every type of textile.

Fletcher herself notes that this simplified approach could be problematic. Restrictive guidelines of this nature, whilst attempting to do good, if they stand-alone outside of wider systems could easily make things worse. For example, as Fletcher (2008) explains, textile purity could limit the variety of textiles in circulation. Although this could be advantageous for the recycling markets, it also might encourage inappropriate use of fibres and a dominance of monoculture crops.

A more specific approach has been taken by Roos et al. (2019a) with guidelines that have been broken down by fibre category. More unusually, they have provided simple guidance for fashion companies when both designing from recycling and for recyclability. Yet, regardless of fibre type the advice is consistently repeated; to keep materials, whichever type, separate. When collating the advice across the literature there is overwhelming consensus that Design for Recycling should follow two approaches: mono-materiality and disassembly.

MONO-MATERIALITY

Mono-materiality is commonly described as the use of a single material type for a product. Whilst this approach was promoted throughout research in the 1990s, it was first brought into the mainstream by Braungart and McDonough's (2002) cradle-to-cradle theory in which they condemn the combination of different material types. Specifically, combinations from their two cycles: biological and technical. This promotion, of what Fletcher (2008) terms, purity of materials is also described as a 'single-material system' by Gulich (2006:28). This removes the challenges of contamination of fibres and allows materials to flow into specific fibre recycling systems.

Textile designers, such as Goldsworthy (2012), have started to get creative in their approaches to mono-materiality. Through her PhD research Goldsworthy utilised laser finishing to achieve added aesthetics and function to recyclable polyester. She avoided the addition of other materials to create a variety of textiles finishes which would otherwise leave the textiles difficult or impossible to recycle. The industry has been slow to explore mono-materials as a viable option as it involves redesigning the way products are made and therefore the production processes. There are examples of concept projects, such as Adidas's Futurecraft.Loop producing a small run of mono-material trainers that are fully recyclable. During this project they had to ensure the trainer functioned like all their other shoes as well as comply to the mono-material brief. To do this the whole production had to be rethought. This meant, for example, replacing glue with laser welding techniques to attach the fabric top to the solid base (Burgess, 2019). While projects like this are to be commended, there is much to do in this space if this is to be become a widespread solution.

DISASSEMBLY

The Design for Disassembly (DfD) approach allows materials to be combined, and crucially, separated at the end-of-life. These are then free to enter mono-material recycling streams. In practice, DfD is often presented as a set of design rules (much like DfR), which Bogue (2007) suggests should be split into two categories. Firstly, product architecture guidelines and secondly, joints and fastener related guidelines. Ziout (2014) further elaborates that using a DfD approach allows products to be maintained, repaired, refurbished, remanufactured and then recycled. In addition, the component parts can also be re-used and go through the same processes. This is supported by van den Berg and Bakker (2015) who present very similar DfD guidelines within the context of their circular design framework. Importantly, here, they additionally specify that only materials that can be recycled should be used.

The DfD approach has been used most successfully by the product and electronic industries. Webster (2013) explores industry examples such as Steelcase's think chair which has been designed with component parts that can be disassembled in approximately five minutes and with only standardised tools. However, until recently, the field of DfD has not been widely translated into a textile design context. This has been addressed by Forst (2019) whose research argues that combined materials are a key attribute of textile design creativity. She insists that this 'creativity' can be harnessed for a circular design brief through DfD. Her PhD thesis 'Textile Design for Disassembly' goes on to describe the four main types of textile assembly for detachable combinations: light connections, redundant thread, dovetail and textile lock (Forst, 2020). Whilst Forst acknowledges that textile design for disassembly is one approach that can be applied, her research focuses on the production of DfD fabrics and products. Textile disassembly created at the yarn production stage is a more problematic challenge that is currently only starting to be met by chemical recycling technology.

4.1.2 DEFINING DESIGN FOR RECYCLING

DfR approaches ,it is argued here, are oversimplified. The two approaches, in the context of textiles, do not account for the complexity of the materials produced and the requirements we place on them. Aside from the limited practical design guidelines previously explored, the next logical question is what are the objectives of DfR?

Across the literature, DfR is often split between two objectives: both the input of recycled materials (Design from Recycling) and their onward recyclability (Design for Cyclability). Maris et al. (2014:421) define DfR as "designing a recyclable product and using recycled materials to replace virgin materials". Not only does this definition cover both objectives but also incorporates a replaceability clause required by Zink and Geyer (2017) to avoid the 'circular rebound effect' (see also section 3.2.2, page 72). Both these objectives are explored in further detail below.

DESIGN FOR CYCLABILITY

Defining design approaches for recyclability often centre around promoting material loops (RSA, 2016; Hultgren, 2012). This, Goldsworthy (2014) describes should be termed 'Design for Cyclability' meaning, as Rose and Ishii (1999:5) suggest, that designers need guidelines and methodologies for end-of-life paths. Goldsworthy (2014) explains, this is a pro-active approach (see also section 4.2.2, page 102). It wipes the slate clean to imagine new systems from scratch. However, it does nothing to address the waste problem that we already have.

DESIGN FROM RECYCLING

In contrast, Design from Recycling (DfromR) places its focus on developing products made from recycled content alone. This entails understanding the design specification required when using these recycled materials (Veelaert et al., 2017). Investigated as part of technology transfer (TETRA) project Veelaert et al. (2017) definition of DfromR goes beyond the typical approach of simply substituting and mimicking traditional materials but to understand the challenges of designing with these problematic materials. They suggest this approach allows recycled materials to be used for successful products to enter the market that will be socially accepted. This approach could be criticised as re-active, doing nothing to prevent the situation from getting worse (see also section 4.2.2, page 102).

DESIGN FOR RECYCLING

The definitions of these three approaches (Design for Cyclability, Design from Recycling and Design for Recycling) have been outlined in Table 8 adapted from, Goldsworthy, (2014a), Veelaert et al. (2017) and Maris et al. (2014). On the whole, there is a tendency in research to focus on looking forward (Hall and Earley, 2019). However, it is argued here, by combining these approaches, as Maris et al. (2014) has outlined in her definition, looking back (to the waste problem) and forward (to the onward recyclability), that comprehensive solutions might be found.

Table 8. Definitions of three types of design in relation to recycling

DESIGN FOR CYCABILITY	The focus of this approach is during the design process on the recyclability of materials at their end-of-life for future use
DESIGN FROM RECYCLING	The focus of this approach is for new product to be produced from existing flows of recycled materials and the design specifications this entails
DESIGN FOR RECYCLING	The focus of this approach is designing a recyclable product and using recycled materials to replace virgin materials

4.2 DESIGN FOR RECYCLING INTERVENTIONS

Design for Recycling, sometime referred to as Design for Recovery, has been born from the circular economy's mantra to 'design out waste'. As Goldsworthy (2014) points out, often our approach to this problem starts from the point of disposal. She proposes four design strategies that we can use to address the waste problem: Design for Re-use (a single user at product level), Design for Re-Distribution (multiple users at product level), Design for Re-manufacture (product and material level) and Design for Recovery (chemical level).

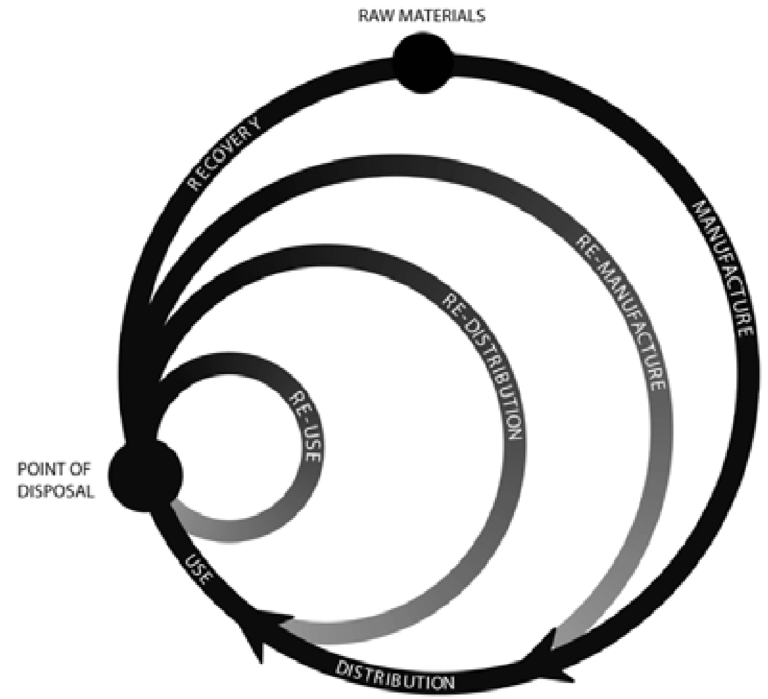


Figure 40. Four design approaches with the point of disposal as a starting point, (Goldsworthy, 2014)

4.2.1 DESIGN AT POINT OF DISPOSAL FROM MANY LEVELS

Across Goldsworthy's (2014) four design approaches she distinguishes the levels in which design occurs. Whereas Goldsworthy suggest that re-use and de-distribution are strategies at product level, re-manufacture occurs at product and material level. Finally, Goldsworthy argues that recovery can only occur at chemical level. However, the context of her research is taken from the perspective of polyester which considers the future opportunity of chemical recycling of the polymers and monomers back to virgin quality. Therefore, her model does not address other types of textile fibres, such as wool textiles that cannot be transformed chemically textile-to-textile.

Mechanical recycling might also be considered a form of recovery rather than just re-manufacture approach as Goldsworthy suggests. This refers to the recovery of textile building blocks - the fibres - through recycling. In fact, all forms of re-manufacture cover a variety of activities that could be described as recovery but at different levels. This Goldsworthy goes some way to explaining. First, at product level in which a garment is updated and adapted (such as over printing or changing element of a design such as a sleeve). Second, at material level the fabric of a garment is salvaged and re-designed to create a wholly different product. For example, patching different fabrics or re-imagining the fabric from one garment to form a completely new design. Finally, it is argued here, recovery can be conducted at fibre level (mechanical recycling) as well as Goldsworthy's chemical level (chemical recycling). These together create four levels at which design can be used to create value from waste (Table 9).

Table 9. Levels mapped against design strategies as defined in this research

LEVEL	DESIGN STRATEGY
PRODUCT	Re-use
	Re-Distribution
MATERIAL	Re-manufacture
FIBRE	Mechanical Recycling
CHEMICAL	Chemical Recycling

However, Goldsworthy argues the focus of design should be in value retention and it is the reason why recovery at chemical level is so desirable. If recovery can retain material value, as chemical recovery of polyester can, then the materials can perpetually cycle achieving the aim of the circular economy to design out waste. However, as Goldsworthy explains, it is not the strategies themselves but rather how the designer addresses these strategies that is important. She suggests there are two methods the designer can employ, either a re-active or pro-active approach.

4.2.2 RE-ACTIVE VS PRO-ACTIVE

A re-active approach to designing, as Goldsworthy (2014) clarifies, begins at the point of disposal (Figure 41). It is at this point where the materials are assessed, and design can intervene in an attempt to return the materials back to use. However, as Goldsworthy points out, in this approach, as the materials are used, their value fades. This is always the case unless the material can go through a process of 'recovery' which should be repeated endlessly. This can be difficult to achieve, both mechanically and chemically, as our ways of designing functional products are not always suitable for the recovery stage. Design, here, is reacting to a problem that already exists.

In contrast, Goldsworthy argues that design should be taking the opposite approach and intervening much earlier in the cycle, at the raw material stage. She asks, "what if we identify the best possible routes for material value retention (recovery) and begin our design process from that point forward?" (Goldsworthy, 2014:8). This is a pro-active design approach, Goldsworthy explains, which starts from the beginning and "embeds future recycling into the very DNA of the products we design" (ibid). Goldsworthy concludes that for this approach to work recovery needs to be incorporated into the design brief.

The key message that Goldsworthy provides is that design can be harnessed earlier in a product's lifecycle in order to retain value at the raw material stage. Goldsworthy illuminates that it is the materials that hold the true value. Products are just vehicles for materials to flow in and out.

4.2.3 DESIGN FOR RECYCLING KNITWEAR

While designing pro-actively seems like the simplest solution, the reality of doing this in practice is far from simplistic. In addition, taking a sole focus on designing pro-actively leaves the current resources in our products (not designed pro-actively) as waste. As outlined previously when defining 'Design for Recycling', this approach should incorporate both Designing from Recycling and Design for Cyclability (section 4.1.2, page 98). While each of these activities has been addressed by themselves the challenge now is to join up the thinking and explore a design strategy which incorporates both re-active and pro-active approaches. It is this gap in knowledge that will be addressed in this research by exploring the space between the point of disposal, through the recovery of fibres and into new products with future loops designed in. This is described as Design for Recycling Knitwear (Figure 42).

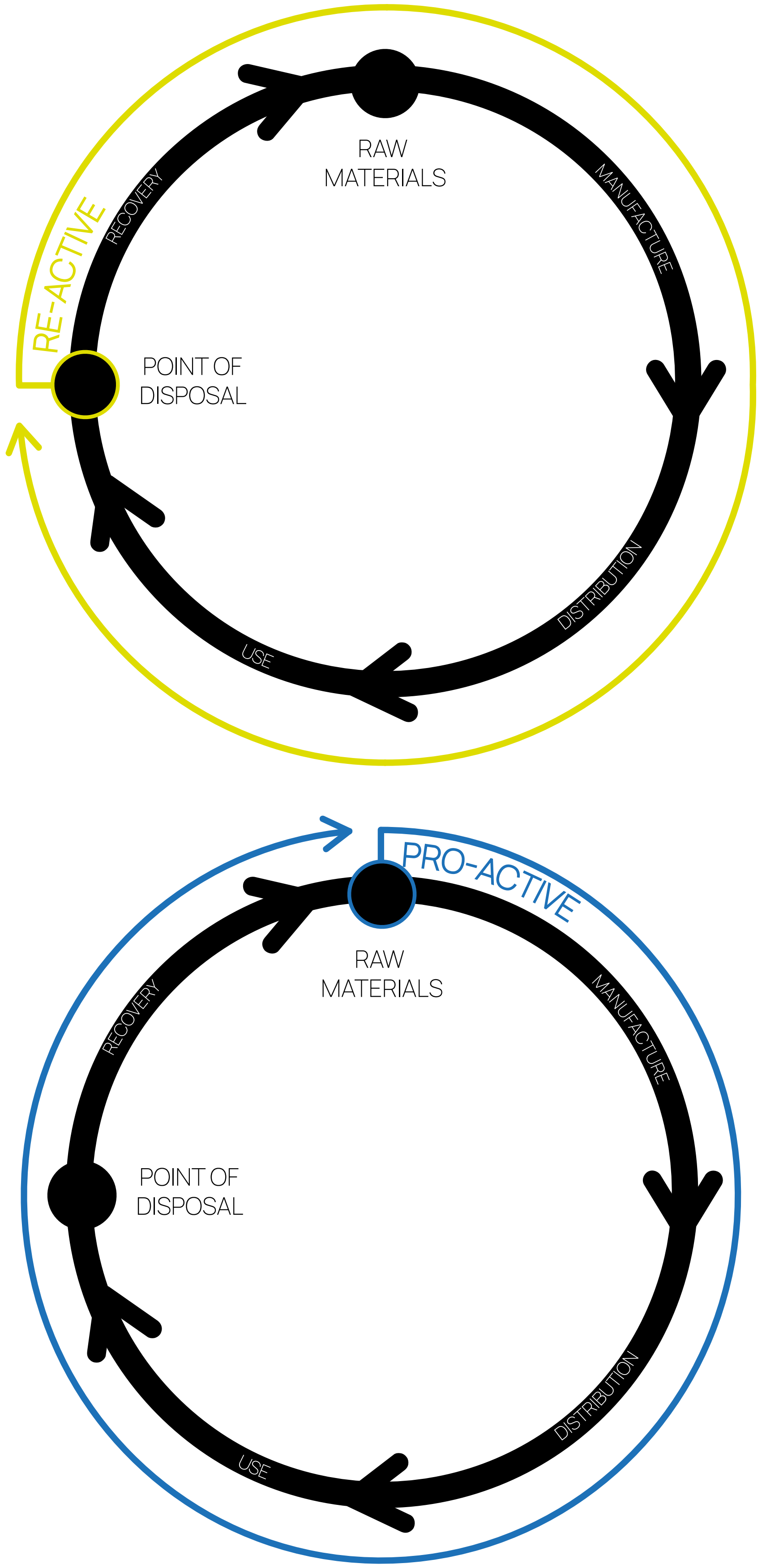


Figure 41. Re-active and Pro-active design intervention mapped onto lifecycle, adapted from Goldsworthy (2014)

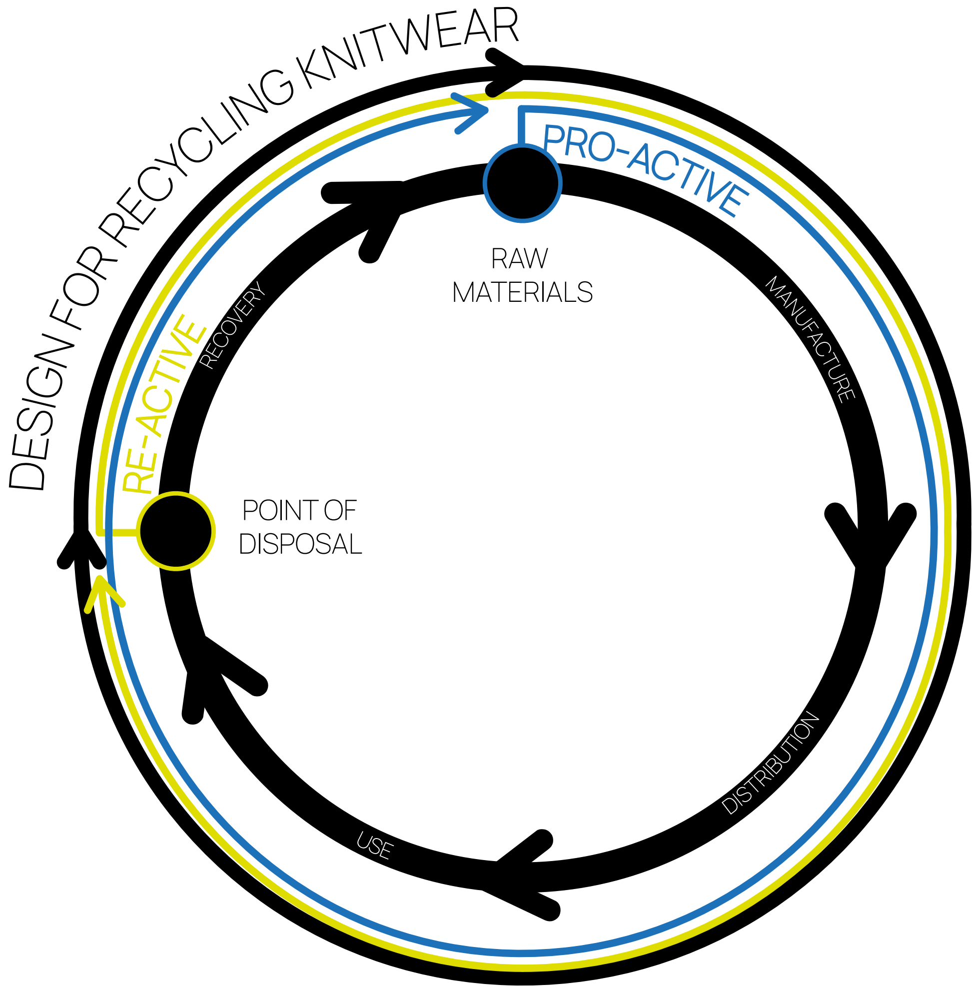


Figure 42. Design for Recycling Knitwear is both a re-active and pro-active design approach

4.3 THE ROLE OF THE DESIGNER FOR RECYCLING

The designer's role, Gulich (2006) describes, is one that specifies both the structure and material choice, as well as considering the functionality of and budget for a product. But with the introduction of eco-design and circularity, this role has expanded. It is commonly repeated that an estimated 80-90% of a product's lifecycle impacts are decided during the design phase (Graedel, Comrie and Sekutowski, 1995). This extends the role of the designer to encompass responsibility for environmental concerns, including their influence over a product's end-of-life which was previously outside of their remit. Yet, as Hornbuckle (2016) points out, this new role, that has been thrust upon designers, is far from straightforward. Constrained by the existing systems, supply chains and methods of production; change can only take place with the support of a large number of actors. Even the simplest of objectives such as 'specifying recycled materials', Hornbuckle advocates, presents the designer with countless challenges.

A designer situated in industry also has other challenges when working towards circular change. As Karell and Niinimäki (2020) explain,

> A designer works in a restricted space, which is framed by company strategy and mindset, the designer's role in the company, the time allocated for the design process and the designer's limited knowledge base (Karell and Niinimäki, 2020:20)

They continue, by noting that designers in the context of the EU have relativity poor knowledge of circular practices. Furthermore, there are designers that work in other situations, not just for a large brand, such as those that work within the supply chains of the bigger brands, called suppliers. This, as Franco (2017) discovered when studying the cross section of the textile supply chain, provides further challenges towards sustainable development which is often influenced by supply chain position. This is represented by those who have the power to push (top down) or those that can pull (bottom up) or those that have little power to do anything; situated in the middle. She also found that implementation could be made easier depending on how developed/strong the relationships between stakeholders were.

4.3.1 DESIGNER AS TRANSLATOR

The designer's role according to Ralph and Wand (2009) is one of a 'specifier'. This means producing a design specification, described as "a detailed description of an object in terms of its structure, namely the components used…and their connections" (ibid:108). If a specification is made, this in turn is used to communicate to the other stakeholders in the supply chain. It is this 'communication' when discussing design for circularity that is not often considered. This has started to be addressed through the research of Hornbuckle (2013; 2016; 2018) who has studied the communication of sustainable materials for designers.

There are many different types of designers and they interact in many different ways with materials. Hornbuckle (2018:12) splits the designers into two groups: 'function-led' designers based in industry that specify materials, in line with Ralph and Wand's definition, and 'material-led' designers (Karana et al., 2015) that tend to be more craft-based. In her research, Hornbuckle focuses on the function-led designers in industry that are more distant from the materials they design with. Instead, they rely on the expertise of others to inform them. To fill this gap, Hornbuckle has coined the term 'Material Translator', defined as "the specialists who collate materials information and can translate the benefits for designers" (Hornbuckle, 2013:107). This role, as Hornbuckle suggests, has many similarities to the 'boundary spanners' proposed by Rieple, Haberberg and Gander (2010). These, they describe, are individuals that work across partner organisations (large and small) translating effectively the needs and requirements from both sides back and forth. Hornbuckle (2013) puts this role in the context of sustainable materials. The boundary-spanner's, or to use her term 'material translator's' role, takes the language of one discipline such as the properties and appropriateness of materials, and translates it into language the designer can understand and use.

This idea has been explored further within the EU funded Trash2Cash project with the development of both recycled and recyclable materials (Hornbuckle, 2018). During the project, in which many different disciplines collaborated, 'Material Liaison Officers' were created to aid communication and dialogue. This material liaison approach, Hornbuckle (2018) explains, was - in part - set up to bridge the gap between the designers and material developers. It enabled them to "reach a shared understanding of desired characteristics when prototyping materials for the first time" (ibid:12). The material translator role in this context, Hornbuckle (2016) expands, should have 'design knowledge' and an understanding of design thinking and methods. Therefore, designers, she argues, have more to offer than just the specification and selection of more appropriate materials for circularity.

For this research, the role of Design for Recycling Knitwear incorporates the complex challenges of mixed fibres which are required to be transformed into a marketable product. It is argued in this research that the designer becomes the 'boundary spanner' or 'material translator'. This role provides a bridge, as Hornbuckle (2018) suggests, between the designers demanding quality recycled materials and the complexities of manufacturing faced by the material developers using recycled content.

4.3.2 DESIGNER-CENTRED RECYCLING NETWORKS

If we are to encourage sustainable practices within design, facilitating dialogue and communication, which is consistently posed as a challenge within the field of recycling, between designers and knowledgeable people (such as material developers or suppliers) is key (Hornbuckle, 2013; Hornbuckle, Qualmann and Sutton, 2009). This is supported by Kriwet, Zussman and Seliger (1995) in the context of an industrial recycling system, they describe the desired shift from the traditional relationships of manufacturer with supplier and consumer to a more communicative 'recycling network'. In this network, the designer becomes the server and is central to fostering collaboration and effective communication between the recyclers, consumers and material suppliers. They provide the 'clients' with data and an assessment of the different decisions.

> The recycling network acts along the life-cycle of the system and provides the relevant information at each phase. Starting at the conceptual design stage the network allows designers to represent and communicate pertinent information…The network allows exchange of information on monetary and environmental issues and an access to environmental databases providing information on legislation, materials, recycling processes and product history. Conflicts arising during product design (e.g. materials compatibility for recycling) can be resolved since the different network partners can make informed decisions collaboratively. (Kriwet, Zussman and Seliger, 1995:18)

This designer-centred approach is supported by Cleveland's PhD research (2018) in the field of textile recycling. Her localised model also places the (textile) designer in the centre of the many recycling processing stages. She identifies that the designer plays a vital role reconnecting people with the value of their (textile) waste materials. This centralised position allows the designer to not only lead but be responsive. It is this responsiveness within the platform that Cleveland proposes "could curate information pertaining to an individual company's waste stream that could highlight their individual potential" (Ibid, 2018:173).

4.3.3 TEXTILE DESIGNER'S ROLE - THE REALITY

The reality of being a designer in industry, specifically for textiles, paints a slightly more complex picture. The 2017 Nordic Council's report 'Stimulating textile-to-textile recycling' demonstrates some successful examples of brands producing garments that are made from recycled materials that can be recycled. However, there is also a long way to go before this is seen as a wide-spread approach (Watson et al., 2017). Communication, as explored by Hornbuckle (2013), Kriwet, Zussman and Seliger (1995) and Cleveland (2018), is cited time and again as one of the most important strategies that needs to be employed between sorters, recyclers, manufactures, and brands (Elander and Ljungkvist, 2016; Fibersort, 2020a). While the research suggests that communication and collaboration is vital, the Nordic Council's report found that this communication is difficult to establish in practice.

> Both brands and suppliers point to a communication gap between the actors in the value chain….There is a lack of common language and common understanding on what brands wish for, on the one hand, and what can be realized by suppliers on the other. (Watson et al., 2017:36)

The responsibility of the designer at the centre of the recycling system (as previously discussed) does not always rest with a single person but could represent a brand as a whole. Watson et al. (2017) expresses challenges of gaining buy-in from senior leadership for the use of recycled materials. If this buy-in occurs, they suggest, it could encourage responsibility and uptake from all parts of the organisation so that products can be

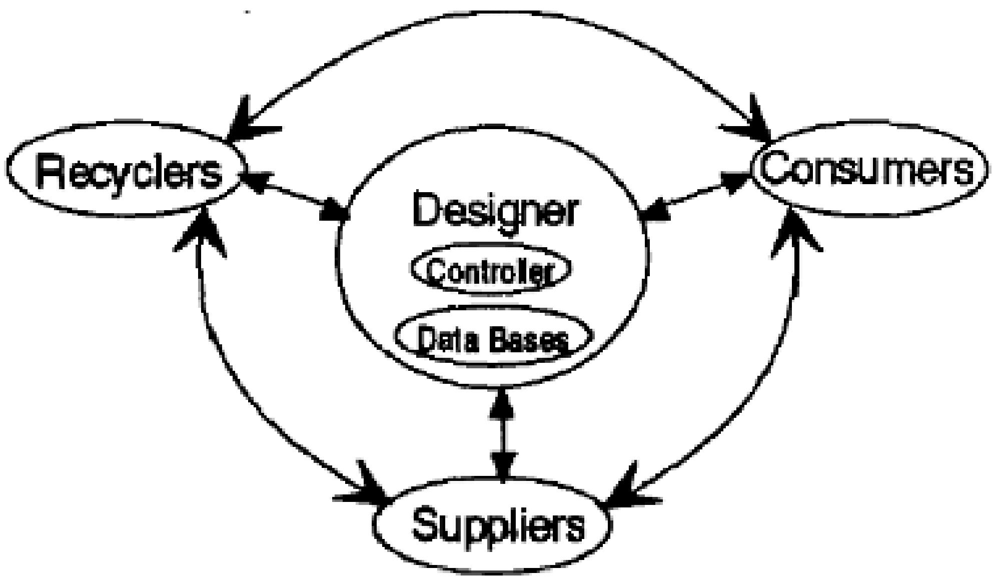


Figure 43. A Recycling Network, Source: Kriwet, Zussman and Seliger (1995:18)

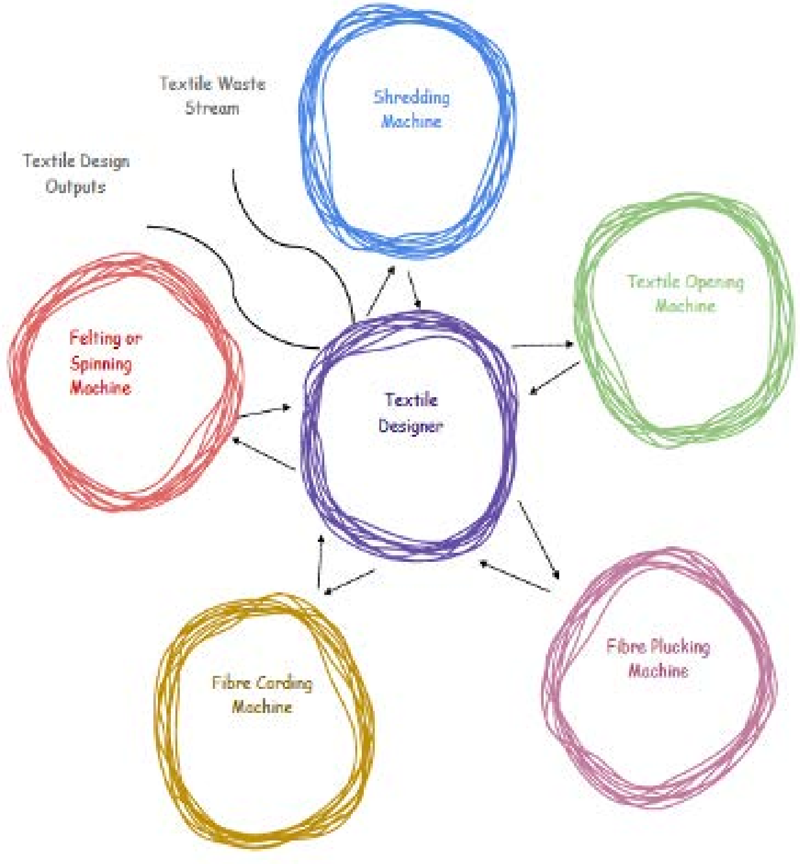


Figure 44. The design centred system showing how the materials move through different mechanised processes, (Cleveland, 2018:172)

designed with sustainability from the outset. However, it is vital that the complex structure of the organisations that designers sit within support their role.

Yet, the role of the designer for recycling textiles, suggested by Hornbuckle (2013) and Cleveland (2018) as a bridge and connector, is more akin to 'expert' designer-researcher. This role involves, as Hornbuckle advocates, translating knowledge for industry designers to understand. For Design for Recycling Knitwear the suggestion of a design centred system might not be suitable for an industry designer that solely 'specifies'. This is only compounded by Watson et al. (2017) finding that designers require support from within their organisations. Therefore, either new expert design roles need to be created in industry which sit between the actors in the recycling networks or this role must be provided by research. In the context of this PhD (a research project) the role of design-researcher is explored to find solutions to be used by industry designers and the recycling industry. However, it is also conducted by a researcher with prior experience as an industry designer-specifier. Therefore, this research bridges the experience of both industry designer and designer-researcher to ensure the findings created by the designer-researcher are suitable for the industry-designer to work with. This dual role approach has been discussed in greater detail in the chapter 11 (section 11.2, page 295).

4.4 SUMMARY

This chapter has completed the second objective of the research to understand the role of design in the current textile recycling system. This chapter argues that the current approaches used for Design for Recycling are over-simplified. While we often divide solutions between re-active approaches such as Design from Recycling and pro-active approaches, such as Design for Cyclability, this research argues we need to use both together to find solutions for waste textiles.

The designer's role in the recycling industry is established as one of communicator to bridge between the manufacturing of recycled materials and designing of products (Hornbuckle, 2013; Cleveland, 2018). This chapter concludes that the role of the designer for recycling is not a traditional industry-based designer that specifies materials. It is reasoned that either a new role needs to be created for the designer in recycling for circular economy or this role would be held by a designer-researcher. This research, therefore, will focus on the role of designer-researcher, which this chapter has argued is central to the recycling system (Kriwet, Zussman and Seliger, 1995; Cleveland, 2018).

PRACTICE 2

AIM

To explore how recycled yarns can be designed and made into commercial woven textiles and go through a finishing process ready to use.

This experiment (Practice 2) was accomplished using the recycled yarns created in Practice 0. It was conducted early in the PhD's explorative stage and only considered using recycled materials omitting designing for onward recyclability. The practice was achieved in collaboration with a specialist weave designer and weave technician to create a proof-of-concept fabric. This demonstrated that both yarns were suitable for the warp and weft in the weaving process and were finished to industry standards. The woven design was developed to reduce waste and maximise the use of the fabric for a range of cushions. The navy and grey yarns formed both warp and weft of the material creating plain and patterned sections within the fabric. These sections became the cut lines for the final cushion construction.

The final fabric was sent to a finishing company and was washed and milled (a controlled felting process used for wool). Here it was discovered shorter fibres were desirable during the milling process. Therefore, shorter recycled woollen fibres could be a benefit within the design of fabric which would be finished in this way.

While the aim of the experiment was achieved, later a 'Design for Cyclability' lens was used to reflect on this practice leading to new insights. The material was split between plain (single-coloured sections) and patterned (multi-colour sections). While the patterned sections were striking, the plain areas highlighted the design's texture. A preference for either plain or patterned fabric is subjective and falls within the designer's creative scope. But designing for a mechanical recycling system would prioritise a single colour material thereby avoiding colour contamination. Therefore, this highlighted the tension between creativity of design and design specifically for recycling purposes.

Figure 45. Practice 2: Navy and grey recycled yarns woven into a fabric

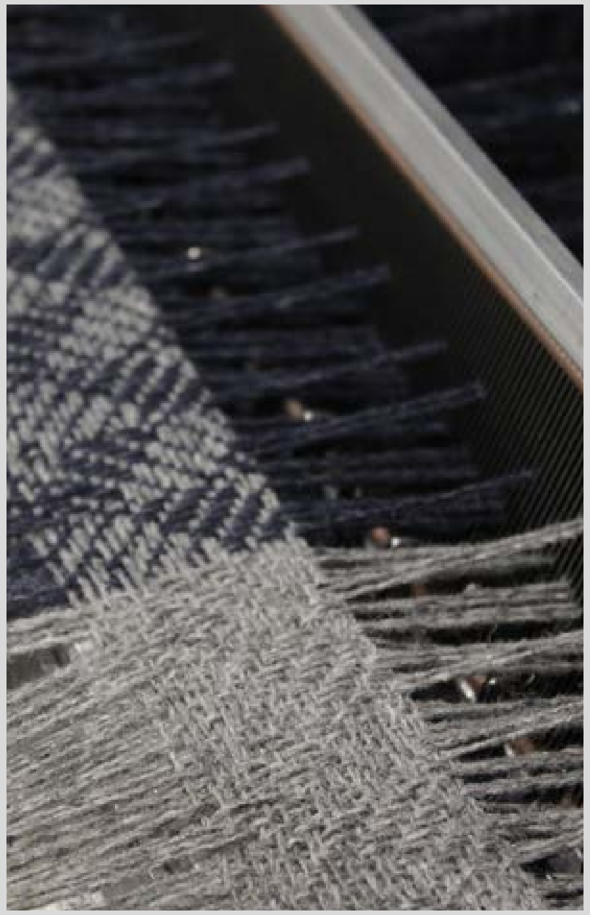


Figure 46. Plain and patterned sections of the woven fabric

Figure 47. Plain and patterned sections of the woven fabric

In another example, during the production of the textiles the technician pointed out the tension was slightly looser than he would generally expect. This, he explained, could be amended if another run of fabric was to be created. It was only later understood that the 'looser' construction would aid the recycling process. It is generally accepted that recycling very tightly woven textiles is much more difficult. This is because it is harder for fibres to be teased from fabric. The looser the construction, the less damage is done during the pulling/shredding process and a higher quality recycled fibre is produced. Once again tensions were highlighted between the traditional structural design of a textile and the design of a material to the aid the recycling process.

ACHIEVED AIM

The aim of Practice 2 was achieved through the design and manufacture of woven textiles from recycled yarns which went through a finishing process ready to use.

INSIGHT

Practice 2, additionally, aided the understanding of the design decisions that occur when transforming yarn into a finished material. This highlighted the tensions between decision making for design purposes and those for recycling.

5 CASCADING

This chapter explores the concept of cascading, starting with a review of the theory. This encompasses three different cascading approaches, and each are described in relation to the field of sustainable textile design. The chapter concludes by reviewing the current literature of how cascading and circular economy frameworks might be combined.

5.1 WHAT IS CASCADING?

Cascading is described by Vis et al. (2016:8) as "a complex interaction of material flows and their utilisation in different products and sectors. It is often described as a strategy to increase resource efficiency". Within the textile and fashion literature, cascading has been given little or no attention, often referred to as 'downcycling' and is only critiqued. Condemned by Fletcher (2008), she maintains that all approaches including, re-use, re-manufacture and re-cycling are influenced by the trend for downcycling. This results in their value cascading very quickly downwards into cheap products.

The discussion of this topic predominantly focuses on the cascading of wood products. However, even within this literature both Olsson et al. (2016) and Mair and Stern (2017) agree that there is great uncertainty as to what cascading actually entails. Furthermore, Mair and Stern (2017:283) reason that both a circular economy and cascading utilisation core value is to "use materials and products multiple times to increase utilisation time and resource efficiency". Yet, both concepts, they highlight, are rarely discussed in the same context. Campbell-Johnston et al. (2020) start to address this arguing that previous papers, such as Mair and Stern's, have done little to demonstrate how cascading and the circular economy could be practically combined.

5.1.1 ORIGINS OF CASCADING

Resource cascading was introduced in the 1990's by Sirkin and ten Houten (1994) in their paper 'The cascade chain'. They present cascading as a theoretical construct for the optimal exploitation of resource quality. They explain the concept as a metaphor; a river flowing over a series of rocks until it reaches a lake. In practice is it a chain of sequential 'uses'. Use in this context can refer to any end-of-use option, including but not limited to, re-use, re-manufacture and recycling (Campbell-Johnston et al., 2020). From one link in the chain to the next, the highest quality use is selected dependent on the condition of the resource at the end of each subsequent use (Figure 48).

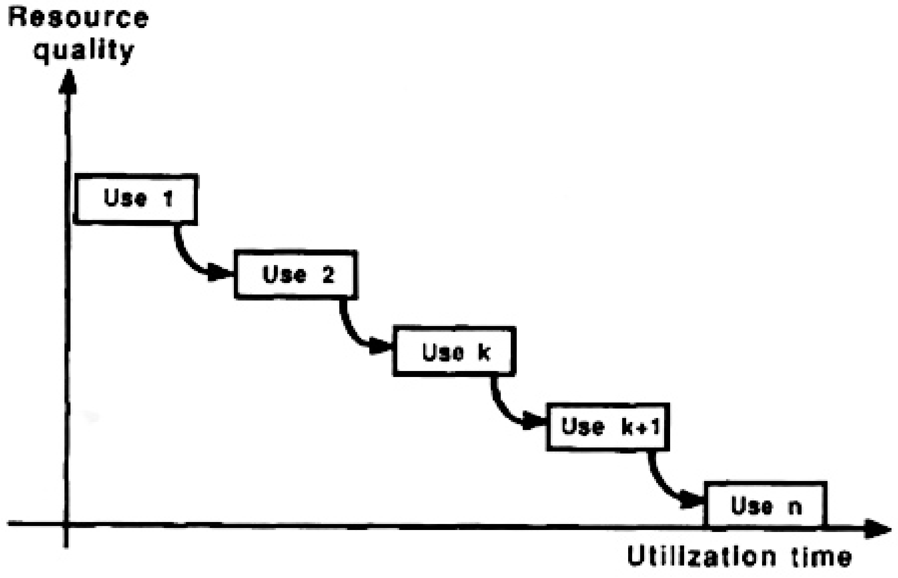


Figure 48. Cascading Approach, (Sirkin and ten Houten, 1994)

Since its conception in the 1990s the cascading approach has drawn traction in the fields of renewable energy (Haberl and Geissler, 2000), the bio-economy (Fritsche and Iriarte, 2014) and the circular economy (EMF, 2013). In particular, since the EU Commission (2012) promoted the use of cascading of bio-based waste streams, much research in this area has emerged. This is most commonly applied to wood-based products (Mair and Stern, 2017; Vis et al., 2016).

5.2 CASCADING APPROACHES

In 2012, Odegard, Croezen and Bergsma produced three categories of cascading which have been adopted across the literature: cascading-in-time, cascading-in-value and cascading-in-function. Ultimately, they point out, cascading comes down to a series of choices between different applications. These choices impact future possibilities, hence, the necessity of a chain approach.

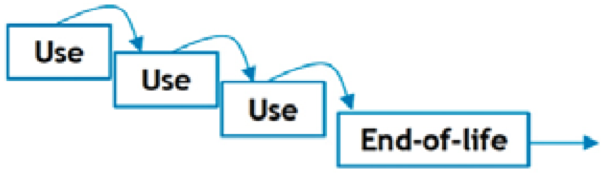


Figure 49. Cascading-in-Time, (Odegard, Croezen and Bergsma, 2012)

5.2.1 CASCADING-IN-TIME

Cascading-in-time, defined by Odegard, Croezen and Bergsma (2012), is the most commonly perceived version of cascading and is a simplified version of the original model proposed by Sirkin and ten Houten (1994). In essence, this approach allows materials to stay within a system longer and therefore reduce the need for virgin resources (Olsson et al., 2016; Fraanje, 1997).

There has been some debate as to whether this form of cascading refers to maximum time spent in the system or number of cascades. As ascertained by Olsson et al. (2016:8), either a number or timescale approach has its own merits. Essel et al. (2014) conclude the decision should be made on a case-by-case basis. But they emphasise, whichever approach is taken, cascading should always be used as strategy ending with a viable option for the end-of-life.

Essel et al. continues to distinguish between singular or multi-stage cascades. The former flows into a single use application before end-of-life and the latter is required to have two of more use stages. This is emphasised by Campbell-Johnston et al. (2020) as a choice between the undesirable (single cascade) and desirable (multi-cascade) and is illustrated in the textile recycling system by Hawley (2006) through the material life of a t-shirt. This material, she explains, is often only extended through one additional cycle, such as being cut/re-manufactured for wiper-cloths before being disposed of.

An example of cascading through time in the field of textiles is offered by Smosarski:

> A woollen jumper which lasts seven years can be recycled into a woollen coating fabric, which can be made into an overcoat that is good for perhaps ten more years. The discarded overcoat can then go on to become a blanket, which can again yield service for ten years. The blanket can then be recycled as filling for furniture or bedding or perhaps as the insulation or soundproofing in a motor car. So, a wool fibre, starting life on the back of a sheep, can have a useful life of 50 years before nothing more can be done with it. (Smosarski 1995:113-114 cited in Norris, 2005).

From a textile design perspective, Goldsworthy (2017:10) highlights that "how we think about 'time' in our design process is crucial". Goldsworthy refers to the Circular Design Speeds (2019) research that was conducted as part of the Mistra Future Fashion consortium. This looks at the speed of use and the impacts this creates when designing textiles. This was conducted jointly with a lifecycle assessment (LCA) study in which the base measurement was 'impact per wear'. However, as Goldsworthy (2017) questions, it might make no difference in this approach if a garment was used ten times in one year or ten times in five years. Therefore, as designers we need to understand more about the rhythms of use and how it effects the way we might design products and materials. This concept was first introduced by Fletcher and Tham's lifetimes project (2004) and now it has been explored in depth, by Goldsworthy, Earley and Politowicz (2019), within the circular design speeds research.

5.2.2 CASCADING-IN-VALUE

Cascading-in-value is described by Odegard, Croezen and Bergsma (2012) as a strategy to ensure the highest possible value of a material is achieved when choosing between use options. The value of the overall cascade should also be maximised. This approach Vis, Reumerman and Gärtner (2014:17) maintain, cannot exist without the cascading-in-time approach, otherwise it would become a simple selection process of what is preferred. To make matters more complex, Olsson et al. (2016) reasons that the term 'value', in the context of cascading literature, is not well defined. Some focus purely on the economic (Dammer et al., 2016), where others also consider environmental, social and moral value (Vis, Reumerman and Gärtner, 2014). Campbell-Johnston et al. (2020) combine monetary value, quality and function of materials with the triple-p: people, planet and prosperity. These three dimensions provide broader considerations, which, they argue, guide cascading decisions and valorisation processe, specially for the circular economy.

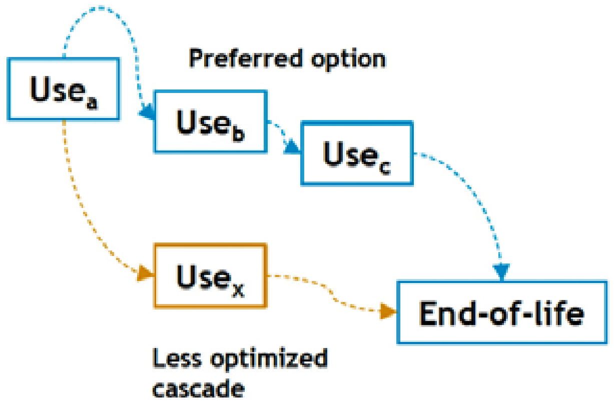


Figure 50. Cascading Value, (Odegard, Croezen and Bergsma, 2012)

DEFINING VALUE

Value has not been meaningfully referred to throughout the text, so far. This is mainly due to the fact that value is a complex concept. Much like the cascading literature, it is often used in reference to recycled materials accompanied by little or no explanation to what is meant.

Moeran (2009) explains that there are three broad streams of value, but it is the first two (excluding linguistic value) that will be considered here:

> One is economic: the measurable degree to which people desire an object and how much they will forego to get it. A second is sociological: a focus on what is seen to be good, appropriate or desirable in human life. (Moeran, 2009:6)

Moeran's (2009) notes on this topic explore the ideas that our social/cultural values might be transformed, at least in part, into economic value. This supports the original theory put forward by Marx (1990) in which he proposes that labour can be embodied within a commodity to form value. In both these definitions value is created through a transformation.

This topic is wide and far reaching and beyond the scope of this research to discuss in depth. Here, this brief dialogue is offered as context for the discussion ahead. Value in the circular economy brings together economic, social and, importantly, environmental value. As described by Katie Beverley on 'the circular economy podcast', the challenge we are facing is to consider the environment as a stakeholder as well as all the others when we design (Weetman, 2019). While these overarching themes of value in a circular economy are important, in the context of this research the value of waste textile in the recycling system will be addressed.

WASTE TEXTILE RECYCLING VALUE

Value in the textile recycling industry as Crang et al. (2013:19) explains "appears from something that is not only at the end of one life, but given away for nothing". This corresponds to Thompson and Reno's (2017) 'rubbish theory' which they describe as follows:

> a transient object gradually declining in value and in expected life-span may slide across into rubbish. In an ideal world, free of nature's negative attitude, an object would reach zero value and zero expected life-span at the same instant, and then…disappear into dust. But, in reality, it usually does not do this; it just continues to exist in a timeless and valueless limbo where at some later date (if it has not by that time turned, or been made, into dust) it has the chance of being discovered. (Thompson and Reno, 2017:27)

This aptly describes the textile recycling system particularly in relation to economic value. There are, as previously explained, other forms of value at play, but the focus going forward will be on the economic which many of the other values transform into. For example, clothing starts at one economic value, namely, the cost at which it is purchased. We might consider, for instance, a low-priced acrylic jumper purchased in a department store. Once in the possession of the consumer, the value of this jumper would slowly decrease over its lifetime, in just the way that it would be sold at a lower price in a second-hand shop. The garment would eventually be discarded, reaching zero economic value. If captured by the recycling network, however, as Norris (2012d:135) describes, "cast-offs become source material for markets… and value is extracted and re-inscribed through processes of decomposition and reincarnation".

In order to reincarnate this value, there are a network of actors (sorters, importers, market retailers etc..) along the chain which, as Norris (2012d:135) proposes, produces 'exchange-value'. The difficulty facing the waste textile industry is pushing these apparently valueless materials back up the economic scale. Working towards a circular economy, this value is demanded by most to return to the same or higher value than it was before. If we are to transition into a 'New Textile Economy', as EMF (2017) suggest, we need to address the current loss of more than 100 billion USD worth of materials that could be being circulated. It is this 'circulation' or movement that seems to be the crux of the issue. As Norris (2012d:140) concludes "the only way to make money out of the used clothing trade is to keep it moving, keep sorting and recombining it, imagining new contexts and creating those pathways". Therefore, although the value of the garment when it is in use is important, this discussion highlights the need for more prioritisation of the value of textiles entering the recycling system. This opens up the research question: can we design for the sorting and recombining of textile waste that Norris describes? In order to answer this research question, the focus on textile value in this thesis will reside in value of waste when it enters the recycling system. This will be called recycling value.

5.2.3 CASCADING-IN-FUNCTION

Cascading-in-function is the third and final approach used in the cascading theory. Odegard, Croezen and Bergsma (2012) equate this with co-production – the production of multiple functional streams from one original source, which maximises the total functional use. There is consensus across the biomass literature that this approach should be first completed followed by cascading-in-time and/or value (Figure 51).

This approach might be compared to the design for disassembly approach in which a product can be separated into its component parts to be re-used or recycled in different ways. As previously discussed in chapter 4 (page 98) disassembly within textiles has been generally ignored due to the nature of the way's textiles are combined. 'Textile Design for Disassembly' research conducted by Forst (2020) provides an optimal way to approach the cascade-in-function framework. It, however, falls outside the scope of this research which is focused on the following stage of recycling the materials that have been disassembled.

5.3 CASCADING UP AND DOWN

Traditionally cascading has been seen as an approach solely for reducing quality. This is often reported very negatively. Something to be avoided. Overwhelmingly the focus is on the quality of materials increasing. And whilst cascading does include elements in which quality deceases it is also attached to two other important approaches, namely, relinking (salvageability) and maintenance. These approaches Sirkin and ten Houten (1994) describe are used to determine optimal resource pathways (Figure 52).

Relinking or salvageability, Sirkin and ten Houten (1994) define, is a method which allows resources to travel back to higher levels of the cascade or into new substance cycles. They emphasise that salvation of resource quality is not restricted to its original cascade chain but may be utilised in any number of chains (Figure 53).

5.4 RESOURCE AND PRODUCT CASCADES

Sirkin and ten Houten (1994) have established two different ways the cascading approach can be applied: resource or product cascades. Products, they suggest, are the assembly of various resources. When a product can no longer be repaired or maintained for its original purpose, it may be broken down or dismantled into basic resources (disassembly). This allows it to be salvaged (re-linked) or to be further cascaded, referred to as resource cascading.

In contrast, a product could also be cascaded through re-use in 'almost' its original form. However, this must be on a lower quality level and must be for a different function. For textiles this could equate to a different user and might commonly be described as a garment becoming second or third hand. Repairing or maintaining, Sirkin and ten Houten emphasis, cannot be classified as cascading.

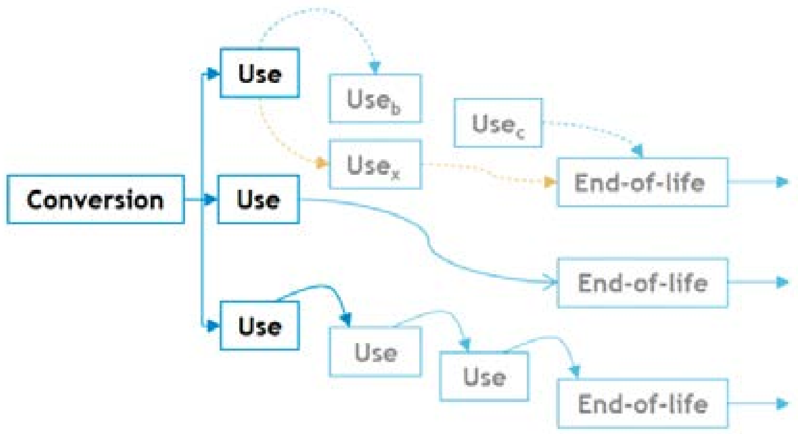


Figure 51. Cascading-in-Function, Source: Odegard, Croezen and Bergsma (2012)

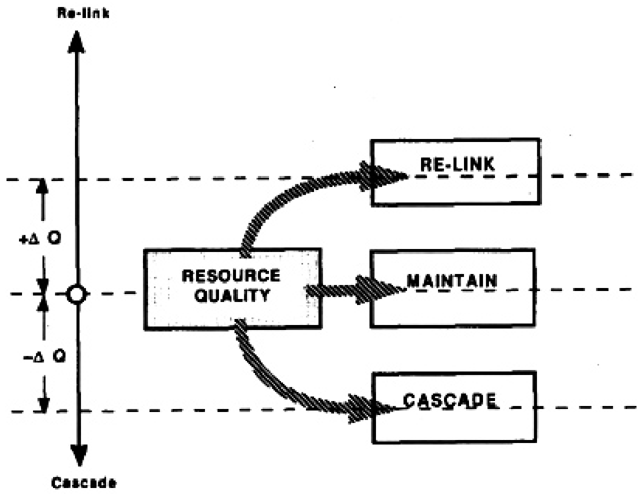


Figure 52. Optimal resource pathway, (Sirkin and ten Houten, 1994:217)

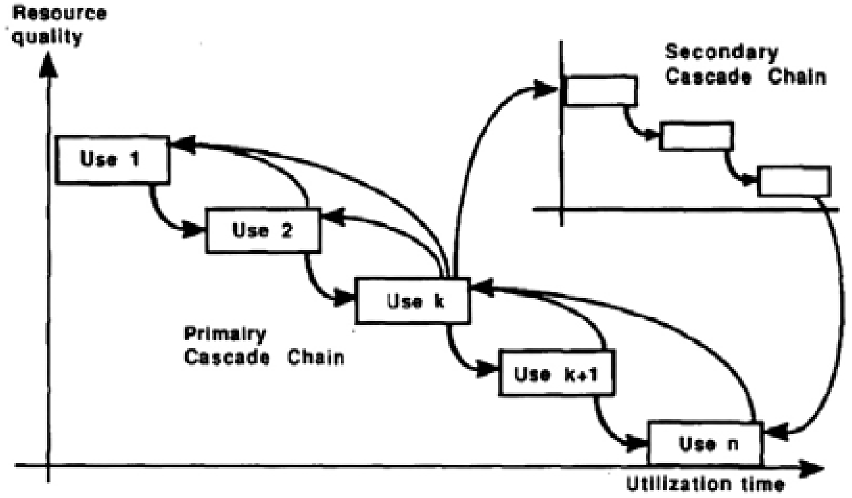


Figure 53. The cascade chain and salvageability, (Sirkin and ten Houten, 1994:217)

5.5 CASCADING AND THE CIRCULAR ECONOMY

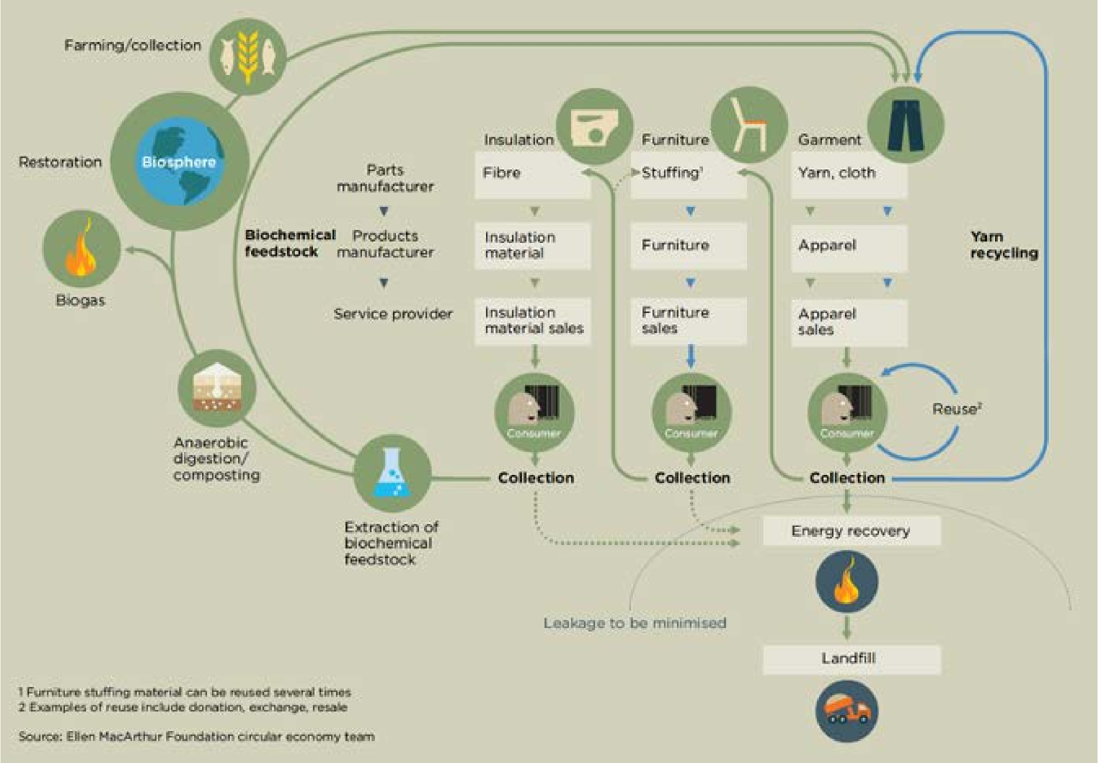
The cascading approach is often overlooked within the context of a circular economy. First discussed in EMF's (2013) report 'Towards the Circular Economy', it now (as of 2021) remains undiscussed on their website. EMF (2013:33) provide one example of how cascading in the biological cycle could work in the field of textiles. This follows a pair of jeans (Figure 54): firstly re-used; then recycled into yarn for another garment; recycled once again into furniture stuffing; re-used as insulation and finally at the end-of-life returns to the biosphere. Since this, within the field of textiles, only one example by Fischer and Pascucci (2017), has linked the cascading concept to the circular economy. Here, Fischer and Pascucci (2017), focus on cascaded re-use of textiles through product-service systems. This cascading would occur before the products flow into re-manufacture and re-cycling streams.

When combining the two concepts, cascading and the circular economy, Mair and Stern (2017) question why cascading is only found within the biological cycle. This, as they suggest, is limiting. Mair and Stern's research compares both the circular economy and cascading utilisation literature and conclude that the two fields share many strategies. For example, in line with the cascading definitions, the EMF circular economy model (2013) proposes that materials or products should circulate for the maximum amount of time. This can be achieved either by extending the time in any given cycle or by repeating a cycle before moving to the next loop. In light of this, Mair and Stern (2017) put forward a new version of the circular economy model in which technical loops, namely, repair, re-use, remanufacture and recycling, can equally be applied on both sides of the diagram (Figure 55). This is only supported by EMF's (2013) cascading jeans example in which both re-use and recycling cycles are utilised within the cascade.

Moreover, Campbell-Johnston et al. (2020) take this one step further in their paper 'The Circular Economy and Cascading: Towards a Framework'. This provides, as the name suggests, a framework for both the circular economy and cascading theory to be used together. They argue that often the social context where decisions-making processes occur are neglected in the literature as a method for deciding appropriate subsequent uses. They describe this social context as follows:

> the social context… i.e. the application context, which contains actors involved in material exchanges, the regulatory and market context in which they operate and eventual value considerations of the material. (Campbell-Johnston et al., 2020:7)

They suggest that circular economy and cascading principles can be integrated using the 10R framework: Refuse, Reduce, Resell/Re-use, Repair, Refurbish, Re-manufacture, Re-purpose, Recycle, Recovery (energy) and Re-mine (Reike, Vermeulen and Witjes,



1 Furniture stuffing material can be reused several times
2 Examples of reuse include donation, exchange, resale

Source: Ellen MacArthur Foundation circular economy team

Figure 54. Cascading keeps materials in circulation for longer – textile example, (EMF, 2013:33)

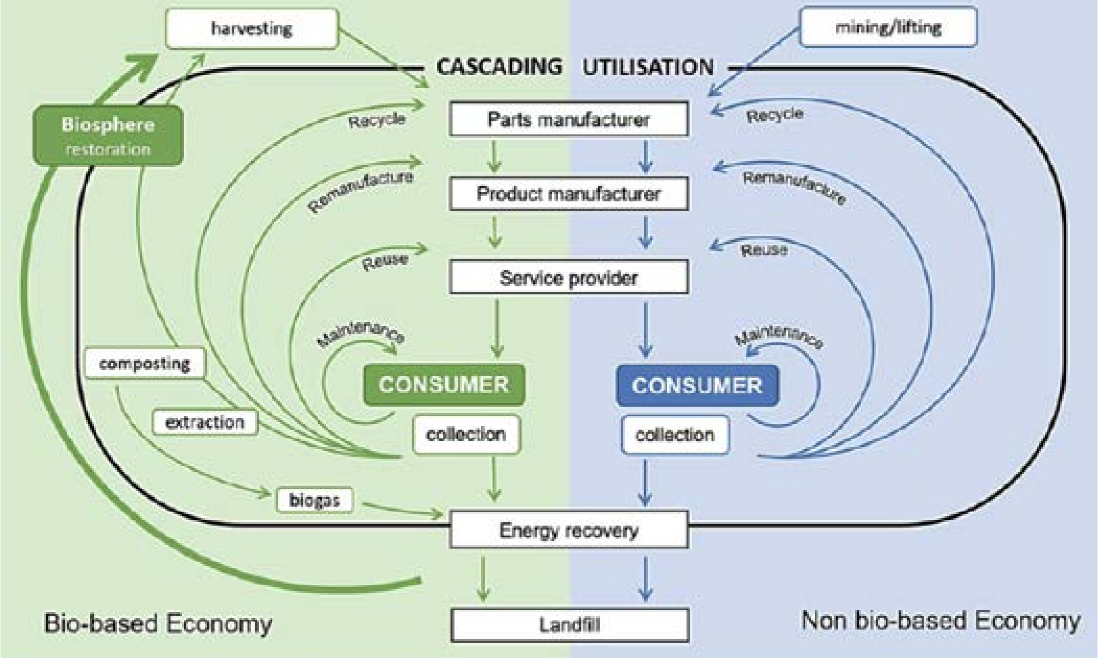


Figure 55. Cascading use within the circular economy, Source: Mair and Stern (2017)

2018). This, they explain, would aid how we make choices for material and product use. Furthermore, they suggest that the cascading framework provides a systems perspective. If combined with the circular economy and the 10R framework, describing exchanges between actors and users, this provides a broader perspective in order to make sustainable material and product choices.

As part of their review, Campbell-Johnston et al. (2020:2) also maintain "little is known about how cascading can be operationalised for practitioners and connected to value creation and retention in a CE [circular economy]". They provide a model that combines cascading and the circular economy (10R's) that also accounts for the more complex social decision-making processes. This, they argue, provides the basis for practitioners to engage in a more holistic description of creating high-value materials and products.

However, Campbell-Johnston et al. rigorous review of literature and their model is, by their own admission, theoretical. It is, therefore, unspecific to product type and is generalised to encompass all the R-approaches. If their model is to be relevant to practitioners, it could be argued, it should be tested in practice. Campbell-Johnston et al. acknowledge the need for further research to validate their model and highlight that this research should be conducted within a specific geography or sector. And it is this specificity of cascading, for the textile practitioner, that this practice research provides. However, unlike Campbell-Johnston et al. whose research takes a broad look at all 10R approaches, the focus of this research resides with the 'R' for recycling. More specific still, this practice-based research will centre on knitted wool/acrylic textiles for the circular economy.

5.6 SUMMARY

This chapter has addressed the third objective. It has explored the three cascading approaches: cascading-in-time, cascading-in-value and cascading-in-function. It is, particularly, the issues of cascading products and materials through time and value combined that provides the focused discussion for the waste textile industry. It has been argued that while many forms of value are at play, for the recycling of waste textiles these other values are often transformed into economic value. For the context of this research, focused on the textile recycling industry, this research will concentrate on 'recycling value'. This is the economic value of clothing when it enters the textile recycling system. This recycling value, highlighted by Norris (2012d) is created through sorting and recombining the textile waste. This poses the research question: can we design for this sorting and recombining? This will be addressed in the next part of the thesis.

Finally, the literature demonstrates that both circular economy and cascading have many similarities and can be combined using the 10R's framework (Campbell-Johnston et al., 2020). The limited literature on this topic to date has provided general theoretical approaches aimed at practitioners. However, the chapter demonstrates that beyond theory, practice research is required to test and explore these ideas. It is here, that this research will specifically look at recycling of knitted wool/acrylic textiles to develop and test a theoretical framework for cascading within a circular economy.

PART 2 SUMMARY

This part of the thesis accomplishes aim one of this research; to understand the fields 'design for mechanical recycling' and cascading in the context of post-consumer wool and acrylic textiles. This part synthesises the two fields 'design for recycling' and 'cascading' in a textile design context. This has been achieved by addressing the three objectives in first aim of the research discussed below.

This first objective was to review the current mechanical recycling industry of wool and acrylic textiles. This is framed within a circular economy model and discussed specifically in the context of recycling. It demonstrates that recycling might be used as a successful tool if the rebound effect is to be avoided. Acrylic knitwear is established as low-value waste stream that is difficult to be re-used. The current recycling methods do not replace the products that form them and are not designed to have future recyclability.

The second objective to understand the role of design in the current textile recycling industrial system has been achieved by arguing that the current Design for Recycling approaches are over-simplified. This research is focused on an industry perspective and the role of the designer-researcher in this context is considered. It is concluded that the designer-researcher can be placed in the centre of the recycling system/network to bridge and communicate between manufacturing and industry designers to help achieve the Design for Recycling aims.

Finally, the third objective was addressed to conduct a review of the current cascading literature in relation to recycled textiles. The cascading approaches (cascading-in-time, cascading-in-value and cascading-in-function) are outlined. Increasing and decreasing value is discussed and value specifically at the recycling stage is highlighted as an area of focus. The research question: can we design for the sorting and recombining of textile waste? is posed to be addressed. The review of the literature demonstrate that both the circular economy model and cascading theory can be successfully combined theoretically for practitioners. However, there is a need for practice research to specifically test these ideas. In this research this will be addressed by testing a specific product type (acrylic and wool knitwear) and specific circular economy approach (recycling).

3

PART 3 – SENSE-MAKING THROUGH DESIGN

This part of the thesis has been constructed to address the second aim of this research. This is to establish the role of cascading, blending and sorting and it will specifically address the research question posed in the second part of this thesis: can we design for the sorting and recombining of textile waste? This has been outlined across three objectives which forms the structure of the three chapters in this part.

Chapter 6 will address the first objective to understand how the field of cascading intersects with design for recycling of post-consumer textile waste. It provides a model for how cascading resources and cycling products can be combined.

Chapter 7 looks at the second objective to identify the role of blending within virgin and recycled textile production. It outlines the reasons for blending in textiles and those used with the textile recycling industry and highlights the importance of understanding blending for recyclability across three levels: yarn, material and product.

Chapter 8 tackles the third objective, to investigate the methods of sorting for mechanical recycling of wool and acrylic textiles. It outlines how sorting is generally conducted in the textile recycling industry. In addition, it provides an analysis on the sorting categories used for wool/acrylic textiles.

Chapter 9 addresses the final objective, to propose a framework combining cascading, blending and sorting. It brings together all the models in the previous three chapters (Chapter 6, 7 and 8) to suggest an framework to extend the lifetimes of low-value acrylic textile fibres.

PRACTICE 3

AIM

To explore the steps in the recycling process and the impacts on the materials if the garneting stage is removed from the process.

Practice 3 took place with a recycling company who use a traditional needle felting technique to produce a recycled felt. The company had been visited prior to the experiment a number of times. On this occasion the visit was conducted to explore how the different steps in the recycling process might be adapted.

Recycling textile waste is made up of many stages (Figure 56). Pulling/shredding is the first stage, returning materials to fibre which 'opens' the textiles, returning them to a fibrous state. The result of this first rudimentary stage produces fibre which contains remnants of structured textile material. Garneting is a similar but more specialised stage ensuring the transformation of the material into fully fibrous form (Gee, 1950). It had been highlighted through the researcher's field research that this process was one of the most expensive stages. This increased the final materials unit price and therefore negatively affected the profit margin of the resulting products.

During a previous field visit the company advised that they owned a pulling machine and would be willing to complete a recycling trial. However, they did not own a garneting machine, meaning another solution to replace this stage needed to be found. They suggested in lieu of this that the material could be repeatedly put through the carded stage to attempt to replicate this effect.

The trial was organized to test a small batch of jumpers (200kg) to establish:

a) If they could be pulled/shredded using the machine

b) If after a single card they would produce a good quality felt product

c) If double carding might improve the fibre to achieve a similar effect to garneting.

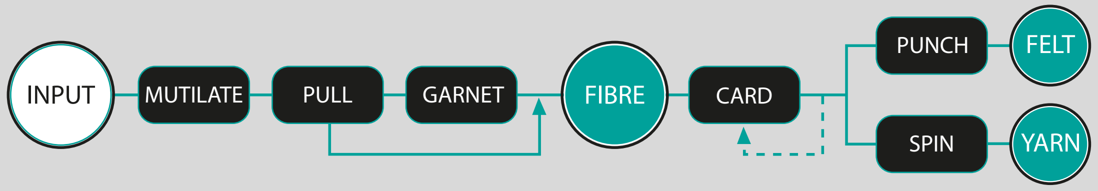


Figure 56. Simplified process of recycling textile indicating the test with the recycling company (skipping the garneting stage and repeating the carding stage)

First, 200kg of white knitwear was obtained from a UK sorting company. These were to be recycled and processed (pulled/shredded and carded) into a non-woven needle punched felt, and also used for a spinning test at the time and at a later date (Practice 9, page 187).

White was specifically chosen to further understand the impacts of contamination in the recycling process. White was selected as it would show up any colour or dirt caused by the process. The colour choice also aided the researcher's understanding of the sorting process. The researcher visited the sorting facility during the sorting process and found that the request for 'white' jumpers had been interpreted slightly differently that she had intended. The researcher spoke directly with the sorter on the factory floor and clarified that she required 'brilliant' or 'true' but not yellow, beige or cream shades also considered 'white'. As a designer obtaining the correct colour for a design is vital and this incident highlighted the impact of every stage in the recycling process on the final outcome of the material/product.

Once the white jumpers were obtained, they were successfully pulled back to fibre. Half of this pulled fibre was taken through the carding machine a single time (Fibre A) before entering the needle punching part of the process. The other half went through carding machines twice (Fibre B) prior to needle punching.

When both non-woven materials A and B had been produced, they were directly compared. It was found that there was very little difference between the two materials. They both formed a very soft non-woven material. These materials (as in Practice 0) had been produced with alternative applications in mind, such as interiors and were created on the same polypropylene mesh backing material. It was concluded that the added time and expense to produce material B was unnecessary.

Following this a small amount of the two fibres were taken to a spinning company. First, the fibre was dismissed as too poor quality to spin. The spinning manager explained that it wouldn't go through the machines. The researcher was keen to understand why and what solutions could be found, such as blending high percentages of virgin. Another colleague was called in, an engineer that worked on the factory floor and ran the operations. He disagreed with the manager and thought the fibres could be processed. A quick test was conducted blending the recycled fibres with polyester.

Yarn A: 50% Fibre A Single carded / 50% Polyester

Yarn B: 50% Fibre B Double carded / 50% Polyester

The results of this test indicated that the engineer was correct; the fibre could be processed. It should be noted, however, in the same way as with non-woven production carding is also used prior to spinning. Therefore, for this test the fibre in Yarn A was carded twice and the Fibre in Yarn B carded three times. In reality double carding is only possible if the company producing the final product is willing to do this as part of their production process. Put simply the non-woven company would not double card the fibre for it to be sent for spinning only. And the spinning company made it clear it would not be possible to double card in their production line.

The results of the yarn tests demonstrated that both fibres types could be spun well. At test scale it was hard to draw any formal conclusions. However, the engineer highlighted that skipping the garneting step would ultimately impact the quality of the resulting materials. He pointed out that the decisions made during the recycling process should always equate with the design of the materials trying to be achieved.

This finding was also reflected during the non-woven experiment with the colour contamination. During the sourcing of the jumpers the cleaning process, which would usually be conducted, was omitted. This resulted in the labels inside the jumpers being left to be recycled along with the materials in the garment themselves. These are often white but also come in other colours such as black. It had been anticipated that the contamination would be very visible. However, surprisingly the contamination was more minor (Figure 59).

This contamination, in this case, could either be removed by hand or might be exploited as an intended design feature. This idea had been employed by the spinning company in an internal project in which contamination presented itself as a 'nep' in the yarn. A nep is a contrasting coloured spec which stands out and, in some cases, protrude from the yarn or fabric surface. Rather than attempt

Figure 57. Fibres being processes into a non-woven material

Figure 58. Yarn B

Figure 59. Contamination visibly present int the material

to remove the contamination the spinner added in other coloured materials to create intentional neps, thereby disguising the contamination. However, if a pure material is required the cleaning stage of the recycling process would then be vital. Therefore, it was concluded that the most appropriate steps in the recycling process needed to be conducted to match the intended end product.

ACHIEVED AIM

The aim of the practice was achieved by testing the removal of garneting step in the recycling process. It was found for non-woven needle punching this was not a necessary step.

INSIGHT

Practice 3 established the importance of appropriately matching the inclusion or removal of steps (for example, garneting or cleaning) in the recycling process with the desired design outcome of the final materials and products.

6 DESIGNING TEXTILE CASCADES FOR LONGEVITY

This chapter explores how cascading theory (as discussed in Chapter 5, page 115) might be used by the textile designer concerned with recycling. It starts by addressing the differences between resource and product cascades. The chapter then explores the similarities between cascading and up/down-cycling concepts used by designers. Finally, a new model which sits between cascading and circular economy is established which helps pose new questions to be answered in the subsequent chapters in this part.

6.1 DESIGNING RESOURCE AND PRODUCT CASCADES

Designing a full product cascade at the beginning of a product's life, warns Sirkin and ten Houten (1994), is a very complex, even an almost impossible task. The longer a product is used the more difficult it becomes to predict what the next uses might be. In a traditional model new designs of the same product adapt over time. For example, a product might be redesigned to improve its performance compared to a previous version, to fall in line with new fashion trends, or to reduce the cost. Any one of these changes would have an impact on an old product designed for a specific cascade path. Other considerations, Sirkin and ten Houten explain, are tied up with the practicalities of cascading such as difficulties with return and re-use. Often companies are reliant on others for the production and delivery of spare parts. As time goes on these spare parts might cost too much to produce or the whole product might end up costing more than a newer designed alternative.

Design implications of cascading products, according to Sirkin and ten Houten (1994:255), are two-fold "the first is in the choice of material for the product; the second is in the actual layout of the product". Therefore, while the focus of design can often centre around the product, it is also important to consider the material or resource cascade that follows. Hildebrandt, Bezama and Thrän (2017) emphasise that the most pressing demand for cascading is the forecasting of future production capacities. This, they reason, is essential to understand the future flow of materials, particularly when they might cascade into recycling systems. EMF (2017) explains there are many trade-offs made between designing for material and product longevity. Their concerns are focused on using strategies to extend the life of a product, but this may prevent material recovery later on. Goldsworthy (2017:4) summaries this concern and advocates that "we must stop viewing the product as the ultimate vehicle for longevity and start to see the materials themselves as holding the true value".

During the 'Circular Design Speeds' project Goldsworthy, Earley and Politowicz, (2019) illustrate the different approaches that can be taken by designers to create non-impactful longevity for both product and material. By using extremes in speeds to illustrate their research they produced both a 'super-slow' and 'super-fast' product cycle. The super-slow item was designed to cycle as a product between many users. This was made possible by continuous adaptation of the product over time. Whereas, the super-fast prototype was designed to be fleeting, and specifically made with low impact materials and processes. This enabled the material resources to be continuously recycled and utilised. While the fast product might, at first, seem unsustainable in its approach the project matches the fast use phases with the appropriate design choices, such as low impact resources suitable for quicker recycling.

Overall, both items utilise different cascading systems. The 'super-slow' is concerned with product cascading and the 'super-fast' with resource cascading. However, even the slow product, ultimately, has been designed to transform from product re-use back into resource re-use but over a very different time frame. For example, while the fast product was recycled to re-use the material after a short time, the slow product was designed to flow, after an extended period, into a recycling system to be chemically relinked into a material cycle. Whilst chemical recycling is not yet commercialised, it was forecast to be ready within the designed super slow - 50 year - time span. In this case it appeases the concerns of Hildebrandt, Bezama and Thrän (2017) that forecasting future capabilities might not be possible.

6.2 DESIGNING APPROPRIATE CASCADES

Sirkin and ten Houten (1994) explain that regardless of whether a product or material goes up or down in a cascade, it is vital that the qualities of a resource match up to the task they are to perform for. They argue, it would be inappropriate and uneconomical to use high-quality resources to produce functional products which otherwise could be achieved with lower-quality ones. The highest quality resources should be reserved for the most demanding performing products and vice versa. Rex, Okcabol and Roos (2019) remind us selecting the most appropriate material for the product we design is the key for increased environmental performance. And Yuksekkaya et al. (2016) explain that value will not increase based on needless design attributes.

For the recycling system, appropriate design of recycled materials comes down to which stages of the process the materials flow through. This has been illustrated by Practice 1 and Practice 3 (page 79 and page 131). For example, it would not be necessary to sort garments by colour if they are intended for hidden applications nor would it be appropriate to garnet the material to create a finer fibre when this attribute is not required. At the opposite end of the spectrum, high value materials are produced because they are processed through these additional steps, such as sorting by colour (see also Practice 1). This was prominently highlighted in Practice 3 where it was concluded that the amount of processing needs to match the requirements of the design. Therefore, the challenge for designing cascades across high and low value is appropriate design.

6.3 DOWNCYCLING AND UPCYCLING

> most of the definitions [within the cascading chain] include the down-cycling of materials with decreasing material quality, the closed-loop recycling of materials with unchanging material quality, and the up-cycling of materials with increasing quality (Vis et al., 2016:7)

Vis et al. (2016) highlight here the interconnected nature of both the cascading chain and the newer terminology found across the literature describing upcycling and downcycling. EMF (2013) define these terms as a process of converting materials into new materials of either higher or lesser quality and increased or decreased functionality. This is supported by 'cradle-to-cradle' authors Braungart and McDonough (2002:56) who state that "most recycling is actually downcycling; it reduces the quality of a material over time". Many materials, they argue, have not been designed to go through more than a single cycle. Forcing these materials into more cycles, they reason, can be messy and complex (ibid:59). The problem remains, however, that while we should strive to design new products for the circular economy, we still need to find solutions for existing waste.

In both their definitions, EMF (2013) and Braungart and McDonough (2002) place the emphasis on quality and functionality. Yet, they offer little explanation to quantify these terms. Campbell-Johnston et al. (2020) review of cascading literature in relation to down/up-cycling suggest definitions are very inconsistent. For example, they found up-cycling definitions are split between value-added and the extraction of higher value. They point out that up/down-cycling "interconnects with the valorisation process, e.g. the innate perception of that material or product at a specific point in time" (Campbell-Johnston et al., 2020:7). However, once again (as discussed in section 5.2.2, page 118) the definition of value is left open.

Across the textile literature the leading critique of the downcycling approach is concerned with speed. Here we start to circle back to the discussions within the cascading-in-time approach (section 5.2.1, page 117). Fletcher (2008:118) illustrates this by describing downcycling as "downgrading the quality of reclaimed materials immediately into cheap, low-value end uses rather than maintaining them as a high-value product or resource". It is this immediacy of the downgrading which Fletcher is suggesting is the problem rather than Braungart and McDonough (2002) criticism of just reducing quality over time.

6.3.1 DOWNCYCLING IN REUSE

Before downcycling is cast as the villain in this scenario, it is crucial to consider how downcycling might be beneficial as an approach. Sirkin and ten Houten (1994:216) describe the traditional system of cascading clothes in which they were passed down as 'hand-me-downs' or were re-sewn into something new. As the material slowly deteriorated in quality and becomes worn out, they are then used as cleaning rags. Supported by Norris and Mitchell (2012) they remind us that this still happens in cultures around the world. For example, in India, where clothing is "used and reused until it literally wears out, handed down to younger siblings and domestic servants" (Norris and Mitchell, 2012:267). Today, this traditional model, of repetitive re-use, is promoted as a method to combat the problems created by over-consumption in western culture. As the prices and often quality of clothing decreases the incremental wearing out of clothing through re-use has become a thing of the past. As we start to find new solutions, such as those offered by the circular economy, combined with growing trends of over-consumption, our mindsets as designers and consumers have shifted. Where historically we understood the cascades in which clothing would deplete in quality and functionality before finally being replaced, in our new world - one in which we are always buying new - to be sustainable we demand that our materials must constantly be increasing in quality, functionality and value.

6.3.2 DOWNCYCLING IN RECYCLING

Downcycling, therefore, can be used as a method to encourage longevity of a garment/product even if the quality decreases over its lifetime. However, this is only in the context of re-use. Downcycling during recycling is frequently condemned (Braungart and McDonough, 2002; Sung, Cooper and Kettley, 2019). In fact, the first use of the terms down-cycling and up-cycling has been traced back by Sung (2017) to an article with Riner Pilz about architecture and interior design who said “Recycling, I call it down-cycling. They smash bricks, they smash everything. What we need is upcycling, where old products are given more value, not less” (Kay, 1994:14).

In the field of textile design, Fletcher (2008) illustrates this by describing the usual route for recycled textiles. Often, she explains, recycled textiles end up as blends used for low-value “amorphous products such as insulation panels or mattress stuffing, rather than being reused as high-value products such as clothing” (ibid:118). This not only reiterates the concern for speed in the process but highlights the importance of the type of product within the cascade. Clothing is hailed as the highest value in comparison to textile building materials. This we must assume is because Fletcher is referring to their economic value, although this is not confirmed. Yet, as we re-use our clothing less and less, an amorphous product used for insulation panels in a building might well be used for a much longer time span. Here, Sirkin and ten Houten (1994), Rex, Okcabol and Roos (2019) and Yuksekkaya et al. (2016) reminds us that the quality of the materials should match the task they are required to perform in. Designing the types of products from recycled fibres in the same way must be appropriate.

6.3.3 UPCYCLING

At the opposite end of the scale is upcycling, which Fletcher (2008) suggest countermands the trend for deteriorating quality. Upcycling, she describes, is “where the processes and practices of reclamation and reuse enhance a piece’s perceived value, quality and design capital” (ibid:218). Here, Fletcher emphasises not only value and quality but the design element of this process. Supported by Han et al. (2017) and McDonough and Braungart (2013) they all present upcycling as an opportunity for designers to combat waste. This has been defined as design-led cycling.

UPCYCLING – WHAT IS THE AIM OF THE GAME?

There is much confusion in the textile recycling system, especially in the discussions around upcycling, over what the aim of the process is. Phases such as ‘textile-to-textile’ or ‘fibre-to-fibre’ have become buzz words when describing recycling and are easily mis-understood. EMF (2017) note this confusion and suggest in the context of their report the term ‘textile-to-textile’ should be avoided. Instead, they suggest ‘clothing-to-clothing’ might be adopted. This is because, textile-to-textile recycling could refer to a garment being downcycled into a non-woven textile material, criticised previously by Fletcher (2008). This is not to be confused with fibre-to-fibre recycling used to describe the chemical or mechanical recycling stage of returning textiles back to fibrous form, omitting the following stages in which the fibres are transforms into materials and onto products (Girn, Livingstone and Calliafas, 2019).

In addition, closed-loop recycling is often hailed as the holy grail of all recycling processes. However, we are reminded by Earley and Goldsworthy (2019b) that the focus shouldn’t always be on neatly directing materials back to the beginning of the same product. Systems thinking is required. Closed-loop practices are defined by Payne (2015:111) as:

- Recycling textile clothing waste for it to re-enter the clothing supply chain
- Cradle-to-cradle streams of technical and biological materials separated and recycled into the same production chain
- Re-use of existing garments

Re-use aside, this definition is dependent on recycling product-to-product or in this context clothing-to-clothing. In contrast, Payne (2015) defines open-loop recycling as “a system in which a product’s raw material is broken down to be used in a second, often unrelated product system” (ibid:106). Regularly, Payne explains, open-loop recycling results in the product being disposed of after its second life in the same way single cascading is described (Essel et al., 2014). This, McDonough and Braungart (2013) explain, happens when we become preoccupied with making an object ‘work’ in its first cycle that we forget to look forward to what happens next.

6.4 DESIGN-LED CYCLING

If upcycling is a process of increasing the value of waste through design, then it is vital for a circular economy that this design process is explored. According to Murray (2002), this is more than just technical processing. He argues it is created through knowledge:

> not merely conserving the resources that went into the production of particular materials, but adding to the value embodied in them by the application of knowledge in the course of their recirculation (Murray, 2002:27).

This ‘application of knowledge’ is argued by Earley (2010) to be the method designers use to create value. Whether that is economic, intellectual, emotional or material, this is added by the designer to a product. Value once again is centre stage of the argument. Earley’s argument is inspired by Braungart and McDonough’s (2002) cradle-to-cradle, for which she coins this approach as ‘design-led upcycling’. Although Earley’s work focuses on re-use and re-manufacture the explanation she used for the process of upcycling by the designer could be expanded to encompass other methods, such as recycling. Whilst Earley maintains that the designer is perfectly positioned to create value, Norris (2019) confronts this position by challenging designers to produce products that truly convinces the consumer of their transformed status. This can, as Norris critically assesses, sometimes fall short.

Building on this, Goldsworthy (2014) highlights that while we see many encouraging examples of design-led upcycling strategies, these are often used without the consideration of future cycles. This, Goldsworthy explains, only delays our textiles from inevitably ending up in landfill. These 'future cycles' used by both Goldsworthy (2012) in her PHD thesis and by Professor Becky Earley at the Centre for Circular Design (2020) are explored using a 'now, near and far' framework. This promotes a method for designers to understand what is possible to achieve now and consider the impact of nearer or future scenarios. Goldsworthy (2014) specifically considers the life span of materials, not products, which she argues are often compared to our human-centric time frames. We forget that materials have the ability to outlive us.

Therefore, if we are to consider cascading both up and down as an approach, it is argued here that the process should be designed. Design should be used to maximise the flow of resources, thereby re-valuing the materials with the consideration of future cycles through time.

6.5 DESIGNING RESOURCE SPIRALS FOR LONGEVITY

If we are to design our recycled textile fibres to cascade both up and down towards a circular economy, we must first ascertain how the two models can be combined. As previously discussed in Chapter 5 (page 115), cascading is presented as a downward flowing stepped or 'staircase' shaped model. It illustrates both upward and downward movements across both time and value (Sirkin and ten Houten, 1994). Cascading, as also described, is split into two approaches namely product and resource cascades.

In contrast the circular economy is represented with multiple circles signifying product lifecycles which are collected after use ready to be utilised again. This is described by Goldsworthy (2014) as 'cycling' (section 4.1.2, page 98). In order to bring these two concepts together a new visual was found. If materials are to flow both around and up/down, Murray (2002) proposes that for the context of upcycling, "we should talk of material spirals rather than cycles" (ibid:27). This is supported by Thackara (2006) who reminds us that speed is never free; if we speed through the process going straight rather than spiralling, then we will pay the price of wasting our resources.

This spiralling concept is visualised in Figure 60 and shares many similarities to the growing circles found within the EMF's (2013) butterfly diagram, Goldsworthy (2012) design for material ecologies visual and many others inspired by the circular economy concept throughout the design literature. The difference for this resource spiral is the sole focus on recycling (although it has the potential to be adapted for other end uses) and the ability to be designed to flow both up and down. This is emphasised by the arrows on each loop of the spiral. In essence each loop represents a product lifecycle returning as a resource at the end-of-use.

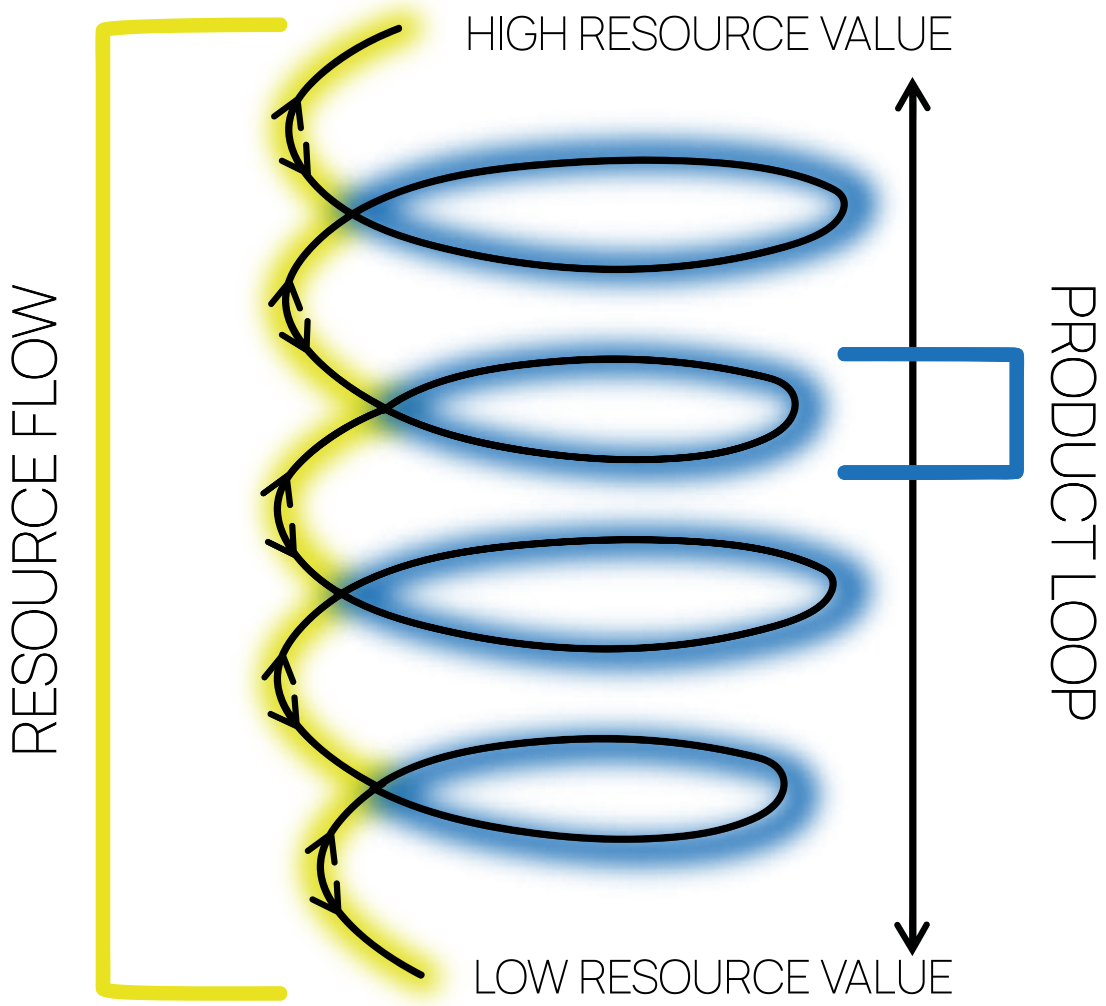


Figure 60. Combined cascading and cycling - a resource Spiral

Ultimately it is the designer's responsibility to re-value our resources using design as a tool to determine the speed and route of travel in a spiral. It should be noted there is no rule that states materials must start at the top and move down to the bottom. For this reason, time is not represented, for example, for a resource's travel route to move down and back up again within the spiral does not reverse time. The direction and route of travel is open for the designer to interpret appropriately. To do this the designer must understand the tools they have to affect the movement of resources within the spiral and vitally what type of value is being prescribed to determine this movement. This is the challenge put forward in this research and generates two research questions:

- What design tools can designers use to determine speed and route of travel within a spiral?
- What type of recycled value is being used to determine the direction of travel?

These two questions will be addressed in the following two chapters (Chapter 7, page 151 and Chapter 8, page 193). First chapter 7 will explore in detail the findings from Practice 4 in which blending is highlighted as a design tool to re-value our resources at the end of life. Second, in Chapter 8, sorting is established as the process for which recycling value is determined. The insights from Practice 7 are drawn upon, in which it is concluded that sorting systems should be mapped and analysed. This is in order to combine blending as a design strategy for specific sorting grades as a method to cascade up and down in the spiral. These ideas are brought together in the emerging Design for Recycling Knitwear framework (Chapter 9, page 211) which aims to address new ways to Design for Recycling and Longevity simultaneously.

6.6 SUMMARY

In the context of the circular economy the focus is placed on continuously increasing the quality and value of materials and products. Therefore, cascading, which is often interchangeably used for the term down-cycling, is critiqued as an approach. The chapter argues that downcycling, particularly in the context of re-use, has been historically encouraged. However, it is only downcycling for recycling that has negative connotations. This is often due to inappropriate use of materials for products after recycling, paired with the speed of which materials flow straight down to the lowest value. It is concluded that to combine both cascading and the circular economy, that our resources need to spiral both up and down through product lives. This could be achieved through the design of appropriate cascading choices and is visualised as a spiralling cascade. The chapter concludes with two challenges to be addressed in the research going forward. First, what tools should be established for the designer to affect the movement of resources within the spiral and second what type of value is being prescribed to determine this movement.

PRACTICE 4

AIM

To explore design for 'repeated cyclability' approaches for end-of-use textiles.

In the earlier stages of this research the inclusion of recycled fibres (Design from Recycling) was prioritised over ensuring their onward recyclability (Practice 0, 1 and 2). In Practice 4 'repeated cyclability' was explored through the creation and facilitation of a series of three workshops. The participants in these workshops, both students and industry professionals, were given a garment composed of two or more fibre types. They were instructed to redesign it for a specific end-of-use process, such as re-manufacture, mechanical or chemical recycling. For example, if the participants were given a wool blend knitted jumper, they might choose to re-design it in 100% wool for a mechanical recycling system. This was followed by a visual 'storytelling' exercise in which the participants were asked to use their re-designed garment to visually explain how it would cycle repetitively across three product lives (Figure 61).

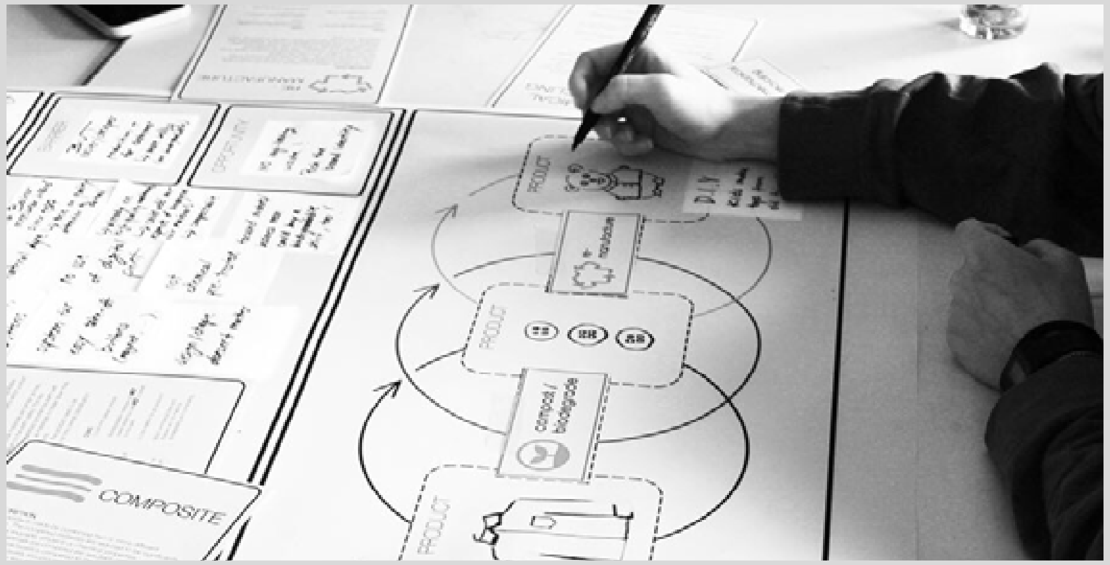


Figure 61. Workshop participant working on their 'story'.

The story boards created included two different end-of-use options. This was to maximise the participants' thinking and avoid the same product appearing multiple times. It was understood later that the workshop had been designed to consider both product cascade and cascades for resources. Ultimately, three designs would be produced. Firstly a starting design, which would go through an end-of-use process resulting in a new second design. This would then enter a second end-of-use process to complete the story with a final product design. This method of story boarding enabled the participants to understand the impacts of their design decisions for a cascade.

Figure 62. Storyboard from a workshop 1 illustrating the journey from jumper to mask to yarn

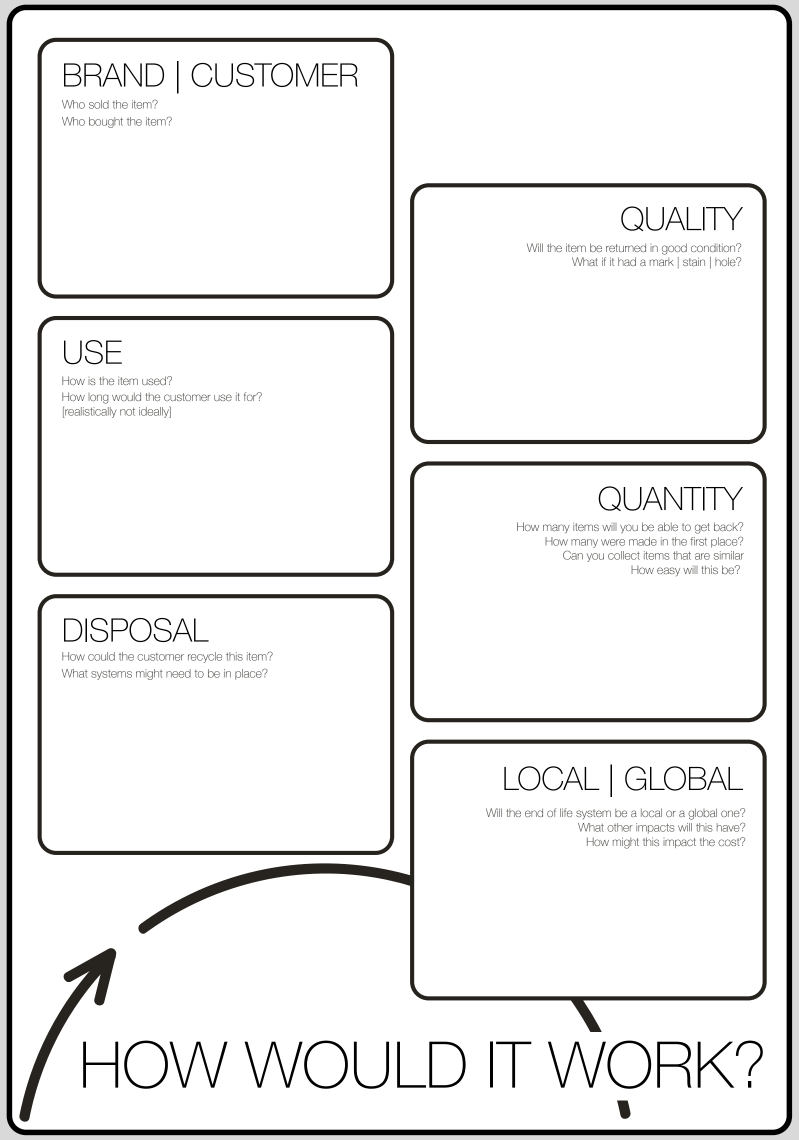
The participants quickly established that designing difficult to reprocess elements or features would be more challenging for the next design phase. In the course of the storytelling task participants regularly moved back and forth between the three product designs adapting and changing elements to ease reprocessing later on.

Although they found it difficult at first to adapt their designs to meet end-of-use requirements, the participants soon began to rise to the challenge. In Workshop 2 for instance, one group, faced with the difficulty of mechanically recycling multi-coloured garments, created a two-coloured design using blue and red which could be recycled as a blend to produce a purple fibre. Rather than considering this a hindrance, here blending was being exploited as a design tool for the longevity of materials.

The participants in Workshop 3 started to consider and combine chemical and mechanical processes in parallel. At the first stage of the storyboard, they designed two separate garments, one polyester and the other cotton, that would flow into chemical and mechanical recycling processes respectively. The participants then designed a new polyester/cotton garment by specifying that the fibres should blend together. This resulted not only in a more durable product but one that could flow into chemical recycling processes designed specifically for the recapture of poly/cotton. This workshop highlighted how blending could be exploited for onward cyclability.

Having the opportunity to run this workshop on three occasions with different participants led to a better understanding of the aims of the PhD research. In the first iteration, the workshop ended once the story board had been completed. While the ideas were creative, many of the suggestions were very visionary and future bound. This sort of thinking was encouraged but for the next iterations in Workshops 2 and 3 a balance between the 'big' ideas and solutions for our current industry was sought. This came in the form of a question sheet 'How would it work?' (Figure 63 and Appendix 14.6 page 389) which was introduced near the end of the session. The first set of questions asked the participants what happens to their garment during its lifetime and the second set of questions focused on the value of the garments as they entered the recycling system.

The three workshops proved to have vital role in the research process by creating space for the researcher to identify opportunities and barriers relating to repeated cyclability. In particular, the 'How would it work?' question sheet identified the connection between how garments are used and disposed of during their lifetime and the value they hold within the recycling system. The participants' creative ideas and responses highlighted the importance of the designer in creating resource value in recycling. The workshops helped the researcher identify how blending as a design tool could generate value in the recycling process, and it was only later fully understood that these workshops had been exploring a design for cascading approach.



BRAND | CUSTOMER
Who sold the item?
Who bought the item?

USE
How is the item used?
How long would the customer use it for?
[realistically not ideally]

DISPOSAL
How could the customer recycle this item?
What systems might need to be in place?

QUALITY
Will the item be returned in good condition?
What if it had a mark | stain | hole?

QUANTITY
How many items will you be able to get back?
How many were made in the first place?
Can you collect items that are similar
How easy will this be?

LOCAL | GLOBAL
Will the end of life system be a local or a global one?
What other impacts will this have?
How might this impact the cost?

HOW WOULD IT WORK?

Figure 63. How would it work? worksheet used in the workshop

ACHIEVED AIM

The aim of the practice to explore repeated recyclability was achieved through three workshops.

INSIGHT

Practice 4 generated an understanding of the opportunities for Design for Cascading. In particular, the workshops highlighted how the designer could add value at the recycling stage, and how blending could be used as a design tool to achieve this.

7 DESIGN FOR RECYCLING BLENDS

This chapter provides an outline of the historical and current context of blending. The reasons why we blend and the challenges of blending for recycling are explored. Furthermore, a review of the limited literature combining textile blending and recycling is presented, in which the tensions between longevity/functionality and recyclability is emphasised. The chapter investigates the overlapping role of the engineer and the designer for recyclability and how a bridge between the technical information regarding blending and design needs to be created. The chapter concludes by providing blending levels for designers and how these aid the ratios required for the Design for Recycling challenges specific to this research.

7.1 BROKEN BUTTERFLY WINGS

Blending has been defined by Sinclair (2014:162) as "the bringing together of fibres of different types". Sinclair also distinguishes between mixing of the same fibre types, but here blending will be used as an all-encompassing term. The practice of blending different materials, Hatch reveals, can be traced back as early as 150 B.C. when cotton and flax yarns would be woven together to form a blended material (Hatch, 1993). Blending in this way was used from the 16th until 19th Centuries often as a method to reduce costs. Blended yarns were not introduced until 1963. Since then, designers and manufacturers have found numerous creative ways to combine materials.

More recently, with the rise of cradle-to-cradle principles, blending has been demonised as 'monstrous hybrids' used to create 'Frankenstein products'. This refers specifically to the blending of technical and biological materials that cannot be salvaged at the end-of-use (Braungart and McDonough, 2002). Famously, the EMF (2013) circular economy model, commonly known as the 'butterfly' with two wing-like sides, follows cradle-to-cradle thinking with biological and technical flows. In the context of textiles this would mean natural and synthetic materials should never be combined. This has given rise to the two main Design for Recycling principles: mono-materiality and disassembly (discussed in Chapter 4.1, page 95). In our current linear system, which wastes rather than circulates materials, the butterfly wings are broken.

However, applying theoretical principles to real world situations is often more complex than it may seem. Reay, McCool and Withell (2011) explore this issue in relation to cradle-to-cradle theory by interviewing key scientific researchers on the topic. Concerns were raised that "while the ideas of biological and technical nutrient cycles were generally viewed as being interesting, some participants argued that these approaches might not always be possible, or practical" (ibid: 38). This is supported by Bakker et al. (2010) who suggest that a cradle-to-cradle approach in industry is helpful but shouldn't be utilised alone. In one case study they used complementary approaches considering both Life-Cycle Analysis (LCA) and cradle-to-cradle values. In doing so they designed a polyester and cotton blended polo shirt which could be chemically recycled. As Bakker et al. (2010:12) warn, cradle-to-cradle "seems to induce dogmatism", arguing that the bigger picture should therefore be considered. Victor Papanek (2019) takes the view that designers in the real-world lack social engagement, and as a result they only consider a very small proportion of the real problem they are attempting to solve. Therefore, in the context of this research, unpacking the reasons why we blend and the challenge this poses for textile recycling, is vital.

7.2. WHY DO WE BLEND?

Together Gulich (2006) and Payne (2015) suggest that textiles are designed for a number of reasons such as functionality, appearance and cost. The designer's role is one that attends to these aspects through specification of materials for products (Gulich, 2006:27). Sinclair highlights that in order to create a mix of properties, different blends of fibres can be engineered to suit the final use. The five reasons she provides for the blending of different fibres are shown in Table 10. These five reasons can be reduced to three criteria of appearance, functionality and cost. For example, a fibre is combined to improve the function of a weaker attribute or to enhance efficiency of the process which often helps to reduce cost. These reasons for blending have been explored in more detail in Practice 5 (page 153) in which blending to create yarns using recycled fibres rather than virgin ones was explored.

Table 10. Reasons to blend. Adapted from Sinclair (2014:4)

FUNCTIONALITY	To compensate for weaker attributes or properties of one type of fibre
	To improve the performance of the resulting yarn or fabric
APPEARENCE	To improve or provide a different appearance
COST	To improve the efficiency of processing, especially of spinning, weaving and knitting
	To reduce costs

PRACTICE 5

AIM

To establish what type of blends could work effectively with recycled acrylic-mix fibre.

Practice 5 was formed of multiple small experiments in collaboration with an engineer/technician at a yarn spinning facility in the UK. After an initial visit to the factory a testing session was arranged to take place across a single afternoon. The recycled fibre, left over from Practice 0, was used to explore blending decisions for recycled materials.

The session started with a little uncertainty due to a lack of a design brief. The testing session had been set up by the researcher to be open and flexible and avoid restricting ideas and was only limited by the materials available in the room. First, each material type available for blending was assessed leading to questions regarding hand feel, properties and cost.

Without a concrete brief the conversation turned towards Company's own preferences for blending and a small range of the company's core yarns were examined. It was highlighted that each yarn had been blended towards a specific end use (interiors). Normally, this centred around how the material would perform in its various applications.

The researcher, taking the role of designer, was focused on the aesthetics and hand feel of the blends to be created. She was particularly interested in the use of unusual material combinations such as the company's wool and flax blend. A discussion followed and it was established that wool was used often in blends for its fire-retardant properties. If blended together with flax the resulting material had greater fire-retardancy then either of the individual materials on their own. However, the production of this yarn was tricky. For the first iteration of this commercial blend, a very harsh flax fibre was used. This caused problems in the manufacture and for a time it looked as though it would have to be dropped from the range due to its uneconomical processing. However, a softer version was sourced and was now used in the yarns to great effect. This inspired the testing which followed.

For the tests, each blend composition was calculated using a small set of accurate scales. This meant any successful combinations could be repeated. The use of coloured fibre for the blends was suggested by the engineer as a method to visually analyse how the fibres appeared in the finished yarns. For example, deciphering how evenly the fibre was distributed and what texture it created. This would be harder to see if the blend was all the same colour.

Three sample blends were used for the test:

1. 70% grey acrylic-mix fibre / 30% Yellow Flax
2. 70% grey acrylic-mix fibre / 25% white wool / 5% Yellow Flax
3. 50% grey acrylic-mix fibre / 45% white wool / 5% white polypropene

The first combination was between the recycled acrylic-mix fibre and flax. The researcher wanted to incorporate as much recycled fibre into the blend as possible and as 70% had been used during Practice 0, this was replicated in this first test. In addition, using a high recycled content would also reduce the cost. A yellow-coloured flax was selected to contrast with the grey recycled fibre. These were carded three times, combing the fibres and blending them into a 'pad' ready to spin.

The first yarn, after blending, was tricky to spin. It was concluded that the combination of the challenging flax and the shorter recycled fibres might make manufacture difficult. However, the flax's wiry texture against the softer acrylic produced a pleasing visual result (Figure 66).

The second test was adapted to make the spinning process easier. The same 70% of recycled content was used but the flax fibre was reduced to 5%, replacing the difference with wool. It was still difficult to spin, but was easier than Yarn 1 and the result was significantly softer (Figure 67).

The final test reduced the recycled content to 50%. The flax was removed completely and the wool content was increased to 45%. The final 5% was man-made polypropylene (similar to polyester). This, like some of the company's own blends, was added to strengthen the yarn and would be vital it was to be used

Figure 64. Weighing the fibres to ensure the correct composition had been created.

Figure 65. Test 1: three iterations using the test carding machining to blend the fibres ready for mock spinning

Figure 66. Test 1 - blend pad, singles yarn and double ply yarn (right to left)

Figure 67. Test 2 - blend pad and double ply yarn

Figure 68. Test 3 - blend pad, singles yarn, double ply yarn

for the warp in woven fabric. However, without a specific design brief no end use application had been decided. Therefore, this 5% content was incorporated to see if this made any dramatic effect to the aesthetics of the yarn. Yarn 3 was the easiest fibre to spin and resulted in a lightly textured and strong yarn. However, what had been gained by strength was lost in hand feel (Figure 68).

All three tests used a mock spinning technique done by hand. This resulted in a yarn that was not wholly representative of production. For example, Yarn 3 visually was loftier and more uneven that a commercially manufactured yarn might have been.

These three experiments were conducted early in the PhD research and therefore did not consider onward recyclability. However, keeping a singular focus on Design from Recycling created the space to understand how blending for a commercial product was conducted alongside the added challenge of using recycled fibres.

ACHIEVED AIM

The aim of Practice 5 was achieved by testing three blend combinations with recycled acrylic-mix fibre and establishing that the blend design needed to be specific to the end product.

INSIGHT

Practice 5 developed an understanding of the different performance, aesthetic/hand-feel and cost implications of selecting a fibre blend and the effect recycled fibre has on a blend.

7.3 THE CHALLENGE OF BLENDS FOR RECYCLING

One of the greatest challenges facing the post-consumer textile recycling industry is the increasing use of blends in our clothing (Cupit, 1996; Elander and Ljungkvist, 2016). This problem is highlighted in two studies, one by Ward, Hewitt and Russell (2013) and the other by the Dutch Clothing Mountain (2017). They both demonstrate that a third of their respective samples of post-consumer textiles were made up of more than one fibre type. While mono-fibre textiles still occupy the majority of all discarded textiles, it is the blends within the unwearable fractions that are cause for concern. These fall into the lowest value recycling grades typically used for non-woven materials and include automotive materials, carpet underlays, and insulation (EcoTLC, 2019). A further study by the Fibersort project (2018b:6) has explored this unwearable segment in more detail. Of their sample, 36% of the clothing was deemed unwearable and of this a quarter were made up of blended textiles of two or three fibre types. This highlights the size of the problem of blends within the unwearable recycling grades.

7.3.1 CHALLENGES OF FIBRE TYPE

As it has been highlighted in chapter 3 that the mechanical recycling system and its machinery has developed around mono-material inputs. Blends are seen as contaminants to these mono-material driven processes. While it is possible for the machinery to pull/shred blended textiles back to fibre the main problem is returning these recycled fibres to textiles again.

Langley, Kim and Lewis (2000) demonstrate this point by successfully recycling blended jersey textile for sportswear, comprised of 43% cotton/43% polyester/14% Lycra, back to fibrous form. Relevant to this study was the inclusion of Lycra (commonly known as elastane or spandex) which is used widely in the textile industry for its stretchy quality aiding the fit of garments. It is generally considered the worst contaminant for recycling as it decreases the quality of the resulting fibre (Fibersort, 2018b). It was commonly thought the presence of large percentages of elastane could not be recycled. However, in their experiment with this material Langley, Kim and Lewis (2000) reported that it could be easily pulled/shredded back to fibre. The problem lay in transforming the recycled fibre into a yarn or a non-woven material. They concluded that the fibre was best suited for amorphous materials such as flocking. This is used for applications such as insulation that require no additional processing after recycling.

While we can see that some blends are fatal in the mechanical conversion from waste into yarn, this does not apply to all fibre types. This is clearly evident across the shoddy industry in India in which yarns are created from textile blends such a wool and acrylic (Gupta and Saggu, 2015). These yarns, when designed well, can be utilised across several different product applications. This has been explored within Gupta's (2014) PhD thesis in which a number of shoddy yarns made up of different combinations of wool/acrylic/polyester and other fibres were designed into a variety of interior and accessories for the Indian market. A sub-sample of sixty women were chosen by Gupta to assess consumer acceptability. It should be pointed out that these yarns were not created for the high-value clothing application which are demanded for a circular economy. However, the results of the sixty respondents suggested the "shoddy yarn was found to be economically utilised and has potential use for developing different textile products" (Gupta, 2014:90). While Gupta's research did not explore the design process specifically, it does suggest the designer has an important role to play in the process of recycling blended materials.

7.4 RECYCLED BLENDING

Blending is a corner stone of the textile recycling industry, one that is littered with impure feedstocks. Due to the majority of wastes being contaminated to some degree, blending is most commonly used by the industry as a method to control material composition. Norris (2012a) illustrates this by describing the procedures used in the wool recycling industry in India. As she writes, "In order to increase the wool content of a batch to complete a particular order specifying for example 75 per cent wool, factory managers have to buy in bales of wool-rich rags to mix with existing stocks" (Norris, 2012a:395).

Many of the reasons why blending is used in the recycling industry are similar to those for blending virgin materials. However, there are some approaches that are specific to the recycling field. The blending categories, described below, have been established through a combination of literature, field practice research in Prato, Italy (Practice 1, page 79 and Appendix 14.8.1, page 405) as well as a visit to a now closed shoddy recycling business Henry Day and Sons Ltd (Practice 6, overleaf).

PRACTICE 6

AIM

To understand how textile recycling occurred historically.

A field visit was taken to the now closed shoddy recycling business Henry Day and Sons Ltd in West Yorkshire. Until the company ceased trading in 2000, they mostly processed wool fibres. They also recycled mixed synthetics from knitted garments which they supplied to various manufacturers in large quantities. At the time of the visit, all the machinery had long been sold off and much of the warehouse space was being leased for rental income. Charles Day, descendent and owner of Henry Day & Sons, provided a 'show and tell' of shoddy materials from the remaining archive in one of the back rooms.

As each recycled fibre sample was taken out of its box and discussed, a fuller picture developed of the different types of products the company had been commissioned to produce. Much of the discussion centred around why and how sorting and blending methods were used and Charles explained that all decisions were dependent on the requirements of the end product. Many of these would not be directly applicable today. For each product, Charles pointed out, there would be a brief which in turn translated into a different combination of wastes and colours to complete the order.

A noteworthy example of how the company combined different types of waste was their development of woollen cloth for the overcoats and jackets of the Royal Ulster Constabulary (the police force in Northern Ireland from 1922-2001). The cloth for these garments was made with a mixture of recycled woollen and worsted spun woven textiles that produced very short mungo fibres. These, Charles explained, would be combined by the yarn spinner with longer virgin wool to create the new yarn. The virgin wool would be dyed so that it would blend with the recycled fibre to form the exact Royal Ulster Constabulary shade. If the mungo was too dark

Figure 69. Archived boxes with samples of different recycled fibre blends

the virgin wool could be dyed lighter and vice versa. The short mungo fibres, he highlighted, were especially useful for the milling process to convert the woven fabric into a dense felt required for the product. Henry Day & Sons would then exclusively buy back the uniforms after use to recycle them again and again.

In another example, a recycled fibre was labelled ‘NBC (National Bus Company), double carded 1975’. Charles confirmed that this sample may have been double carded on the sampling machine, but this would not have been the case for bulk production. The fibre composition was 55% Shoddy (wool), 25% Dyed Wool (virgin) and 10% Brush (worsted waste, long fibres). The remaining 10% ‘Harwood’ was sourced from a local company by that name that produced yarn and woven materials. Although Charles was unable to confirm its specific type of pre-consumer waste, the sample illustrated how recycled and virgin, pre- and post-consumer, knitted and woven, long and short fibres had been specifically designed to create the final blend for the product.

Samples of each recycled blend combination were gifted to the researcher to analyse after the visit. From this she was able to better understand the four ways to blend in recycling: virgin and recycled, colour, structure and pre- and post-consumer wastes.

ACHIEVED AIM

The aim of Practice 6 was achieved by discussing and analysing archival fibre samples at Henry Day & Sons to establish the different methods used historically when recycling.

INSIGHT

Practice 6 established four categories of blending during the production of recycled materials. It was also highlighted that blending correlated directly with the requirements of the final materials.

7.4.1 VIRGIN AND RECYCLED FIBRE

It is well known that longer virgin fibres outperform the shorter recycled ones that have been ripped from the cloth in the recycling process (Merati and Okamura, 2004). The addition of virgin fibre is often required to aid the movement of the recycled fibres as they travel through yarn spinning machinery. Sakthivel et al. (2010) estimate that in the shoddy industry this addition is about 15%. However, virgin fibres are not only blended with recycled ones for this reason. Blending might occur for all the same reasons outlined for virgin production (functionality, appearance and cost). For example, recycled fibre of any type is often blended with polyester chosen for its strength and economic price point.

On the flip side, rather than virgin fibres supporting the recycled content, the inverse is also possible. Smaller amounts of recycled fibres might be blended with virgin to save on costs. For example, seam waste from the cleaning process of cashmere jumpers could be added to a virgin batch to achieve a 10 or 20% cashmere blend (Hall, 2018:11, Appendix 14.8.1, page 405 & Practice 1, page 79). In this example, the addition of recycled materials is used to promote the luxury qualities of cashmere at a low price point.

7.4.2 COLOUR

Sorting waste by colour is one of the most common methods used in the industry. This eliminates the need to strip the colour and dye from the material. Any recycled fibre colour can either be used as its own colour or be blended with others to create a specific shade. However, as Norris (2005) points out, in the shoddy industry choice of colour is determined by what happens to be available. If a colour is fashionable one year the industry may struggle to provide the fibres needed to create the exact colour blend. Conversely, when that trend comes to an end, recyclers may end up with too much of a given colour.

If the shade cannot be obtained by the available recycled fibres, an overdyeing method can be used. This can either be done to a whole batch or to one component of a blend (Hall, 2018). For example, a light green fibre could be overdyed to create a darker green shade. This, in turn, might be used with a variety of other colours to form an exact shade. Overdyeing recycled fibres, particularly those which are impure, can be problematic as different fibre types need to be dyed in different ways. As a result, this is not necessarily the easiest method to produce a specific colour. Rather than using overdyed recycled fibres, more sustainably dyed virgin fibres can be added to fulfil the requirements of the colour blend (ECAP, 2019e). This combined approach (blending colour and virgin fibre) is commonplace within the recycling industry, one that has been developed out of complex sources of waste material.

7.4.3 STRUCTURE

Historically the wool recycling industry grouped materials according to their structure. The term 'shoddy' is generally used to describe the longer quality fibres usually extracted from knitwear. Mungo, in contrast, is so named for the shorter fibres usually from woven textiles (Day, 2016c). This is still the approach used in today's mechanical recycling industry (Hall, 2018). While the main focus of sorting technology research has concentrated on fibre type, the importance of sorting by structure has started to be realised (Fibersort, 2020a). The different fibre lengths produced from the two textile structures can be combined for the advantage of the spinner. For example, blending shorter, lower quality, cheaper fibres with the longer, more expensive ones can help control the quality and economic value of the final material. Alternatively, shorter fibre can be included to benefit the performance of a later production stage such as milling of wool fabrics to achieve a controlled felted finish. This process, as Pailthorpe and Wood (2012) explain, is made easier when done with shorter fibres.

7.4.4 WASTE TYPES

The blending of different types of waste, pre- and post-consumer, is the most common approach used throughout the shoddy industry. Pre-consumer is material diverted from waste in the manufacturing process (ISO, 2016). This covers a range of materials, but is generally sourced in more consistent fibre type, colour and structure than their post-consumer counterparts (Fontell and Heikkilä, 2017). While the details of a pre-consumer system can be complex (Runnel et al., 2017), this approach is made easier when a recycling industry is located within an area of virgin production. For example, the wool recycling industry in Italy is located within Prato which also has virgin wool textile production. While the recyclers import post-consumer waste, they also have easy access to the local industry waste (Roos et al., 2019b). As with all other blending, this ultimately occurs in order to balance the requirements of the final material.

7.5 BLENDING AND RECYCLING

Understanding the complexity of how we combine textiles, in the context of recycling, has been studied in detail by Gulich (2006a). In his book chapter 'Designing textile products that are easy to recycle' Gulich considers the tension between simplifying blends for recyclability and blending for functional performance. Based in the field of engineering, Gulich's model is derived from working with technical textiles in which he maps blends across five levels.

The first level is a 'single-material system'. This is a mono-material which does not require disassembly and is easy to recycle. However, this first stage provides the least amount of functionality. Gradually blending complexity and functionality are added across the five stages reaching the most complex level. This final blend cannot be disassembled or recycled but has the greatest function. These complex textiles he concludes can only be designed to be re-used or disposed.

Gulich's research highlights that there is a balance to be found between designing for function and recyclability which, he reasons, is underpinned by the economics of processing. This is supported by the findings from the ECAP (2019b) 'Fibre to Fibre' project. One of the trade-offs they found was the balance between creating a strong blended yarn that would be detrimental to recycling, or a pure but weaker recyclable one. In addition, ECAP emphasised the balance between aesthetics and technical design for recyclability. Design for Recycling often enforces a minimalist approach which, they point out, is not to everyone's taste. If combining materials was banned this might stunt creativity which is argued, by Forst (2020), to be an important part of the textile designer's remit. ECAP (2019b) concluded that "in the end, whether or not the product is technically recyclable, it still has to be appealing to customers". Therefore, the emphasis is placed on the designers having "important decision[s] to make".

DESIGN FOR LONGEVITY VS RECYCLABILITY OF BLENDS

Often the trade-offs between recyclability and other benefits such as durability can be difficult to balance in circular design (Elander and Ljungkvist, 2016:38). We can see from Gulich's work that functionality can be fatal for the recycling process. Although this is cause for concern, Beton et al (2014) point out that in some cases design decisions for longevity, such as blending, can have lower environmental impacts and even environment improvement potential. For example, incorporating a more durable component might extend the useful life of a fragile fibre. The problem is summarised by Tanttu, Kohtala and Niinimäki (2016) who deduce that the two approaches, longevity and recyclability, compete with each other. They further suggest a choice between the two may have to be made. However, they do point out that, even when designing for longevity the product will ultimately still need to be recycled. The challenge, therefore, offered by Tanttu, Kohtala and Niinimäki is finding a way to reconcile both these approaches. It is this gap in knowledge that this research will start to fill using cascading theory.

PRACTICE 7

AIM

To understand the implications of repetitive blending.

Practice 7 was conducted in collaboration with a second UK spinning company. At an initial visit to the facility, it was agreed that the experiment would explore repetitive blending of recycled materials. This would be done by blending virgin fibres with recycled ones and carding them into a 'pad' ready for spinning. At the next stage, part of the pad would act as the new recycled content to be blended with the same new virgin fibre. By doing this, the researcher would be able to understand the implications of repetitively blending recycled materials with the same virgin fibres.

While the plan gave the experiment a direction, the fibre type and percentages were left open-ended. This led to a discussion with the engineer regarding the most appropriate fibres to be used. Drawing on findings in Practice 1 in Prato Italy where companies used either polyester or nylon as a blending agent, nylon was selected. In addition, virgin wool was added to create texture and enhance the recycled acrylic-mix fibre (left over from Practice 0) which was soft and lofty. The resulting blend was:

50% grey acrylic-mix fibre / 30% blue wool / 20% white nylon

Once again colour was used as a visualisation tool. The recycled acrylic-mix fibre was grey, the virgin wool was blue, and the nylon was white. The first pad was produced and mock-recycled by roughly tearing it apart by hand. It was then re-blended with another 30% wool /20% nylon. The entire process was then repeated, producing three blend compositions:

Figure 71. Carding the fibres to form a pad

Figure 70. Blend 1 (recycled acrylic-mix fibre, wool and nylon) being re-blended with more wool (30%) and nylon (20%)

Blend 1: 50% grey acrylic-mix fibre / 30% blue wool / 20% white nylon

Blend 2: 25% grey acrylic-mix fibre / 45% blue wool / 30% white nylon

Blend 3: 12.5% grey acrylic-mix fibre / 52.5% blue wool / 35% white nylon

As one would expect, the ratio of wool and nylon increased across the three blends. This was reflected in the blend changing from a grey-blue to a brighter blue tone. The final stage was to spin Blend 3 into a yarn. This was the largest fibre pad which had not split for re-blending. As expected, it spun well due the high virgin content and although very strong, it had a synthetic 'squeaky' hand-feel due to the high percentage of nylon.

Reflection on the experiment drew attention to the undesigned nature of the blends themselves. For example, the designer-researcher had given little thought to the choice in using nylon for onward recyclability and she had not considered if this would help or hinder the mechanical recycling process. In addition, the fibres were not processed into yarns or materials that occur during the recycling process. Therefore, this could never be truly reflective of the process.

With the aid of the 'How it Would Work?' question sheet in Practice 4 (page 147), the researcher noted that the three blends designed during Practice 7 would not flow into specific recycling grades for acrylic/nylon/wool. In reality, the blends would flow into

Figure 72. Blending recycled acrylic-mix fibre (grey) with wool (blue) and nylon (white)

Figure 73. Blend 1, 2 and 3 (top to bottom)

Figure 74. Weighting the fibres to ensure the correct percentages of fibre is used

the wool recycling system and their value would be assessed on the amount of wool present. Blend 1 would hold low value because of its low wool and high acrylic content. In contrast, Blend 3 would hold a higher value because of its increased wool composition. This highlighted the specific need to map and analyse the sorting systems for recycled textiles in order for designers to appropriately design blends that could help but not hinder their recyclability.

The second phase of the testing focused on spinning the fibres into yarns. For this a number of alternative colours and percentages of recycled content were designed. First, the pad from Blend 3 was spun into the first yarn. Next, a repeat of Blend 1 was created in two new colour ways, purple and grey, to establish its potential as a yarn in bright and subtle shades. Finally, waste wool, rather than virgin wool, from the facilities production process was spun to test a higher percentage of recycled content. The final four yarns were as follows:

Yarn A: 12.5% grey acrylic-mix fibre / 52.5% blue wool / 35% white nylon (Blend 3)

Yarn B: 50% grey acrylic-mix fibre / 30% purple wool / 20% white nylon

Yarn C: 50% grey acrylic-mix fibre / 30% grey wool / 20% white nylon

Yarn D: 50% grey acrylic-mix fibre / 30% grey-brown waste wool / 20% white nylon

Rather than spin the yarns using a hand process, as in Practice 5, this time the test was conducted in a mock-manufacturing process. The yarns were quickly attached to various parts of larger machines to create a more realistic likeness to a commercial result (Figure 75 & Figure 76). The yarns were then washed to simulate the finishing process (Figure 77). All four yarns were produced in a fine count which could be utilised for either interiors or fashion. Yarn B (purple) illustrated the even spread of recycled fibres through the yarns. Yarn C demonstrates an evenness of colour illustrating that to the naked eye you could not tell the yarns contained recycled content when using subtle colour combinations. The engineer explained that Yarn D might be problematic in production as the waste was not generally colour sorted and therefore it might be difficult to obtain in high enough quantities.

During the experiment, discussion between the engineer and the designer-researcher went back and forth regarding the manufacturing requirements, cost implications and the aesthetics trying to be achieved. While the engineer focused on requirements for manufacture and cost, the designer-researcher was concerned on the yarn's suitability for various end markets and understanding the impact of using recycled content in the process. Both roles had a different set of priorities and the researcher highlighted this would be important to understand for the future development of recycled materials for a circular economy.

ACHIEVED AIM

The aim of Practice 7 was achieved by testing repetitive blending of recycled materials in a rudimentary way, but it was difficult to emulate the full recycling process in a small test.

INSIGHT

Practice 7 highlighted a need to map and analyse the sorting systems for recycled textiles in order for designers to appropriately design blends that could help and not hinder their recyclability.

Furthermore, the test indicated the different priorities between the designer and engineer, which would be important to understand for the future development of recycled materials for a circular economy.

Figure 75. Stage one of the blended fibres being spin into yarns

Figure 76. Stage two of the blended fibres being spin into yarns

Figure 77. The final sample yarns after washing

7.6 THE ROLE OF ENGINEER VS DESIGNER

The literature around textile blending has been highlighted by Forst (2020) as predominantly coming from a technical perspective. Traditionally, the responsibility for function or performance of a textile was given to engineers and the responsibility for costs were seen as a concern of business. Finally, the aesthetics fell into the designer's hands. However, the designer role goes beyond solely the appearance. Press and Cooper (2003) explain that the design discipline has dramatically expanded in the past few years and there is no fixed way of describing a designer's role as they bridge many different disciplines.

Specifically, the overlap between the role of designers and engineers in the creation of textiles is complex. The detailed technical properties including tensile strength, uniformity, crease recovery, shrinkage resistance, elasticity etc… are generally viewed as the responsibility of textile engineers (Sinclair, 2014). Additionally, it is the engineers or technicians who use blending of fibres to ease the process of manufacture, and this is usually considered outside of the textile or fashion designer's remit.

Toomey and Kapsali (2014) suggest that the designer is often viewed as a passive user of materials rather than an active influencer and Veelaert et al. (2016) suggest that tools available for designers to select materials for products are predominantly technical. This, Ashby and Johnson (2010) point out, is frustrating for designers as they do not have the equivalent support compared to their technical counterparts.

Toomey and Kapsali (2014) highlight that design is normally introduced at the latter stages of the innovation process created by Science, Technology, Engineering and Maths (STEM) research. This is in part because, they argue, designers are no longer being taught the technical skills in their undergraduate training. They conclude that design and STEM innovation should work together from conception through the research and experimentation stages, to the final design development. The only area omitted is the final prototype stage. This, in itself, suggests that the designer's role in practice exceeds that of the engineer.

A circular designer's role goes one step further to include the end-of-life of the product. This, Ashby and Johnson (2010) describe as design with intention. The intention, for this research, is to design for recyclability linking the selection of materials to a product's end-of-life. Beyond the selection of materials, Toomey and Kapsali suggest that the designer can take a holistic view, collaborating with technicians and innovators around the lifecycle to influence the way materials are made and used.

PRACTICE 8

AIM

To understand how acrylic textiles are recycled in the industry and what new innovations are currently happening in this area.

Unlike other field visits that took place on the factory floor, Practice 8 visited a textile recycling Company's head office. Here the company's innovative materials and product samples were discussed with one of its designers. During the visit the company's three core production processes were identified. Two of these were of particular relevance to this research; one was the recycling of mixed fibre garments for the generation of non-woven products and the other was the recycling of majority acrylic mixed fibre into yarns for garment/interior applications. The designer explained that for both processes the wool content was mostly removed at the sorting stage. The resulting fibres for both processes (mixed but predominantly acrylic) were considered to be low value. However, the company used both of these fibre types for innovation in the creation of higher value materials and products.

Usually, the mixed fibre non-woven materials would be used in traditional hidden applications. Instead, colour sorted waste was used to create non-woven materials for visible applications. The colour sorted waste was needle felted to form a textured fabric and applied to a collection of lampshades. These were displayed in the head office with great impact (Figure 79). The company had investigated other experimental non-woven processes to incorporate the shortest and most difficult to recycle fibres. While these processes trapped the fibres inhibiting further recycling, the company had concluded that this was preferable to the current alternatives of landfill or incineration.

The company's other core business was the production of recycled yarns to create blankets for the Moroccan market. During the visit all samples could be felt and touched, and the researcher found the recycled brushed acrylic blankets to be far softer than expected (Figure 78).

Figure 79. Recycled mixed fibre needle felted lamp shade in a textured light grey tone

Figure 78. Recycled Acrylic woven and brushed blanket

The development of higher value applications for the company's acrylic mixed fibre yarns was the hallmark of its innovations. The designer had conducted a variety of yarn experiments for both woven and knit applications. The composition of these was 65% acrylic/10% cotton/20% polyester/5% other fibres. 90% of this composition was recycled from the waste they collected. Virgin fibre was kept to a minimum to comply with the company's ethos of producing materials as close as possible to 100% of their own recycled content. However, because the recycled fibres produced were low quality, they required some longer fibres in order to create a usable yarn. This, the company insisted, would be no more than 10% Recycled Polyethylene terephthalate (RPET) from plastic bottles sourced externally. This formed 10% of the polyester part of the yarn. It, therefore, could be accurately described as having 100% recycled content.

However, for the knitted yarn, gains made in recycled content caused manufacturing difficulties. To capture the high percentage of shorter recycled fibres, as the designer at the company explained, the yarn had to be spun more tightly. This involved ‘trapping’ the fibres within the yarn which in turn created a harsher hand-feel. To overcome this challenge a number of different finishing processes were being explored.

This difficulty was not replicated in the woven yarn designed for an interior market, where a ‘tighter’ spin was desirable. Again, due to the high content of recycled fibre the strength of the yarn was lacking. These yarns were therefore only suitable for the weave’s weft. To combat this, the warp was offered in either virgin organic cotton or RPET. Blending in this case had thus been transferred from yarn level to a material level.

In these two examples, avoiding blending at yarn level compromised the functionality and aesthetics of the end products. For the knitted yarn, if blending could be applied at yarn level there would be no need for additional chemical treatments. For the woven material blending was not avoided it just occurred at a different stage. This led the researcher to question and further explore how designers might better understand the impacts of blending during the textile manufacturing process and how blending could be used as a tool for the recycling process.

ACHIEVED AIM

The aim was achieved through an analysis of the Company’s innovative recycled mixed fibre knitted, woven and non-woven materials and their applications.

INSIGHT

Practice 8 established two levels of blending (yarn and material) that can occur when designing a textile and how these blending design decisions impact the recycling process.

7.7 BLENDING LEVELS AND RATIO'S

For designers to understand how materials are blended, they must delve into the technical texts and translate them for their needs. This approach has been used by Forst (2020) in her PhD research by her desire to communicate the challenge of textile blends to designers. In doing this she produced a variety of 'blown-up' textile structures representing the different ways materials can be combined. However, this research was specifically aimed at understanding assembly methods of textiles to be translated into disassembly at the end-of-use. She points out that her research does not cover the causality between textile combinations and recyclability. A gap in knowledge which will be filled in this research.

Blends are formed by bringing together different fibre types, and Hatch (1993) has examined five different ways in which this can be done:

1. Self-Blend or Mixture
2. Intimate Blend
3. Combination Yarn
4. Mixture Fabric
5. Compound Fabric

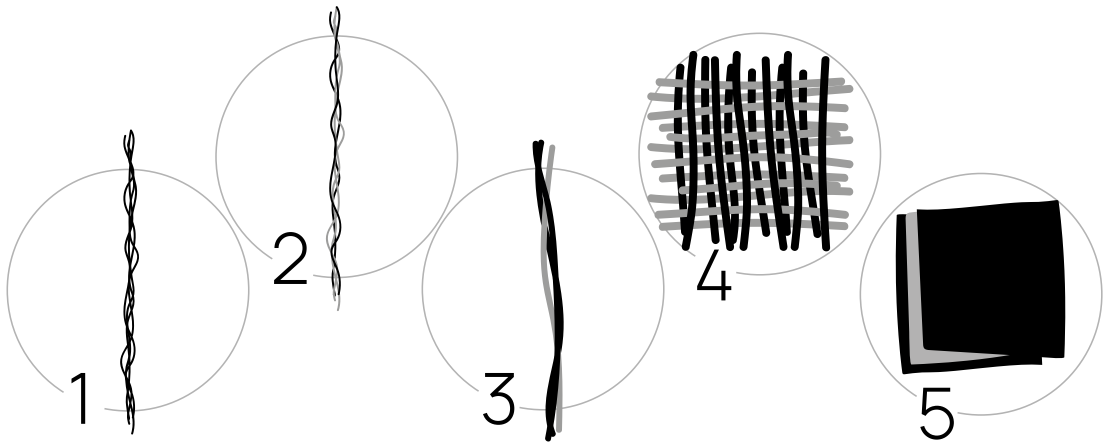


Figure 80. Five types of material combinations, Adapted from (Hatch, 1993) and (Forst, 2020:124)

The first method brings together fibres to form a yarn, either using two or more of the same species of fibre to form what is referred to as a 'self-blend' (Hatch, 1993) or a 'mixture' (Sinclair, 2014); The second blends together different fibre types to form a 'intimate blend within a yarn'. The third method of blending creates a 'combination yarn' which is achieved by the twisting together (or plying) of two different yarns (Hatch, 1993). In these first three approaches blends are created at the yarn level as confirmed during Practice 8 exploration (page 177).

The fourth blending method produces what Hatch (1993:298) calls 'a mixture fabric'; this might be created by the warp and weft in a woven textile being comprised of two different yarns. Alternatively, this might be created with the use of two differing yarns in a knitted fabric, for example when creating stripes. This form of blending at material level was also established during Practice 8 (page 177). The use of mixture fabrics might also extend to some non-woven materials such as those that are stitch bonded with a thread made from a different material, not explored by Hatch. The fifth blending approach is through the creation of a 'compound fabric' which Hatch (1993:372) describes as being "composed of two or more layers of fabric [or another component] …. held together by stitching, fusing, adhesive" etc… generating a blend at a material level.

Forst (2020) adds a sixth method of blending to Hatch's typology, which involves combining textile materials during the construction of products. Such combinations of materials, she suggests, could occur when stitching a mono-material garment together with a different fibre sewing thread. This would be classified as blending at a product level. Relevant to recycling, this has been extended to include the contaminants that are removed in the cleaning stages such as care labels and buttons made of different materials to the garment.

This form of blending is not restricted to only virgin materials, the recycling industry also blends across the same levels. Norris (2012c) provides an example of this in the production of shoddy blankets. If a recycled yarn, she explains, is specified to have 50% recycled wool it will be blended with cheaper fibres such as recycled acrylic knits (yarn level blending). When it is woven, the warp will made from stronger synthetic materials to hold the fragile shoddy yarns together (material level blending).

While blending thus far has been concerned with combining different fibre types, blending can also occur with colour. The mechanical recycling industry specifically prefers pure colours as these are carried forward into the products' next life (Norris, 2012c). This can also be utilised for chemical recycling (Smirnova, 2017), such as the 0° Shirt master case produced in the Trash2Cash project (Trash-2-Cash, 2018). As with fibre blending, colour blending occurs across the three levels: yarn, material and product. At yarn level colours are brough together just as different fibre types are; either blended into a single yarn or plying the different coloured strands together. At material level, colour blending occurs when multiple different yarns are combined in one fabric, often in the form of a pattern. At product level, coloured materials are brought together to form a garment, such as sleeves that are different colours to the body. While black and grey colours in Figure 80 have been used to represent the different fibre types in the blends these also represent how two colours can be combined.

This hierarchy of blending across yarn, material and product has been illustrated in Figure 81. Inspired by both Forst and Gulich, it has been completed to show how complexity builds across the three textile processes. Mono-materiality, however, is still possible. This acts as a simple tool for designers to understand how and when blending in the design process occurs.

7.7.1 BLEND RATIOS FOR RECYCLABILITY

For recyclability, there is less concern for pinpointing precisely where blending occurs. It matters little to a recycler (unlike the designer) if blending happens at yarn, material or product stage, the blended garment is still ultimately a blend. Rather, it is the ratio of fibre types or colours in the blend that is a priority. For example, if we take a fibre type blend of 50% Wool / 50% Acrylic. For the designer, one that is concerned with Design for Recycling, it will be vital to understand how the decisions made across the blending levels affect this ratio and what this will means for the garment in the recycling system.

For example, at yarn level two fibres are blended together for cost, such as 50% wool and 50% acrylic. This is then knitted into a fabric with a stripe of equal size for aesthetic reasons, made from an 100% wool yarn. The knitted fabric is then transformed into a jumper linked together with polyester thread chosen for its strength and economic price point. The result is a blended garment with three different fibre types. Contamination here was created at both the yarn and product stages. However, the most important element is the

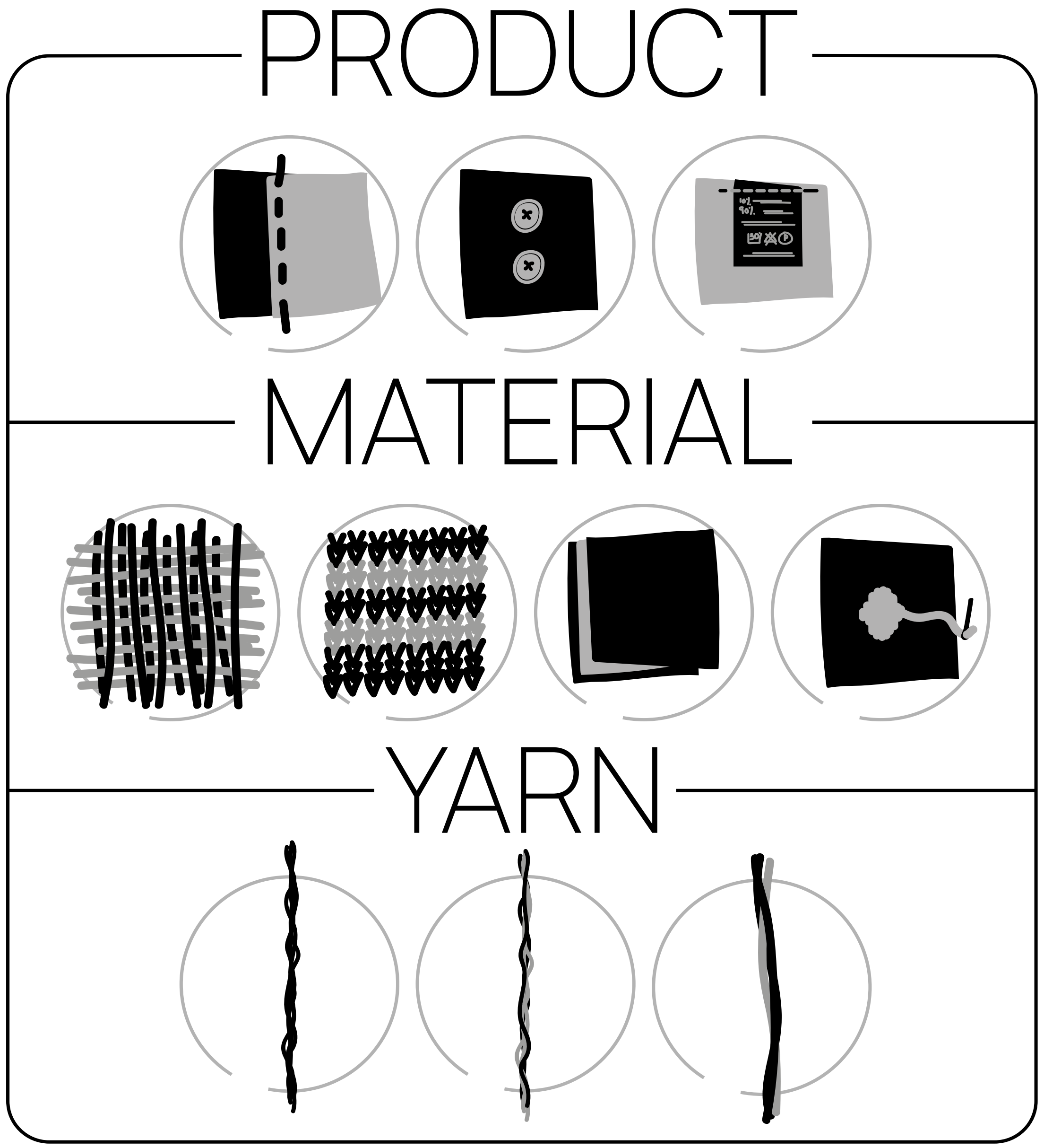


Figure 81. A simplified diagram demonstrating for designers the three levels of blending that affect recycling

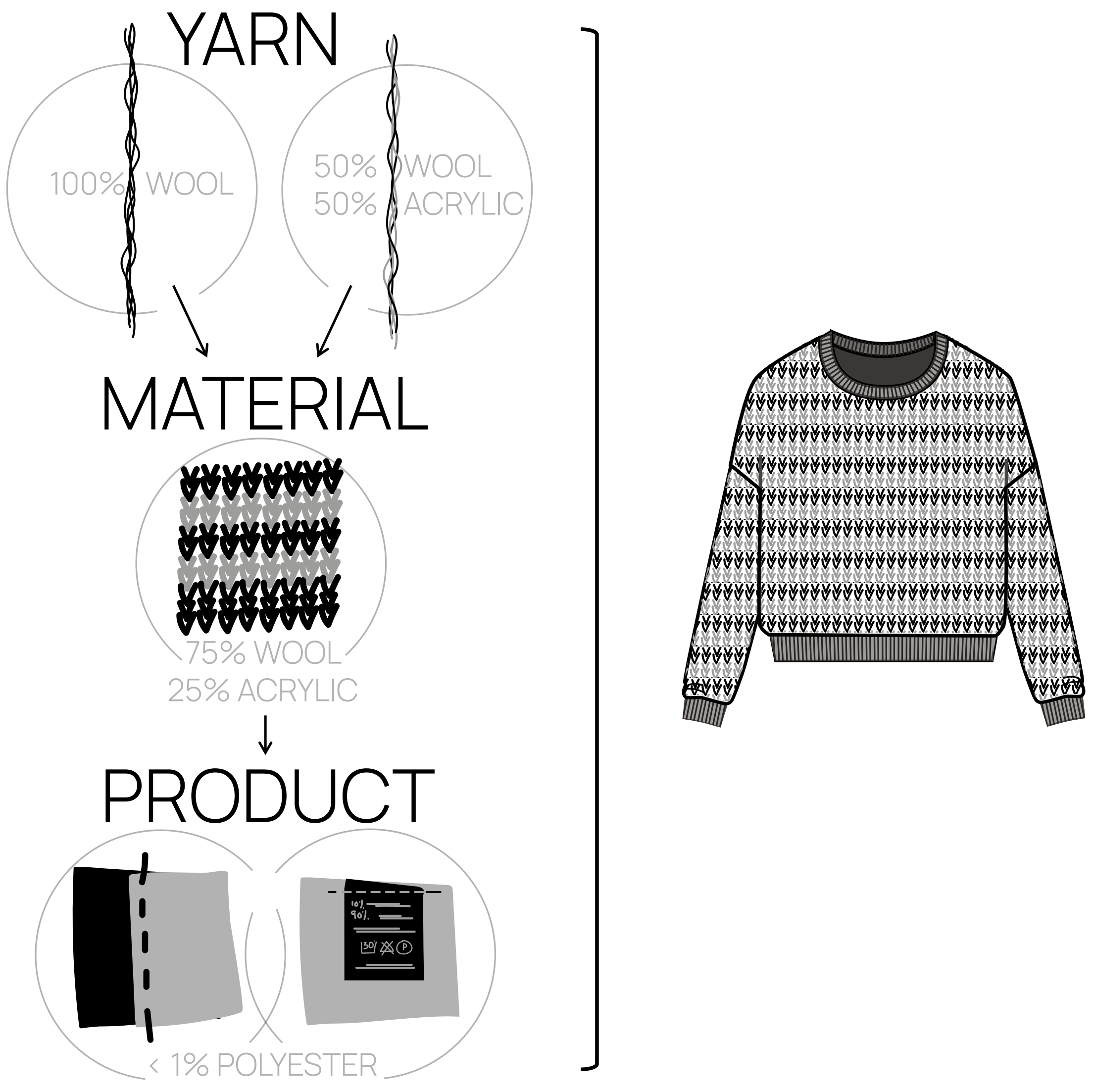


Figure 82. An example of a blending ratio increasing at material level

blending at the material stage. This has not contaminated the blend any further as the yarn was already made of both wool and acrylic. It has merely increased the ratio of wool within the blend. For the designer the choice to increase or decrease a blend ratio can happen at any level.

7.7.2 BLENDING AS A DESIGN TOOL

As demonstrated in this chapter, from a design perspective, a combined understanding of blending levels and ratios can contribute to final textile recyclability. However, a broader understanding of blending is required to provide context for the designer when making these decisions.

This chapter has highlighted the various purposes of blending during virgin production, such as to promote function, aesthetic and cost for a product. It has also been shown that during the recycling process virgin fibres, which are longer and stronger, are often blended to support shorter recycled ones. Three additional approaches to blending during the recycling process have also been outlined: blending the different length fibres produced from recycling different textile structures, blending the fibres produced from recycling different waste types (pre- and post-consumer), and blending different colours to create the desired shade. All these forms of blending are conducted to create material value.

When a designer is using blends in virgin production, blending levels and ratios can contribute to a Design for Cyclability approach. Blending generally is a vital aspect of recycled material production and is described as a 'design from recycled' approach. However, understanding blending levels and ratios for recycled production is also vital for the material's onward recyclability. Blending levels and ratios, therefore, acts as a bridge between 'Design from Recycled' and 'Design for Cyclability', to truly enable Design for Recycling.

However, in order to use these tools for Design for Recycling, the designer must engage with the specific recycling system they are designing for. For example, designing for polyester recycling would require a very different approach to that used for wool or cotton. This will be addressed in the next chapter in which sorting systems for recycling will be explored to fully understand Design for Recycling as an approach.

7.8 SUMMARY

This chapter accomplishes the objective of identifying the role of blending within virgin and recycled textile production by taking a broad look at the topic of blending and recycling. This is explored by first providing the current literature's 'demonising' of blends within the circular economy. This is juxtaposed with the reasons blending in virgin and recycled textiles still occurs. For virgin materials, blending is used for three reasons: functionality, aesthetics and cost. For recycling, blending is utilised for the same three reasons and applied across four different methods. Firstly, the combination of virgin and recycled fibre. Secondly, blending to create exacting colours. Thirdly, to combine different length fibres, such as the longer fibres generated by recycling knitted structures and the shorter fibres created from recycling woven structures. The fourth and final approach is combining different waste types, such as pre- and post-consumer textiles.

Moreover, the tensions between longevity/functionality and recyclability are emphasised and the research is positioned to move the field forward using cascading theory. The chapter continues to explore tensions between the role of engineer and designer for recycling. It is argued that the two roles should be brought together to aid progress. However, the tensions between these roles extends into the literature/technical information that is available to understand the problem of blends. The majority of this information is written and described for the context of engineering. For textile blending, this technical information has been translated by Forst (2020) into visualisations for the designer to understand. These visuals have been re-organised to provide a tool for designers to identify the levels in which blending occurs. This, by extension, aids the designer concerned with a Design for Recycling brief. It provides a tool in which to assess the impact of blend ratios for onward recyclability. The chapter concludes that the designer requires a broad understanding of blending in order to use blending as a tool for recyclability. It is highlighted that recycling systems need to be first understood and in particular the different categories in which blends enter the recycling system is vital. If this is not understood, then design decisions for blending across the levels and the ratios it creates cannot be made appropriately.

PRACTICE 9

AIM

To explore 'Design for Recycling' (from recycled and for cyclability) when designing a yarn.

Learning from the previous practice experiments, Practice 9 explored how to design both with and for recyclability. The tests conducted were split into two lines of enquiry, designing for mechanical recycling and designing for chemical recycling through blending with wool and polyester respectively. The recycled acrylic-mix fibre used in the experiment was left over from Practice 3.

This experiment started by drawing on the knowledge developed during practice 7. First, wool was selected as a blending agent since acrylic and wool are frequently combined in the textile industry and therefore are regularly mechanically recycled together. Polyester, on the other hand, is one of the most widely used textile fibres and is often used in virgin and recycling production in small quantities to provide strength. Chemical recycling processes have specifically been developed to address both pure and blended polyester materials. This, therefore, was selected as the second type of blending material.

As acrylic-mix fibres were being used as the primary fibre in blend, this would become a contaminant once it entered the chemical recycling system. In this case, as chemical recycling is such a new technology, it is unknown what would happen to these contaminants. Nonetheless, it is assumed that during the development of the technology they would be disposed of appropriately. The rationale for blending in this way was not only to ease recycling production but to investigate how to extend the life of fibres. Ultimately, Practice 9 focused on establishing the balance between designing for chemical recycling of polyester (requiring a high content of polyester), creating a functional yarn and extending the life of low-value fibres (acrylic-mix). If all these elements could be balanced this would determine if the reality of designing for onward recyclability was possible.

On the day of the test there was no polyester fibre available. In lieu, polypropylene was used as it acts in a very similar way to polyester. Learning from all the open brief approach of previous practice tests in which ideas were bounced off the engineer, in Practice 9, there was greater design direction from the start. However, it was only in Practice 10 that a full creative design brief was used. As the spinning company mainly produced textiles for interior based applications this was deemed the most appropriate design direction. Because of this, the engineer highlighted that the materials would have to comply with fire retardancy regulations if used for furniture. Viscose, known for its fire retardancy properties was thus suggested as a component of the blend. As a cellulose based material, this would be unsuitable for the polyester-specific chemical recycling technologies. However, chemical recycling of polyester and cellulose blends are currently being developed at scale (Worn Again, 2020) and were therefore considered appropriate for this design.

The engineer explained that because of its high cost this fibre was often used in small quantities. Another benefit of viscose in the blend was its soft-hand feel which counter-balanced the harsher polypropylene feel. Two yarns were tested. The compositions were as follows:

> Yarn 1: 50% white acrylic-mix fibre / 40% green polypropylene / 10% teal viscose
>
> Yarn 2: 30% white acrylic-mix fibre / 60% blue Polypropylene / 10% teal viscose

In keeping with many of the other tests, the first yarn had a 50% recycled content. For the second yarn this was reduced to 30%. The polypropylene content was adapted accordingly. Both tests created a mottled yarn with white texture running through it. This mottled effect was created by the unevenness of the recycled fibre and produced an attractive yarn and generated inspiration for fabric designs.

While Yarns 1 and 2 were designed using polyester and viscose for their chemical recyclability, the recycled acrylic fibres were included to design longevity into this low-value resource. Furthermore, although the test was conducted to design for chemical recycling at the end of use, chemical technologies would prioritise capturing polyester and cellulose. However, the acrylic would still become waste. Constituting the bare minimum in terms of resource longevity, nonetheless, one additional life is preferential to none. Given this, it was concluded that for recycled acrylic-mix fibre a mechanical wool recycling process would be more appropriate as it offered multiple onwards uses. In light of this, Yarn 3 was produced and comprised:


Figure 83. Yarn 1: blending and carding process three


Figure 86. Yarn 1: fibre choice for blending

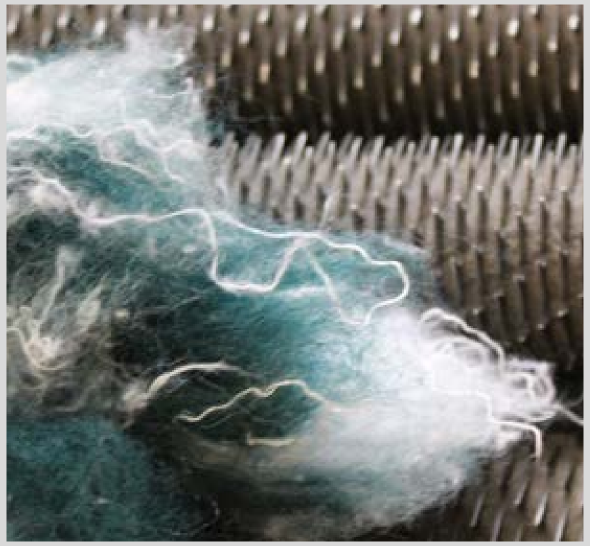


Figure 85. Yarn 1: blending and carding process two


Figure 84. Yarn 1: blending and carding process one

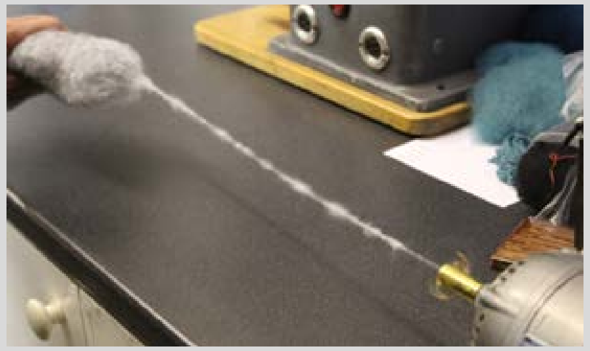


Figure 88. Yarn 3: mock spinning by hand


Figure 87. Yarn 3: carded pad

Yarn 3: 50% white acrylic-mix fibre / 30% black wool / 20% white recycled wool

This final yarn combined both recycled acrylic-mix fibre and recycled pre-consumer wool sourced from UK carpet industry. This was an extension of the experiment that established another way of increasing recycled content.

During the experiment, the focus of onward recycling was at the forefront of the researcher's mind. Based on the tacit knowledge developed in Practice 1, acrylic fibre was understood as a contaminant of the wool recycling industry and during the sorting stage the focus was solely placed on the amount of wool present. The natural assumption would be to design acrylic out of the process. The question of why this low-value material was being used was reiterated again and again by the engineers, especially in the case of Yarn 3. The researcher, in response, repeatedly stressed that problematic fibre groups such as acrylic are still present in our virgin textile systems. While it would be easy for designers to avoid using this fibre from the start, doing so does not address the issue of the waste we currently have. Solutions for longevity and appropriate use of these problematic fibres need to be found.

The resulting Yarn 3 surprised both the designer-researcher and the engineer. It had a softer hand-feel and was stronger than expected. This was attributed to the recycled acrylic-mix fibre creating balance against the slightly harsher texture of the wool. Contrasting colours (black wool against the white acrylic-mix fibre) were once again used to visualise the blend, creating a grey melange shade. The final yarn was not dissimilar in feel and touch to the sorted knitted waste waiting to be recycled that had been observed in Prato during Practice 1. From this, it was concluded that Yarn 3 might flow seamlessly into this established recycling system.

ACHIEVED AIM

The aim Practice 9 demonstrated how recycled fibres can be used to create yarns for specific recycling systems.

INSIGHT

Practice 9 established that the most appropriate recycling system for acrylic-mix fibre is mechanical recycling.

8 DESIGN FOR TEXTILE SORTING

This chapter explores the role of sorting for the field of textile recycling. Firstly, the chapter outlines the two methods used for sorting post-consumer textile waste, by hand and by machine. It is highlighted that sorting prioritises re-use rather than recycling. Therefore, the methods of sorting for recycling are deliberated in detail. This covers the main three aspects: fibre type, colour and structure. The chapter continues by outlining the current thinking for a design for sorting approach which is to be used in this research. The chapter concludes by conducting a review of the literature combined with interviews to investigate the methods of sorting for mechanical recycling of wool and acrylic textiles.

8.1 SORTING POST-CONSUMER TEXTILE WASTE

Prior to the physical recycling of rags, the sorting stage is one of the most crucial and complex steps and has become a global industry (Morley, Bartlett and McGill, 2009:10). Sorting of textile waste is vital for mechanical recycling processes and It should be noted that even chemical processes require the compositions of sorting factions to be accurately identified (Niinimäki and Karell, 2020). When post-consumer textile waste enters the recycling stream it is first sorted into two broad categories: unwearable and wearable (Dutch Clothing Mountain, 2017). The current set up of the system means that garments are sorted for profit-based re-use markets. While waste textiles are often sorted in their country of origin, high labour costs have created an export market for unsorted goods. Textiles can be sent to 'special economic zones' across the globe. These have been created for the import of re-usable waste textiles which would ordinarily be banned. For example, in India importing re-usable clothing is prohibited to protect the local hand-weaving industry. These dedicated processing zones are exempt from such bans and after sorting the clothing is then re-exported (Crang et al., 2013). In recent years the research has driven forward automated sorting practices but notably these are designed for the recycling grades only (Wedin et al., 2017; Zitting, 2017; Fibersort, 2020a). Both approaches, hand and machine sorting, will be discussed below.

8.1.1 SORTING BY HAND

The traditional method of sorting discarded clothing is done by hand. Discarded clothing is collected and transported to sorting facilities to be sorted in a variety of ways. Botticello (2012) has explored this process from a London-based sorting facility. She explains that "goods…return to the factory floor for revaluation, reproduction, and redistribution for further use" (Botticello, 2012:167). To extract the maximum value the sorting process, Botticello argues, is vital. She suggests, however, that the 'personal engagement' of the workers drawing on tacit and embodied knowledge is key. Just looking is not enough, she explains: the tactile interaction with the clothing is critical and for this reason, the wearing of gloves is forbidden. Recognising specific material qualities for revaluation in a new context is crucial to the sorter's role.

When clothing enters sorting facilities it is initially sorted into generalised categories which slowly get more specific. Wedin et al. (2017) reports re-wearable clothing can be sorted into as many as 350 different sub-categories which Hawley (2006) examines in detail. Firstly, clothing is separated into garment type, such as trousers, coats and jumpers. This is then further refined into types. For example, the general trouser category might be sorted into heavier woollens or lighter cottons. Nørup et al. (2019) explain that the first broad categories for sorting are: re-use for further sorting, re-use directly for packing, recyclable textiles, reusable non-textiles, recyclable non-textiles and mixed waste. Even the non-textiles not designed to enter the sorting process are extracted to create value. As Norris (2012a) points out, buyers need to be found for even the poorest quality items to offset the costs of collecting and sorting.

8.1.2 AUTOMATED SORTING

The potential for human error in manual sorting has recently been highlighted. This is emphasised when sorting for recycling grades as the quality requirements, particularly for future chemical recycling, are precise and exacting (Wedin et al., 2017). Therefore, it is argued that automated sorting could provide a solution:

> Automated sorting technologies could enable the industry to turn non-rewearable textiles that currently have no other destination than downcycling, landfill or incineration into valuable feedstock for high-value recycling (Fibersort, 2020a:6)

There are many different approaches that can be taken for automating the textile sorting process. This has been explored by Humpston et al. (2014) in their report 'Technologies for sorting end of life textiles' which highlights three processes: fourier transform infra-red spectroscopy (FTIR); radio frequency identification (RFID) tags; and 2D bar codes. FTIR is one of the hyper-spectral imaging techniques that has the potential to determine the colour and fibre content of a textile. This, Humpston et al. note, is not available commercially. A RFID tag is one that is attached to the textile and holds the complex construction information ready to be sorted for recycling. Unfortunately, however, these tags cannot yet survive more than a few washes. 2D barcodes, are a black and white code attached to the clothing that can be read by a camera and decoded. Humpston et al. consider this technology to have the greatest potential.

Since the publication of Humpston et al's report, more research and development has been conducted exploring the potential of near-infrared (NIR) technology (Wedin et al., 2017). This is specifically designed for recycling grades of post-consumer textiles where the composition of the garment is unknown. It works by measuring the light absorbed by the textile in the NIR part of the spectrum. This process is only able to scan a very thin top layer of any clothing, however, which limits the technology to single material items and, as Wedin et al. explain, means that contamination such as plastic prints will stay in the sorted fractions.

Another limitation is that currently textiles are hand-fed into the system as the machinery can only scan one item at a time (although it is envisioned by Wedin et al. that this process could be performed by robots in the future). After the scanning process the clothes are delivered by a conveyer belt and blown into specified bins according to fibre type or colour. As Fibersort report (2018b) suggests, this could aid increased and detailed sorting to match the waste fibre type with the recycling technologies' requirements.

8.2 SORTING FOR RECYCLING

The majority of waste clothing is sorted by hand for re-use, categorised by the type of garment or the way the material feels, such as 'silky' (Botticello, 2012). Recycling grades are prioritised by their fibre content and colour. In the current method of hand sorting, after the initial sort to remove soiled/wet clothing and the highest quality clothing, the rest is separated into 'useful' or recycling grades (Botticello, 2012). These grades have been further divided into four subcategories by Nørup et al. (2019:313): white cottons, coloured cotton, knitted and other recyclable textiles. According to Nørup et al's material flow analysis of the textile in a sorting centre in Lithuania between 2015 and 2017, recycling grades are on the increase. However, this is not because there has been an increase in recycling options. "Currently, the main global emphasis of recycling is the cutting of cotton-based textiles for wipers/rags, shredding knitwear to non-woven and to a lesser extent recycling into new textile products" (Nørup et al., 2019:315). Generally, there are three main sorting categories considered for recycling grades: fibre, colour and structure. Sorting into these categories depends on the recycling market that is being collected for.

8.2.1 FIBRE TYPE

It is generally recognised that high-value textile recycling is centred around mono-material input (Hall, 2018). For example, 'Recover' is a mechanical recycler utilising mono-material cotton inputs and Prato, Italy has become a hub utilising mono-material wool inputs. The complexity of our textile waste and the presence of blended materials means that sorting for exacting compositions by hand is not practical (Fibersort, 2018b). Even with the automated sorting technology a balance between sorting for every possible blend category and the grades required by the markets needs to be found (Fibersort, 2018a).

Contamination of the required pure feedstocks is the biggest barrier. Even within automated sorting processes, Wedin et al. (2017) explain there has to be an acceptable error level. This means that not only will the fibres be contaminated with yarn or material blends; they could have product blends created by multilayers that the NIR technology cannot identify, as well as metal, plastic and leather parts of the garments such as fastenings.

If, as Elander and Ljungkvist (2016:43) suggest, mono-materiality is unrealistic for the majority of future textile production, blending and the categories for sorting is a problem that is only growing. The current method of sorting within the recycling industry, prioritising 'primary' fibre catagories, sheds some light on the sorting processes when dealing with mixed fibres, as demonstrated in the wool recycling industry in Prato. Here, the waste textiles are sorted prioritising the amount of wool content. For this reason, the need to sort wool and other primary fibre categories is the most practical approach (Hall, 2018).

8.2.2 COLOUR

The second phase of sorting for recycled textile is by colour. Norris (2012c) explains that even when sorting for colour some are more desirable than others. As she writes, "bright shades are at a premium, with sludgy grey mixes at the bottom of the scale" (Norris, 2012c:43). This is put down to the preference for dull clothing in the countries in which the waste originates. In the Indian shoddy industry, she explains, colour sorting is first separated into families and then into shades and sub-shades.

> Each one can be further qualified as bright, light and dark, referring to depth of colour, shininess and purity of shade. 'Uni' (i.e. plain) clothes are the most expensive, 'fancy' (i.e. checks and stripes) are the cheapest, but one can make several types of fancy: '10 fancy' (fancy with ten colours in it), or red fancy, violet fancy, blue fancy. (Norris, 2012c:43)

One of the biggest barriers to effective textile recycling is colour contamination. This is the result of inefficient sorting. Contamination presents in the form of 'neps'; contrasting coloured specs which stand out and, in some cases, protrude from the yarn or fabric surface. Although this is often exploited as a design feature, it is not practical if a solid colour is required (Hall, 2018).

8.2.3 STRUCTURE

The final sorting category is structure. However, the importance of this category is contended. Niinimäki and Karell (2020) point out that greater understanding of the effects of the structure for recycling is needed for a circular economy. They are only referring here to chemical recycling, however; for mechanical recycling they suggest structure has no effect. While the structure of textiles matters little when mechanically recycling low grade textiles into non-woven applications, structure for higher grade mechanical recycling is important (Hall, 2018).

Historically, Day (2016c) explains, the textile recycling industry split textile waste between shoddy, primarily knitted structures and Mungo, woven ones. This is to obtain, in the physical recycling process, longer fibres from the looser knitted materials. These, according to Norris (2012c), are soft and easy to open in the pulling/shredding process, whereas the shorter fibre lengths from the tighter woven textiles are much more difficult to open. As the input of the fibres directly effects the resulting materials that are produced, the length of fibres created from the process is important. This is still the approach used today in the wool sorting industry in Pakistan (Lilani, 2020a) and the wool recycling industry in Italy (Hall, 2018). It is also the approach used in wool recycling in India, where, Norris (2012c) explains, wool-rich knits are separated from wool-rich wovens.

The sorting for structure has been highlighted by the Fibersort NIR sorting technology report. Among its recommendations, it proposes that "sorting on woven qualities for instance or separating bales of lower and higher qualities of woolen (sic) textiles, could enable them to be used for different product applications, and hence avoid waste being created later in the value chain" (Fibersort, 2020a:15).

8.3 DESIGN FOR SORTING

Sorting goods into categories is the main method in resource recovery to create value (Gregson et al., 2014). Crang et al. (2013:11) point out that the value of used goods is realised through the assessment of material quality, specifically "finding and separating the good quality components or materials". Value is, as Crang et al. points out, determined at the sorting stage. Sherbourne (2009) establishes what she describes as 'design-centric recycling'. The designer, she explains, is well placed to create value by being selective of the materials they work with. While this would suggest that value for the designer is generated through sorting, Sherbourne's (2009) approach of selectivity, overlooks the remaining undesirable and unselected materials that are required to be recycled.

The relationship between recycling, sorting and design is a complex one (Elander and Ljungkvist, 2016). Wedin et al. (2017) explain that sorting is dependent on the recycler's requirement for specific materials that they can process. But the sorting process also has to accommodate the end markets for the recycled fibre which, in turn, are determined by designers. After use in a product, the recycled fibres then become the inputs for the sorting process. A lack of end markets for post-consumer textile presents one of the biggest barriers to successfully transforming them into new textiles. (Fibersort, 2020b).

Niinimäki and Karell (2020) argue that designers have the power to affect the efficiency of sorting and recycling technologies by understanding the limitations and possibilities of the processes. This, they conclude, means that designers need to understand the basic requirements of the current and emerging technologies. To do this Niinimäki and Karell (2020) suggest that designers first of all need to know the elements of textiles to be identified in the sorting process, such as their structure, composition, colour and non-textile components. Secondly, they need to identify what grades the textiles are generally sorted into and for what purpose, establishing, for example, whether they are for re-use, re-manufacture, recycling, incineration or landfill. Thirdly, designers need to know the "general limitations and possibilities of textile-to-textile recycling technologies… what can and cannot generally be recycled through them, and what elements in a textile product may disrupt the recycling processes" Niinimäki and Karell (2020:18).

In their 2019 journal article Karell and Niinimäki emphasise the designer's dependency on the recycling and sorting actors in the supply chain. In addition, they point out the interdependency of the two processes. For example, they write, "if textile waste material cannot be reliably identified in the sorting phase, it is not possible to direct the material to appropriate recycling processes" (Karell and Niinimäki, 2019:10). This need for reliably identified materials is true of both mechanical and chemical recycling systems (Niinimäki and Karell, 2020). Furthermore, they continue, the designer is faced with the task of designing for many different types of recycling systems (current and future). Sorting processes, in contrast, tend to be varied which simplifies the designer's task of establishing an approach. Therefore, if designers are going to implement Design for Recycling, Karell and Niinimäki advocate that the sortability of a product must come first and foremost. Based on this, they conclude, a specific 'Design for Sorting' (DfS) approach should be implemented as an initial and discrete strategy from Design for Recycling.

8.3.1 UNDERSTANDING SORTING FOR DESIGN FOR RECYCLING

Practice 7 of this research (page 169) highlighted the need to map and analyse the sorting systems for recycled textiles. As, Crang et al. (2013) suggest recycling value is determined at the sorting stage. Therefore, an understanding of this value needs to be combined with blending design tools to ensure our resources are designed to aid rather than hinder recyclability. It was only later that the DfS approach was found and layered onto these conclusions (Karell and Niinimäki, 2019). This research study has then sought to establish the recommendations for DfS; namely understanding the different elements, the various grades of sorting and the limitations to the recycling process (Niinimäki and Karell, 2020).

This research has already established Niinimäki and Karell's third recommendation of DfS and a full discussion of mechanical recycling technology and the limitations can be found in Chapter 3 (section 3.4, page 85) as well as the different Design for Recycling strategies in Chapter 4 (section 4.1, page 95). In the writing of this current chapter, Niinimäki and Karell's first recommendation for DfS has been addressed Section 8.2 (page 195), where sorting for mechanical recycling is found to occur in three ways: for colour, structure and fibre type. These categories will be considered from the perspective of the designer in the following text. This will be aided by an additional category: cleaning. The researcher proposes that cleaning is a vital stage for separating and eliminating contamination and therefore could be considered part of the sorting process. To do this, insights established in Practices 1, 2 and 4 of the research will be drawn on and discussed. Finally, to complete Niinimäki and Karell's recommendations, textile sorting grades will be investigated. In the context of the research this is specifically applied to post-consumer knitted wool/acrylic waste for mechanical textile recycling.

STRUCTURE

When it comes to discussing the methods of sorting textiles, structure is usually overlooked. Sorting facilities prioritise sorting by garment type (section 8.1.1, page 194) which by default often means they are sorted by structure. For example, sorting for trousers denotes sorting for woven rather than knitted textiles. Further down the recycling chain there are examples of sorting practices for the mechanical recycling of wool in which garments are not only sorted for knitted and woven structure but into more specific categories. This includes sorting between 'fine' and 'ordinary' knit structures in an attempt to increase the quality of the recycled fibre (Practice 1, page 79).

The density of a textile structure also has impact on the recyclability. In Practice 2 (page 111) it was understood that the 'looser' the construction the easier it would be to recycle. For the designer the choices made for the density of a textile are usually associated with its performance and durability and are almost never balanced with recyclability. As Sirkin and ten Houten (1994) reminded us in section 6.2 (page 138) it is vital that the qualities of a resource match up to the task they are to perform for and not needlessly added. The role of the designer, therefore, is to ensure we are creating the most appropriate material for the products we design. Which, for structure, might mean creating looser structures when the denser ones are unnecessary. However, further research would be required to understand if designing in this way would transfer directly into the sorting categories.

COLOUR

Sorting by colour is one of the most well-known stages in the mechanical textile recycling industry. Garments are sorted into a large array of family colours and exact shades. This reduces environmental impacts such as those caused by dyeing by reusing the colour already on the material. Designing textiles for sorting towards mechanical recycling, as highlighted by Practice 2 (page 111), requires the prioritisation of single colour materials to avoid colour contamination. This approach could be critiqued for stunting creativity. However, there are other methods the designer can draw on to overcome this challenge. For example, Forst (2019) argues that textile 'creativity' can be harnessed for recyclability through Design for Disassembly at material and product level (section 4.1.1. page 96). For this to be successful, it could be used for not only different fibre types but also different colours. In this way colours could be combined and then separated at the sorting stage.

However, at a fibre level, disassembly in mechanical recycling is not possible. Practice 1 (page 79) illustrates strict colour sorting procedures are conducted in the mechanical recycling system, yet the resulting pure colours are then re-blended in an almost contradictory fashion. Practice 1 describes the common practice of combining a vast range of sorted pure colours to create a new shade for its second life. Here, the sorters demand mono-colour materials to be used for the design of a product (which will eventually enter the recycling system) but the creativity of blending colours is restricted to the production stages. This procedure was challenged in Practice 4 (page 147) by reinstating creative blending of colour as a tool for designers in which multiple colours were used in the design for a garment factoring in the inevitable blending of colour at the recycling stage. For example, the designers created a two-colour garment, such as red and blue, that would produce a purple colour in the recycling process.

CLEANING

In our current system in which Design for Disassembly strategy is not fully established the best way to achieve purity it through the cleaning stage. This is a labour-intensive step used to increase the quality of the recycling output by cutting off a contaminant, such as zips, buttons, colour etc... Woven labels in knitted garments are a good example of the problems caused by contamination. This is because they differ in structure to the garment; they rarely match in materials type (often being made of the cheapest polyester materials) and are regularly found in white or black rather than matching the colour of the garment. Designing for cleaning, therefore, either requires the omittance of difficult to recycle elements, Design for Textile Disassembly approach (Forst, 2021) or great care in their placement so they can be easily removed (cleaned) at the end of life. Labels currently are positioned at seams which are often removed from garments because of threads contaminating a garment because of their fibre composition.

While cleaning is seen as a costly and wasteful exercise, as most of the elements removed are disposed of, Practice 1 (page 79) illuminates that the cleaning procedures can also become part of a cascading chain. Here, seam waste from a cashmere sorting facility was removed and sold onto another manufacturer. This waste was valued at a lower level for its cashmere contents and therefore the manufacturer was willing to accept the presence of fibres used to link the garment at the seams. In this way, the waste from one process could be designed into another product.

In a similar way, also discussed in Practice 1 another recycling company did not remove the seams when recycling. This was because it was unnecessary for the quality of the product they were producing. This was also explored in Practice 4 (page 147) in which steps in the recycling process were omitted to demonstrate the effect on the final materials. Here no cleaning was conducted and while colour contamination was present the decision to maintain the cleaning step is ultimately connected to what is required by the end material. Once again, as designers we are reminded that appropriate materials should be used in the designs we produce (Sirkin and ten Houten, 1994). If we understand the cleaning part of the sorting stage, we can ensure the design of the textiles we create can appropriately flow into the most appropriate level of a cascade to ensure longevity of our resources.

FIBRE TYPE

Sorting by fibre type is vital when it comes to mechanical recycling. This is demonstrated most prevalently by the way the industry has separated to specialise in reclaiming specific fibres types. For the designer this means designing with the goal of mono-materiality. However, as discussed in depth within Chapter 7, blending textiles can increase the longevity of our clothing (section 7.5 page 166). For the designer concerned with the recycling of their product (once it has lived a long-life) this tension still remains.

To fully understand sorting for fibre types to aid Design for Sorting and Design for Recycling, further research is required. The next section will specifically look at the sorting of fibre types specific to this research (wool and acrylic). The insights already discussed in the above sections (structure, colour cleaning) have been included to create a fuller and richer discussion of this topic but will not be the focus going forward. As highlighted, further research into these areas would be necessary to understand these design challenges in greater depth.

8.4 SORTING WOOL

Wool, as Botticello (2012) explains, is valued for its fire-retardant qualities for non-woven markets and therefore in the sorting process garments must contain a high percentage to be classified as such. She points out that in the past jumpers could be sorted into two basic categories pure wool or synthetic. However, in today's industry wool is "mixed in diverse blends, reducing pure wool content and making the fibre content of the garments more difficult to recognize and categorise" (Botticello, 2012:173).

There are methods the sorters use to decipher wool content. Botticello explains that an over-washed shrunken aspect gives away high wool content or a quick glance at the label. However, the latter method takes up time that often sorters do not have. In addition, the Circle Economy report (2020) 'Clothing Labels: Accurate or not?' identified that clothing labels are not a reliable method in which to sort textiles. Botticello (2012) also cites another method, highlighting the essential nature of the sorter's role to fill the categories required through 'highly qualitative forces' such as feel, touch and smell.

> Here the attributes of the fiber— itchy on tender skin—give away its high wool content, enabling the item to be sorted correctly and quickly. Like the gloveless hands used to discern wet or mouldy items, tender skin is required to discern wool. (Botticello, 2012:173)

The role of categorisation for wool, is important for both the company that sorts (to turn a profit) and the one receiving the goods who rely on the consistency of this grade. Botticello refers to an example of a company in the north of England who use the ready-sorted wool rags to blend into materials consisting of 25% or 50% wool depending on the use. This is to meet fire regulations and standards of the final product. If there is inconsistency in the percentage of wool, the batch will have to be downgraded, such as a batch only reaching 40% wool might be downgraded and used for the 25% wool category. This, as Botticello points out, "creates a loss in resale value of the product and wastes raw materials" (Botticello, 2012:181).

8.4.1 DETAILED CATEGORISING OF WOOL AND ACRYLIC

This section sets out to understand and establish generic sorting grades or categories, specifically of post-consumer wool and acrylic textiles. 'Generic' has been purposefully used as a term for two reasons. First, the analysis of both literature and interviews used to discuss and draw conclusions in this section provide a small but suitable sample for general rather than detailed results and second it might be impossible to establish concrete grades when the sorting industry moves and shifts as end markets change. Therefore, to understand the wool/acrylic post-consumer industry towards Karell and Niinimäki's (2019) Design for Sorting approach, only generic categories will be considered.

SORTING GRADES FOR WOOL/ ACRYLIC NON-WOVENS

The WRAP report by Thompson, Willis and Morley, (2012) 'A review of textile fibre recycling technologies' describes how UK-based recycling markets have developed non-woven materials from a mix of wool, acrylic and blended fibres. Made from recycled textile garments, the fibres are needle-punched to form a non-woven felt-like material, commonly known as flocking, and is used for upholstery and mattresses. The waste is formally categorised into four streams: wool-rich (80% wool), flocking grade (30-35% wool), jazz (acrylic or synthetic mix knits) and low grade (a catch-all grade for mixed material and fibre). Supporting Botticello's findings, the WRAP report suggests that combinations of these grades are used to create the different non-woven flocking requirements. For example, the wool content is required to reduce flammability and to comply with upholstery and mattress regulation. While they note that the non-woven market could become a growth area, there are still some barriers to overcome. A combination of declining wool-rich clothing consumption and heavy competition from flocking made from virgin polyester means this market has not grown as much as it could.

SORTING GRADES FOR WOOL/ACRYLIC YARNS

Elsewhere in the textile post-consumer recycling industry clothes are transformed into yarns. Norris (2005) describes the sorting grades for this industry in India. She explains that they import three main categories of waste textiles: commercial all wool (wool-rich knits containing about 70-80% wool), original wool rag (wool-rich wovens containing 70-80% wool) and acrylic. Norris' categories correspond to the sorting categories for the production of recycled yarns offered by Thompson, Willis and Morley (2012). This is not surprisingly given that personal correspondence between them was cited.

However, there is some disparity between the percentages offered by Norris in 2005 and her later figures in 2012c. For example, in her later text Norris (2012c) suggests the grade 'commercial all wool' contains "about 90% wool", whereas her earlier text (2005) is more pessimistic suggesting 70-80% wool.

Further discrepancies are noted in the 'original wool rag' grade. In 2012 Norris suggests original wool rag contains 50-70% wool while in 2005 she suggests it contains 70-80% wool. Although the percentages are not very different, it should be noted that Norris' text was not focused on the percentages or sorting procedures and was studying the industry from an anthropology perspective. Therefore, rather than suggesting the source is inaccurate, it is more likely that the variances demonstrate the complexity of the recycling industries and the diversity in sorting strategies between companies as well as them changing over time.

AUTOMATED SORTING OF WOOL/ACRYLIC FOR ALL MARKETS

The most recent sorting data published on the fibre content of waste post-consumer textiles is from the Fibersort project (Circle Economy, 2019). Using NIR technology post-consumer textile waste was sorted into thirteen categories based on all the available end markets for recycling. Of these categories, five contained either wool and/or acrylic (Table 11).

Table 11. Wool/Acrylic blends overview of the Fibersort sorting accuracy, (Circle Economy, 2019:2)

FRACTION (%)	THRESHOLD (%)	COMPOSITION (%)
Cotton 50 ; Acrylic 50	>40 ; >40	52 ; 48
Acrylic 100	>95	97
Wool 50 ; Acrylic 50	>40 ; >40	42 ; 58
Wool 30 ; Acrylic 70	>20 ; >60	27 ; 73
Wool 70 ; Polyamide 30	>70 ; >10	51 ; 49

The fibresort machine proved to accuratly sort all but one of the five sorting categories within the threshold set up in the project. The exception was polyamide, and for this the report recommended further adjustment of the machinery to increase reliability. This category is thus excluded from this research. Additionally, the first sorting category, 50% cotton/50% acrylic, falls outside the scope of this research but highlights the crossover of acrylic into the cotton recycling processes. The remaining three categories can be broken down into 50% wool/50% acrylic, 30% wool/70% acrylic and 100% acrylic. These categories demonstrate similarities with the WRAP report's flocking feedstock specifications (Thompson, Willis and Morley, 2012). For this reason, we might assume that these three Fibersort categories have been created for non-woven flocking as an end market. However, this does not apply to the 50% wool category which stands apart from both sorting categories for yarn and non-woven end markets.

WOOL/ACRYLIC SORTER AND RECYCLER INTERVIEWS

Due to the disparity in these sorting categories/grades, two interviews were conducted in 2020. One interview was with textile sorter Hasnain Lilani in Pakistan who has set up 'Recycle wool' a company that specialises in hand sorting post-consumer wool textiles; the other interview was with a post-consumer wool recycler manufacturing acrylic/wool blended yarns in Italy (who will remain anonymous for this research study and will be called Recycler X). The transcriptions of the interviews can be found in Appendix 14.1 and 14.2 (page 341 and page 343)

Lilani (2020a) explains that the generic sorting grades in his process are "100% acrylic, 50% wool/50% acrylic, 80% wool/20% acrylic…or 100% wool". It should be noted that sorters, like any other actors within the recycling system are businesses. Therefore, they "process the materials, as per the requirement of the customer" (Lilani, 2020a). This might explain, in part, the discrepancies between the categories which have been found in the literature. Lilani (2020a) explains;

> we don't work with acrylic. We are focused on wool. Acrylic has a demand from a low category market…we don't mind what the other fibres in the blend are we are only focused on collecting wool and cashmere (Lilani, 2020a, Appendix 14.2, page 343)

This illustrates that acrylic is deemed as a contaminant of the wool recycling industry, making collection and sorting of this fibre lower priority. The 'low category market' for acrylic, to which Lilani refers, corresponds to the sorting grades and markets given in the WRAP report (Thompson, Willis and Morley, 2012) referring to Jazz – acrylic or synthetic mix knits. This illustrates, as we might expect, that the lower the wool content, the lower the value of the material, thus this material is driven into lower value end market applications.

Lilani (2020a) clarifies that the acrylic component in all three of his sorting classifications may well contain other fibre types. For example, '100% acrylic' may in fact contain other synthetics. In addition, Lilani proposes a 100% wool category. However, as he rightly points out "the international law around fibres allows for the possibility of +/- 1% or 2% other fibres." He goes on to explain that if it was tested in a lab, you would find it wasn't 100% wool, despite calling it such. Therefore, true purity in the recycling industry does not exist.

Lilani's '100% wool' is a category that has not been presented in previous literature. It is, however, explored in the author's own conference paper 'Mixing it up in Prato', a field study of the post-consumer wool recycling industry in Italy. The paper includes a description of a company that "brought in high percentage wool input, accepting no lower than 97%" (Hall, 2018:12). As this finding corresponds very nearly to Lilani's "+/- 1% or 2% other fibres" we can assume that this is acknowledged across the industry as a sorting classification.

Interviewee Recycler X also breaks down the sorted post-consumer wool garment categories which his company buys from sources in both Italy and India. Citing only the high-value wool component, he breaks down his sorting classifications into 80% wool, 50% wool and 100% acrylic. It should be noted that Recycler X produces acrylic/wool blended materials and therefore would be unlikely to purchase the highest quality '100% wool' textiles. All the categories from all of the sources have been summarised in Table 12.

Table 12. Comparative sorting grades of wool and acrylic.

CATEGORY	NORRIS	WRAP (FLOCK)	FIBERSORT	LILANI	RECYCLER X
Wool 100				X	
Wool 90	X				
Wool 80		X		X	X
Wool 70-80	X				
Wool 50-70	X				
Wool 50			X	X	X
Wool 30		X	X		
Acrylic 100	X	X	X	X	X

Table 12 demonstrates that the '100% acrylic' grade corresponded across all sources used in this research. While there is specific agreement about the '100% acrylic' grade, Norris' classifications illustrate the anomaly across this study. Notwithstanding the discrepancies in her classifications, two other generic grades are agreed upon by all sources: '80% wool' and '50% wool'. As previously discussed, the '100% wool' grade is also universally acknowledged (Hall, 2018). The generic grades agreed upon in this research all correspond to those provided by Lilani (2020a). The fact that he is the only source directly working in the textile sorting industry only serves to strengthen this finding.

Returning to the discrepancies found in Norris' 2005 text, on closer inspection the generic grades suggested by this research do fall within the ranges she proposes. The only exception is the '90% wool' grade which for the purpose of this research is to be treated as an anomaly. Once again, it is noted that while this study is very small in size its aim is not to establish concrete grades but an overview of more generic ones that are used by the textile sorting industry. While more research is required to fully understand these sorting grades, the literature analysed, and the interviews conducted were deemed appropriate to establish a basis for a DfS strategy as suggested by Karell and Niinimäki (2019).

8.4.2 SORTING COMPLEXITIES

While the focus in this chapter has so far been on specific percentages of the generic sorting grades, the nuances of these classifications will be discussed in this section. Recycler X explains that a 'family' sorting approach is adopted by the sorters he buys his post-consumer textiles from, one that is also often used to sort colours (Norris, 2012c). When sorting for wool content the categories form family percentages. Recycler X points out that he might find a mixture of percentages, and that the average of these roughly determines the named wool content of the overall batch. He uses the example of '80% wool' to clarify: "It doesn't mean that all the jumpers are 80% wool - it is a medium" he explains "you can find 100% wool and 70% wool, and they are mixed". The result might be somewhere in the region of "80 or 85% wool", but regardless of the exact percentage content, it will be generically named '80% wool'. Taking the next grade down (50% wool) Recycler X further clarifies the sorting method. For this category the waste from the preferred '80% wool' grade is utilised. As he explains, these garments could range from 30-69% wool, meaning that the average is more or less 50%.

Recycler X further reveals that the 'family' categories do not always accurately reflect the percentage they are meant to contain. After analysis, he points out, the '50% wool' grade usually only contains 40% wool content. Conversely, for the '100% acrylic' grade Recycler X explains there might be 5%, 10% or even 15% wool content in the overall batch. This corresponds to the thresholds used by Circle Economy's (2019) Fibersort research. As shown in Table 11 earlier, the 50% wool/50% acrylic category, for instance, has a threshold that states that garments falling into this category must have more than 40% wool and more than 40% acrylic content. The table also shows final composition test results. The composition of every given sorting category was tested by recycling the sorted garments into fibre. This fibre was then tested for its exact contents, showing that the '50% wool' category was in fact only made up of 42% wool. This supports Recycler X's explanation as to why sorting grades can easily fall short of their claimed composition. It is these fuzzy boundaries which sum up so well the complexities within the textile recycling system. While the market demands pure fibres, as Lilani (2020a) highlights, these can only be found with virgin content.

8.4.3 THRESHOLDS

The discussion so far brings us to a crucial area of this inquiry which relates to the '30% wool' category shown on Table 12 (page 206) that has not yet been explored. For the purpose of the practical testing (for Practice 10) the interview with Recycler X contained questions regarding the purchase of recycled fibres. Here, the author was offered a 30% wool blend which did not fit into any of the previously specified categories. This new grade, as Recycler X explained, had been created by blending the '50% wool' grade with the '100% acrylic' grade (thought to have 15% wool content). As Recycler X makes clear in the following extract, 30% wool is given as an approximate content:

> "I buy the 50% which is more or less 40%. I also buy acrylic which is more or less 15% wool. When we open the bale and select all the colours usually, we blend the 40% and the 15% together. Sometimes in the blend we can find 40%, 35%, 30%. I said 30% as this is the average that you might get. I have some colours with 35% wool, some colours with 40% wool, some colour with 25% wool."

Previously, Recycler X had spoken about upper and lower percentage thresholds in his generic sorting grades. For example, the '50% wool' grade has an upper threshold of 69% wool and a lower threshold of 30% wool. However, the '100% acrylic' category, Recycler X claims, might contain as much as 15% wool content. This raises the question: which category would 16%-29% wool content fall into? This indicates that Circle Economy's (2019) Fibersort categorisation of '30% wool' with a lower threshold of 20% wool might fill this gap. Previously, it was suggested that the '30% wool' grade was appropriate for non-woven flocking only. Therefore, anything below '30% wool' category would not be considered appropriate for the creation of yarns for an end market.

Having established four widely recognised generic grades (100% wool, 80% wool, 50% wool and 100% acrylic), the importance of the thresholds of these grades has also been highlighted in this chapter. Table 13 (page 209) outlines these ranges based on both Recycler X's definitions and those found in the literature. If we are to 'Design for Sorting' we must take both the broader category and its thresholds into account. For example, if we were to design a garment to enter into the '50% wool' sorting category, it would have to contain between 30% and 69% wool. For this research the lower threshold of 30% will be used as a base level to further understand how to design for sorting grades and between the thresholds in this PhD research (Chapter 10, page 225).

Further research should be undertaken to extend the findings presented in this final table to expand the field of Design for Sorting. However, for the scope of this research, the five basic sorting grades outlined here for wool/acrylic textiles and their thresholds are sufficient for this current study.

Table 13. Wool/Acrylic sorting grades concluded for use in this study

	GRADE	% THRESHOLD
100 97	Wool 100	100 97
80 70	Wool 80	96 70
50 30	Wool 50	69 30
0	Acrylic 100	29 0

8.5 SUMMARY

This chapter meets the second objective of the second aim of this thesis, to investigate the methods of sorting for mechanical recycling of wool and acrylic textiles. Firstly, the chapter illustrates that the sorting of textiles is achieved mainly by hand and is conducted towards re-use markets rather than recycling. However, new automated systems are being developed and tested for the sorting of the unwearable and recyclable fractions of discarded textiles. This, combined with the hand sorting method, gives rise to three methods of sorting for recycling, discussed in detail in this chapter: fibre type, colour and structure.

The chapter continues to discuss the interdependent relationship which exists between textile sorting, recycling and design. Sorting is specifically distinguished as the method the recycling system uses to decipher resource value. Yet, to find solutions in which the design of textiles can be sorted and recycled effectively to feed back into the design process is a complex issue. Karell and Niinimäki (2019) propose in order to achieve 'Design for Recycling' there first needs to be a separate 'Design of Sorting' strategy applied. This has been achieved by summarising the findings from the practice conducted in the thesis for sorting of post-consumer textiles for recycling across structure, colour, cleaning and fibre type.

The chapter concludes by addressing Niinimäki and Karell's challenge in relation to wool/acrylic textiles.

To do this, a short review of the literature is presented to establish the different sorting categories for wool/acrylic waste textiles. This is combined with two interviews with experts in the field to produce four generic sorting grades. In addition, the lower and upper thresholds for these four categories are also discussed and established. These findings will be utilised as method to understand value in Design for Recycling Knitwear framework presented in the next chapter.

9 DESIGN FOR RECYCLING KNITWEAR

This chapter brings together cascading, blending and sorting strategies explored in the previous chapters. Through the amalgamation of all these strategies the Design for Recycling wool/acrylic knitted textiles will start to emerge and provide the conditions for which the final practice to test.

9.1 INCREMENTAL DESIGN FOR LONGEVITY AND RECYCLABILITY

> The critical issue—for people, organizations, and governments alike—is knowing where we want to be. The imaginary, an alternative cultural vision, is vital in shaping expectations and driving transformational change (Thackara, 2006:26)

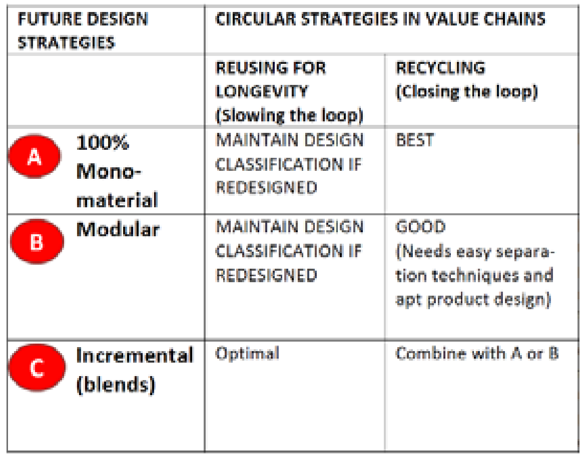
The transition towards a circular economy is extremely complex and involves the transformation of not only our systems but includes the transformation of us as designers (Vuletich, 2015). Transition design, proposed by Irwin (2015), is described as an area of research that advocates for design-led societal transition towards a sustainable future. This involves embracing the iterative changes that happen over time. Transition designers, explains Irwin, "learn to see and solve…problems and view a single design or solution as a single step in a longer transition toward a future-based vision" (Irwin, 2015:237).

These steps across time, Irwin describes, could be likened to incremental innovation, defined by Norman and Verganti (2013) as the small changes which improve a product's performance, desirability, or lower its costs. In essence, they explain incremental innovation is "doing better what we already do" whereas radical innovation is "doing what we did not do before" (Norman and Verganti, 2013:82). While there is a place for both types of innovation in society, this research is not focused on the radical new technology in which to deal with blended fibres, such as chemical recycling. But rather the incremental innovation within existing systems for blends, such as mechanical recycling.

Incremental design has been propositioned by Carlsson et al. (2017) in their paper 'Feasibility of Conditional Design: Organizing a circular textile value chain by design principles' and in which they present their 'conditional design' rules. These, they argue, stem from a design process that is already driven by conditions such as: aesthetics, functionality, consumer approval, brand policies, corporate social responsibility commitments and profitability. When circularity is incorporated, they maintain, two conditions are added: longevity and recyclability. They offer three design strategies. Two of these are Design for Recycling strategies: mono-material design and design for disassembly (described as modular design). The final approach is incremental design. This is the incremental updating of a garment during its lifetime, which Carlsson et al. explains creates 're-designability'. This is a design for longevity strategy which they identify allows for the use of blended materials. They explain that this means designers need to consider the micro design elements that can be incrementally updated leading to garment life extension. For example, the ability to attach or detach pockets.

The crux of the issue, as Tanttu, Kohtala and Niinimäki (2016:204) suggests is combining both longevity and recyclability (as discussed in section 7.5, page 166). Carlsson et al. (2017) explain this in a table format (Table 14) in which re-designability through the incremental updating of a product is combined with the two Design for Recycling strategies. The outcomes of these are less resolved. They highlight the importance of understanding and connecting sorting processes, recycling technologies and markets for the fibres as this thesis investigates. However, they offer no solutions for blends that cannot be separated beyond designing for the longevity of a product. Ultimately, they suggest these would still be downcycled. This strategy of incremental steps is similar to the notion of cascading. Therefore, the next sections will explore the intersections of longevity, cascading and recycling.

Table 14. Strategies for design and applications, (Carlsson et al., 2017)



FUTURE DESIGN STRATEGIES	CIRCULAR STRATEGIES IN VALUE CHAINS	
	REUSING FOR LONGEVITY (Slowing the loop)	RECYCLING (Closing the loop)
A 100% Mono-material	MAINTAIN DESIGN CLASSIFICATION IF REDESIGNED	BEST
B Modular	MAINTAIN DESIGN CLASSIFICATION IF REDESIGNED	GOOD (Needs easy separation techniques and apt product design)
C Incremental (blends)	Optimal	Combine with A or B

9.2 UNDERSTANDING DESIGN FOR RECYCLING KNITWEAR

In order for this research to bring together cascading, blending and sorting to increase value and longevity of resources, the collective insights from Practice 1-9 have been established. While each piece of practice in this thesis outlines both the achieved aim and the main insight, this does not provide a true account of the insights produced from the body of practice as a whole. Organised by theme (cascade, blend and sort) these broader insights have been summarised in Table 15.

Table 15 demonstrates how the practice from all locations in this thesis fed the researcher's understanding of design for cascading, blending and sorting and in turn enabled the findings and models contained in Chapters 6, 7 and 8 to be established. Chapter 6 explored design for cascading in the circular economy and presents a cascading resource spiral model composed of multiple product loops. Chapter 7 explores the landscape of blending and presents this across three levels (yarn, material, product) and conveys how the blending ratios can be used as a design tool to impact recyclability. Finally, Chapter 8 explores design for sortability and presents four textile recycling grades and thresholds of knitted wool/acrylic textiles. These two outcomes can be seen together in Figure 89.

Each of these elements were considered together to investigate knitted wool/acrylic textiles for mechanical textile recycling. First, the cascading resource spiral was used as the main structure for the designer to establish direction and route of travel for resources. In this case, the spiral represents an acrylic and wool resource flow, and each circle a knitted product lifecycle. While further research could be conducted to embed design strategies for re-use or remanufacture, the movement between different product groups (product cascading) falls outside of the research scope.

Second a specific type or spectrum of value is determined. In the context of this research recycling value is adopted. This is defined as the economic value of a product when it enters the recycling system. Vitally, this value is determined at the sorting stage. Therefore, with a focus on wool recycling and its contaminants, namely acrylic, a series of sorting grades were established ranging from highest to lowest economic value. These grades are used as benchmarks for each step in the spiral. These two elements culminate in the visual representation of the wool/acrylic knitted textile spiral (Figure 90).

The final element establishes how the designer can impact and control the direction and route of travel between the sorting grades to aid longevity of resources and onward recyclability. This is resolved through exploring the blending landscape and using this understanding as a design tool (as explored in Chapter 7). Inspired by Carlsson et al. (2017), when using recycled fibre, they can be blended to incrementally enter into new sorting categories. Ultimately this approach provides the designer with the potential to create

Table 15. Insights produced from the practice categorised between: Cascade, Blend and Sort

PRACTICE		INSIGHT	
CACSADE	1	APPROPRIATENESS	Each element of the recycling system, such as sorting, and cleaning impacts the resulting material. The choice to include or exclude a step directly correlates to the final material value.
	3	APPROPRIATENESS	The design requirements need to be matched with the processing decisions.
	4	CASCADING	the workshops highlighted the need for the designer to re-value products and resources at the end-of-life. Opportunities such as combining end-of-use options and using blending as design tool to aid the process were also established.
BLENDING	1	BLENDING	Blending can impact the material outcome of the recycling process
	4	BLENDING FOR CASCADING	Blending can be used as design tool to aid the cascading process, such as blending colours and material types for end-of-use systems. Recycled content within a blend also has an impact of the final yarn.
	5	BLENDING	Fibre type in the blend impacts the performance, aesthetic/hand-feel and cost, this included the recycled content as well.
	6	CATEGORIES OF BLENDING	Four categories for blending during production of recycled materials.
	7	BLEND DESIGN FOR SORTING	Blending can be used as a tool to aid recyclability altering the composition of the material that will enter the recycling system
	8	LEVELS OF BLENDING	Blending at two different levels: fibre and material was established and how this impacts the recycling process.
	9	DESIGNING BLENDS FOR APPROPRIATE RECYCLING	designing blends for specific recycling systems dictated the choice of fibres to target a specific technology. Furthermore, the most appropriate recycling system for recycled acrylic-mix fibre is mechanical wool recycling.
SORTING	1	SORTING	Sorting can have a great impact on the material outcome of the recycling process
	2	DESIGN DECISIONS	Design decisions made when creating a product impact, the way it will be sorted for recycling.
	4	BLENDING FOR CASCADING	Blending of colour was highlighted as something that happened after the sorting stage. This was challenged by suggesting design for blending could occur as part of the creative design process which could be incorporated into the sorting stage. In this way multi colour garments could be designed to be recycled to process a new shade.
	6	BLENDING AND SORTING	Direct correlation between blending and sorting and the required end product
	7	BLEND DESIGN FOR SORTING	The need to map and analysis the sorting systems for recycled textiles was highlighted in order for designers to appropriately design blends that could help and not hinder their recyclability.

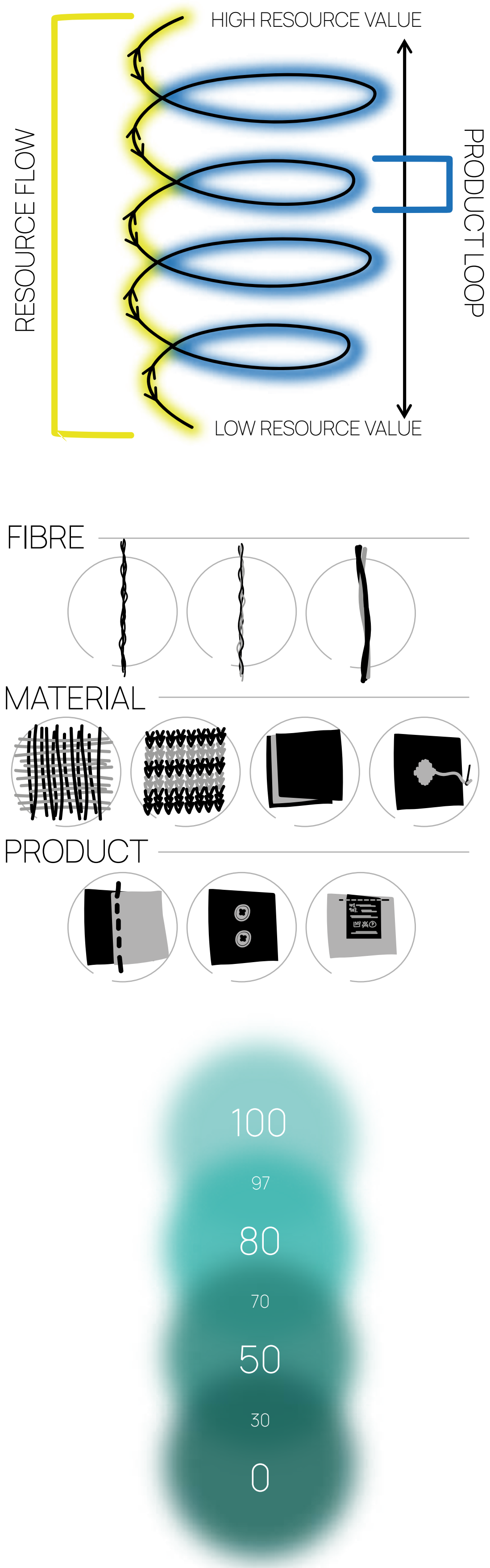


Figure 89. Three outcomes from the research presented in Chapter 6, 7and 8.

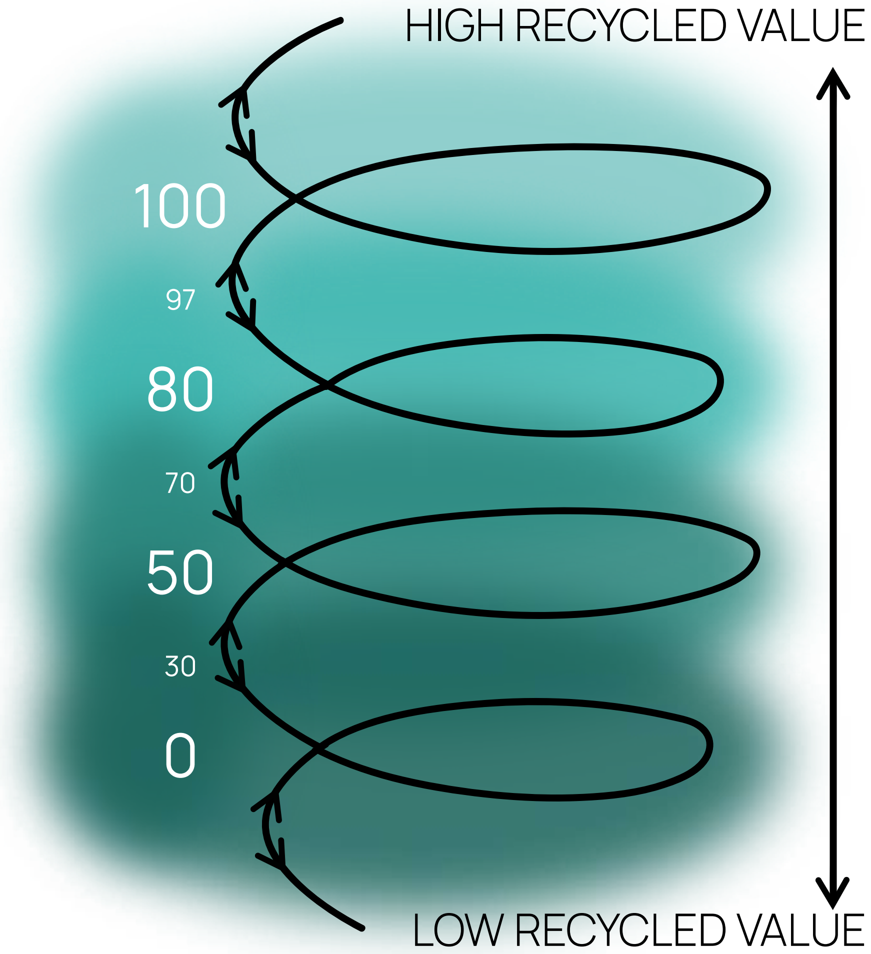


Figure 90. Design for Recycling wool/acrylic knitted textile spiral using sorting categories to define recycled value

upward travel in a spiral rather than only downwards. Specifically, this research will focus on the blending at yarn level when using recycled fibres. While the focus is taken away from the other blending levels, the implication of these must not be overlooked. Designing blending out of the other levels is highlighted by this research through not only the design of the yarns but applying them to knitwear (material) in a jumper application (product).

9.2.1 THE CONTEXT OF WOOL/ACRYLIC KNITWEAR

This research has specifically highlighted the product type (knitwear) and material spectrum (wool/acrylic) as problem areas in the mechanical recycling system (section 3.5.2 page 91). The decision to solely focus on knitted products was in part because this resource has limited re-use options and therefore falls quickly into recycling grades. In addition, knitwear is not often recycled back into knitwear and woven materials are considered lower value (Lilani, 2020a). When woven materials are recycled, they produce shorter fibre lengths (section 7.4.3, page 166). If knitted materials first returned to knitwear in a product cascade this could extend the life of the fibres.

While knitwear comes in many different fibre types, wool and synthetic (mainly acrylic) spectrums are very common grades due to the textile/fashion industry's consistent blending of these two fibre types (Sinclair, 2014). At the sorting stage the purest materials are awarded the highest values. Ironically, as illuminated in Practice 1 (page 79), while the industry demands the purest materials, these are then blended, thus reducing their value when re-entering the recycling system. There may be examples in which pure recycled content is blended with its virgin equivalate to maintain mono materiality, but this is not common practice.

As demonstrated in Chapter 7, when dealing with blended recycling fibre, blending could be used to not only generate market value, by aiding its function, aesthetics and cost, but also aid onward recyclability generating increased recycling value (Section 7.7.2, page 185). This research argues that rather than demand mono-materiality for all materials, leaving the non-mono-materials currently in the world as waste, all resources in the recycling spectrum could be utilised for longevity as a product (market value) and longevity as a resource (recycling value).

Specifically, this research suggests that all fibre grades between wool and acrylic should be valued as potential resources. This means that if the purest recycled wool can be recycled and blended to create usable materials, the same can be applied to lower value grades, such as 100% acrylic. The designer can then utilise blending as a tool to appropriately increase or decrease a yarn, material or product composition ratio depending on the desired outcome. The aim, therefore, is not to transform our materials back into mono-material groups but rather to utilise our resources within a spectrum and for the maximum amount of time.

9.3 TESTING IN PRACTICE

While the wool/acrylic knitted textile spiral presented in the previous section represents a full spectrum between wool and acrylic, the size and scale of this research was limited and therefore limited the testing that could be achieved. To overcome this, only a small section of the spiral was tested (full details see Chapter 10, page 225) to draw conclusions and suggest further research (see Chapter 11, page 265).

To accomplish this the lowest value recycled fibre '100% acrylic' grade will be the focus of the investigation. The recycling value of this fibre is currently considered as almost worthless and the fibres are directed very quickly towards the lowest value applications, typically non-woven products. There are examples in India for which acrylic has been utilised for the creation of yarns (Geetanjali Woollens, 2014), but for the European market where most of the acrylic waste resource originates these are deemed as low quality. Therefore, this research looks to re-value this resource. This will be achieved through its use in a higher value yarn for a knitwear application and through incrementally increasing its recycling value by blending.

This research will specifically investigate the realities of blending the acrylic fibres in order to ensure the resulting knitted product can move up a sorting grade at the point of disposal. This would, therefore, increase its recycling value. It is widely considered easier to move downwards in a cascade than it is to move upwards. This upward movement is limited to a single step and therefore represents fibres from the '100% acrylic' grade moving incrementally into the '50% wool' grade, with its thresholds between 30% and 69% (Figure 91). Increasing its recycling value will determine the fibre's path for subsequent lives and therefore could extend the use of the resource.

The design brief as laid out by the wool/acrylic knitted textile spiral is to create a new yarn that comprises of the following:

- To contain a significant amount of recycled acrylic fibre
- Contain a minimum of 30% wool in the final blend
- The yarn produced will be suitable for a knitted garment

What might appear to be a simplistic method of incrementally blending 'a bit of virgin wool' with the '100% acrylic' to move it up a sorting grade, is in reality more complex. This is especially true in the context of designing and producing a commercial yarn for a knitwear application. As discussed by Carlsson et al (2017), when we design for circularity additional conditions are added to the ones that already exist. These pre-existing conditions, presented in Chapter 6, are functionality, cost and aesthetics. Therefore, the new incremental blending approach for recyclability and longevity must in addition create a yarn that performs, has a realistic cost and is aesthetically pleasing. Carrying this out will create an array of opportunities, challenges and possible compromises. If we are to transition towards a circular economy, it is these realities that need to be established in practice. This challenge of 'design in practice' is explored and tested in the next part of the thesis.

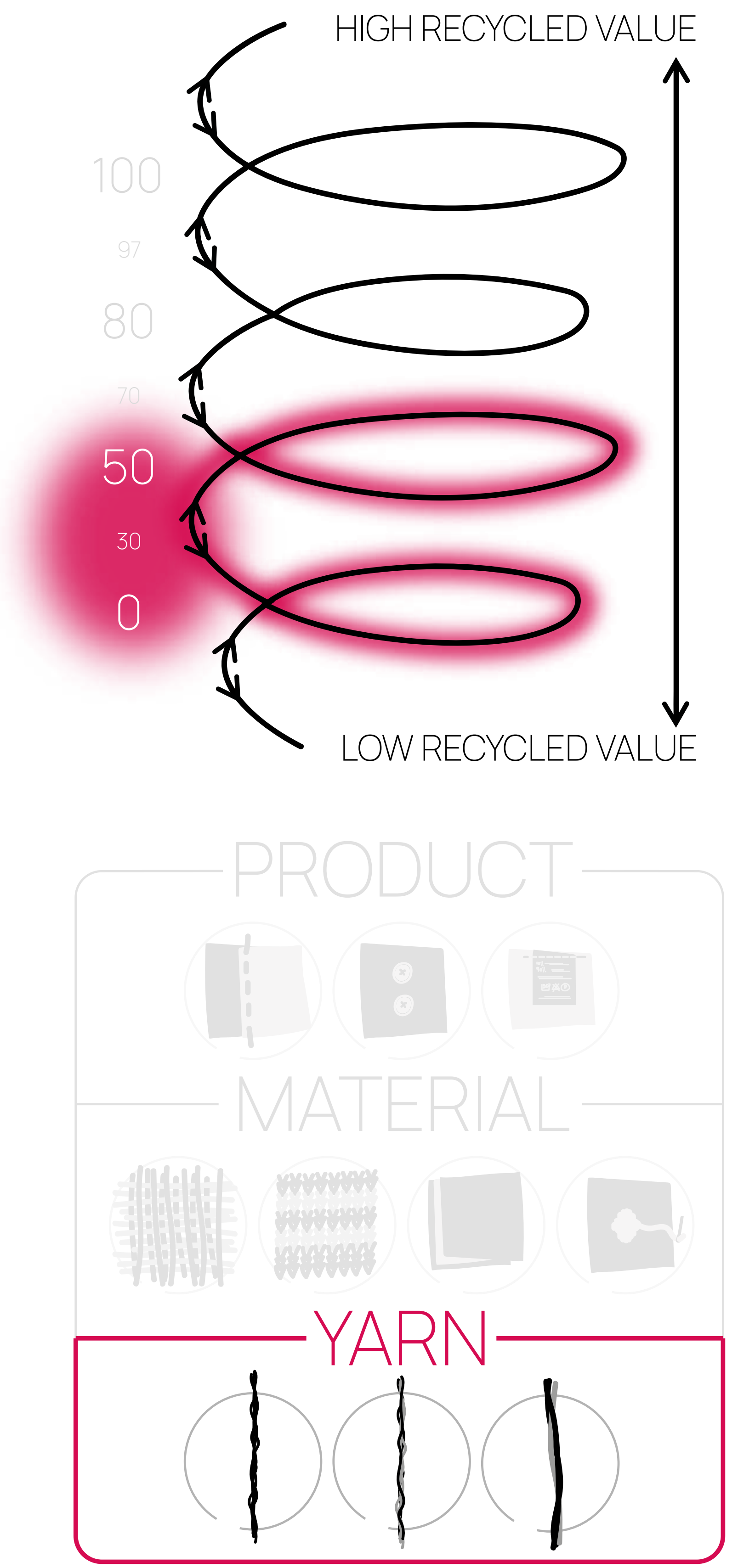


Figure 91. The scope of this research highlighted across the Design for Recycling wool/acrylic knitted textiles spiral for recycled value using blending at yarn level only

9.4 SUMMARY

This chapter has accomplished the objective to understand how the field of 'cascading' intersects with 'design for recycling' of post-consumer textile waste through sorting and blending. The chapter starts by contextualising the research as a transition design approach. This is achieved through incremental design which has been previously developed as a strategy for fashion products (Carlsson et al., 2017). The chapter focuses on how this approach could be applied at fibre level to provide longevity for recycled fibres.

Incremental design is synthetised with cascading using an incremental blending approach to create increased recycling value for the upward travel in a resource cascade. The research scope is framed by wool/acrylic fibres recycled for the use of knitted products. In particular, knitwear is highlighted as a product type that is not often created from mechanically recycled fibres and therefore designing resources to be used in this application would provide another method for resource longevity.

The research and the models presented in chapters 6,7 and 8 are brought together. First the resource spiral as created in Chapter 6 is positioned context. Next the Design for Sorting grades in Chapter 8 are used to represent each step in the spiral. Incremental blending is proposed as a design tool to control the recycling value of the resources (denoted by the sorting grades) and therefore enables the designer to create upward travel in a resource spiral. This is achieved using blending levels and ratios explored in Chapter 7.

The chapter concludes that the Design for Recycling wool/acrylic knitted textile spiral needs to be tested in order to establish the opportunities, challenges and compromises in practice. The scope of the testing explores the upward movement of the '100% acrylic' grade to the '50% wool' grade, noting the threshold of 30% wool. Acrylic would usually hold very little value, but through incremental blending the recycling value can increase creating further opportunities of use and thus, it is argued, that the life of these resources can be extended. The testing is to be explored in the next part of the thesis.

PART 3 SUMMARY

This part of the thesis accomplishes aim two of this research; to establish the role of both blending and sorting. This is achieved across three objectives and are discussed below.

The first objective is to understand how the field of cascading intersects with design for recycling of post-consumer textile waste. This chapter outlines the similarities between cascading theory and up/down-cycling concepts used in textile design. This highlights the difference between cascading resources and cycling products which result in a combined model: a spiral made up of a resource flow and multiple product loops.

This second objective is to identify the role of blending within virgin and recycled textile production. This is achieved by discussing the reason why we blend textile materials even if this is to the detriment of recycling. It is also discussed how blending is used as a tool in mechanical textile recycling. This objective is completed by building on the visual typologies of blends for textile designers by Forst (2021). These are re-organised into levels in which blending can occur. However, it is highlighted that for textile recycling it is understanding the blend's ratio that is important.

The third objective is to investigate the methods of sorting for mechanical recycling of wool and acrylic textiles. To achieve this objective, sorting for textile recycling across hand and automated methods are identified and discussed. Design for sorting is explored as a separate strategy to be applied alongside design for recycling. In the context of this research, literature and interviews are combined to establish the four grades of waste wool/acrylic textiles. These four generic grades are presented along with the upper and lower thresholds that the recycling industry allows for.

Finally, the fourth objective is to propose how cascading blending and sorting might be used together to ensure resource longevity of post-consumer wool/acrylic textiles. This was achieved through consolidating, in Chapter 9, the insights from the previous chapters on cascading (Chapter 6), sorting (Chapter 8) and blending (Chapter 7). This is achieved with the spiral shaped cascading model in which the Design for Sorting grades are used to represent each step in the spiral. Finally, blending levels and ratios are used as a design tool to move resources up and down. This applies to knitted wool/acrylic textiles within mechanical recycling in order to create 'recycling value' and will be tested in the next part of thesis.

4

PART 4 – DESIGN IN PRACTICE

This part explores the practice research both described in the chapter 10 and placed throughout the rest of the thesis. It accomplishes the third aim of this research; to test, through practice, the ideas generated in the previous aims in order to produce the Design for Recycling Knitwear framework and to establish how the methods have been used across research and industry. This is achieved across three objectives which are discussed below.

The first objective is to investigate, and where necessary collaborate with, industrial partners to test the realities of Designing for Recycling Knitwear from yarn to product and is completed in Chapter 10. To achieve this, Chapter ten outlines the final body of practice in which six recycled yarns and knitted swatches were created. These are then sent to automated and hand sorters to be tested for their recycled value.

The second objective is to draw insights from the opportunities and challenges of Designing for Recycling Knitwear in industry to establish how design decisions can bridge recovery and manufacture of textile resources. This objective is achieved through an in-depth discussion of the practice and research as whole in Chapter eleven and presents the Design for Recycling Knitwear framework. This forms one of the contributions to knowledge.

The third objective is to draw insights from Designing for Recycling Knitwear in industry to establish a model of how researching between academia and industry can be conducted. This was also achieved in Chapter eleven and reflects on the research process to produce a methodological framework for working between academia and industry. This forms the next contribution to knowledge.

The part ends with the conclusions drawing the thesis to a close and providing future research opportunities.

10 DESIGN AND TESTING

10.1 PRACTICE CONTEXT

The practice described at intersections in this document (Practice 0-9) explore the research ideas which led to the combined spiralling, sorting and blending design model for wool/acrylic knitted textiles (Chapter 9). In order to test this, a larger-scale experiment was conducted in collaboration with industry partners. The experiment itself involved sourcing acrylic-mix recycled fibres to be blended and spun into yarns suitable for a knitted garment application. This was then followed by producing proof-of-concept prototype jumpers. Finally, knitted swatches of the yarns were sent to both hand and automated sorters to establish if the design of the materials had successfully increased in value at the recycling stage.

First, recycled acrylic fibre needed to be obtained. Unlike Practice 0 where sorting, cleaning and pulling/shredding were conducted by the researcher, the recycled fibre here was sourced directly from the recycling industry to ensure an accurate representation of the fibres available. Second, a yarn spinner was required to advise on and conduct the blending, carding and spinning of the fibres. Third, a knitting manufacturer produced swatches and sample prototypes. These three stages followed the recycling system as highlighted in Figure 92.

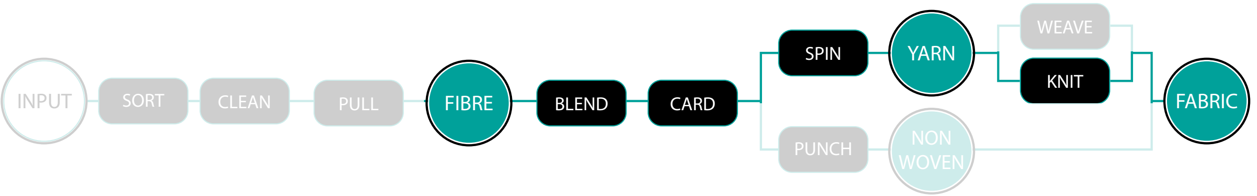


Figure 92. A simplified Recycling system diagram highlighting the elements covered by the practice experiment.

Once the active experimentation had taken place, the knitted materials were sent to a hand and automated sorter for testing. The experiment aimed to move the resulting knitted materials from the lowest (100% acrylic) sorting category into a higher value category, such as 30% or 50% wool. The two sorters would process the swatches and the resulting sorting categories would indicate if the material had increased in recycling value. Because Hasnain Lilinai's interview (Appendix 14.2) and the Fibersort testing results (Circle Economy, 2019) contributed to the generic sorting grades within the model, both these companies were asked to test the final materials.

10.2 THE CREATIVE DESIGN BRIEF

To test the Design for Recycling wool/acrylic knitted textile spiral, a specific brief needed to be created. Unlike the previous practice experiments which were purposely left open-ended, this final experiment needed to have a specific design direction. The criteria of the model provided a basis for the brief. These were as follows:

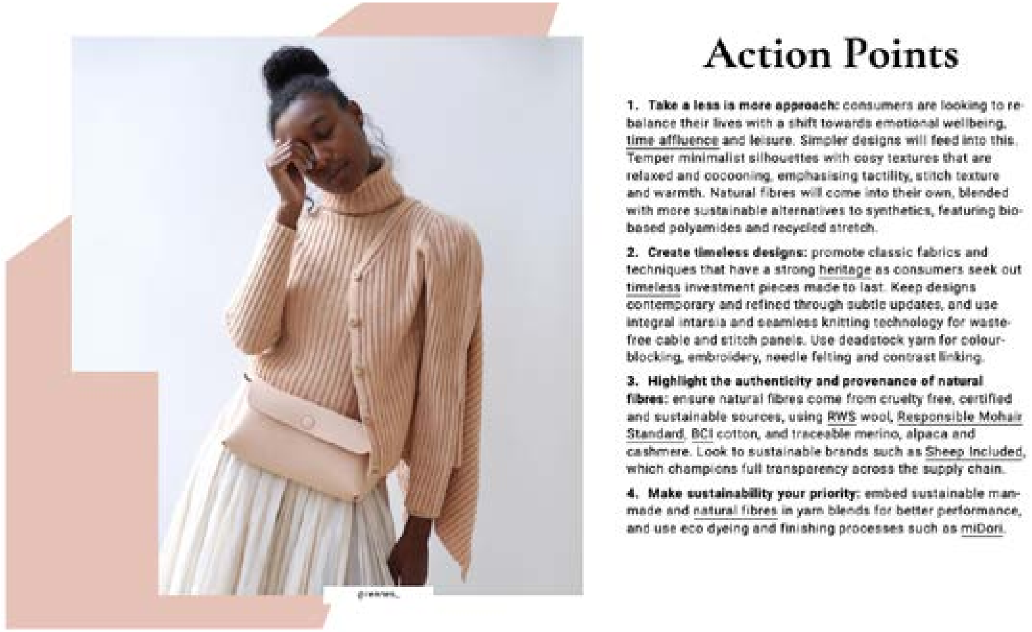
- The use of recycled acrylic fibre as the base material
- A minimum of 30% wool should form the final blend
- A yarn is to be produced that is suitable for a knitted garment.

In addition to the model's recycling and cascading conditions, a creative design brief was formed to provide direction for the performance, aesthetic and cost aspects. Using the researcher's own tacit knowledge of the industry design process, market, trend and inspirational research was undertaken followed by a concept design (Sinclair, 2014).

TREND, MARKET AND INSPIRATION RESEARCH

Trend and market research were conducted both online and by visiting several different types of fashion retailers. To start the process, trend forecasting website, WGSN, was visited and the AW21/22 trend concept 'conscious clarity' was chosen as the start of the inspiration (Figure 93). This highlighted the priority of sustainability in the design process alongside simplified silhouettes and timeless design. This also fitted the research ambition to produce a proof-of-concept garment that focused on the textile material rather than on creating a bold fashion shape or pattern. This type of design, therefore, could be categorised as a 'core' product type; a classic garment found every year in a brand's collection alongside the faster-changing trend-led pieces.

A scoping exercise to assess the acrylic-wool market was undertaken across a range of retailers to complement the more trend-focused inspiration. A combination of online and



Action Points

1. **Take a less is more approach:** consumers are looking to re-balance their lives with a shift towards emotional wellbeing, time affluence and leisure. Simpler designs will feed into this. Temper minimalist silhouettes with cosy textures that are relaxed and cocooning, emphasising tactility, stitch texture and warmth. Natural fibres will come into their own, blended with more sustainable alternatives to synthetics, featuring bio-based polyamides and recycled stretch.
2. **Create timeless designs:** promote classic fabrics and techniques that have a strong heritage as consumers seek out timeless investment pieces made to last. Keep designs contemporary and refined through subtle updates, and use integral intarsia and seamless knitting technology for waste-free cable and stitch panels. Use deadstock yarn for colour-blocking, embroidery, needle felting and contrast linking.
3. **Highlight the authenticity and provenance of natural fibres:** ensure natural fibres come from cruelty free, certified and sustainable sources, using RWS wool, Responsible Mohair Standard, BCI cotton, and traceable merino, alpaca and cashmere. Look to sustainable brands such as Sheep Included, which champions full transparency across the supply chain.
4. **Make sustainability your priority:** embed sustainable man-made and natural fibres in yarn blends for better performance, and use eco dyeing and finishing processes such as miDori.

Figure 93. Women's Knit & Jersey Trend Concepts A/W 21/22: Conscious Clarity- Action points, (Casey, 2020b)

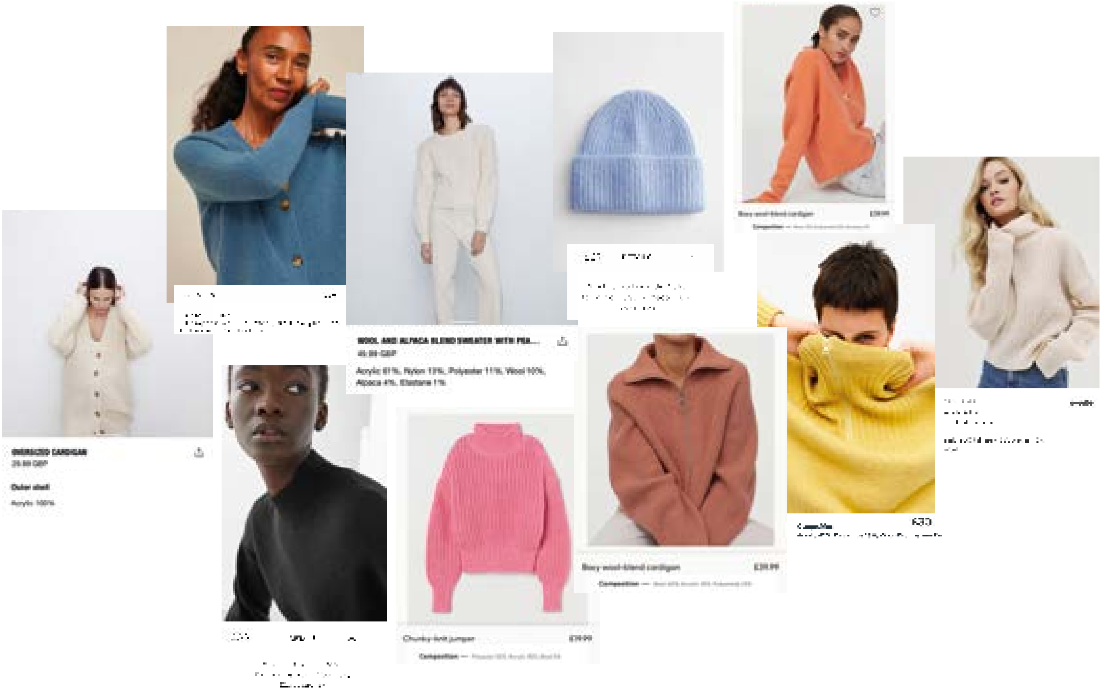


Figure 94. Market research comparing wool and acrylic blended knitwear from a range of brands.

The Roll-Neck

How to update

- For both slim-fitting and slouchy silhouettes, a contrast rib stitch works well either as a yoke placement or on sleeves across all gauges
- Alongside the trend for mood-enhancing colour, look to organic, RWS, sustainable yarn in undyed qualities to emphasise quality and longevity
- Rolled edges and funnel ~~necks update~~ the key high neckline. Explore the split seam detail

Figure 95. The Roll Neck - WGSN Knitwear: Core Item Updates A/W 21/22, (Casey, 2020a)

Softly Blurred

The concept: Enveloping comfort brings reassuring softness to this minimalist theme, enabling sculptural properties to be engineered into soft but protective knits.

Fibre & yarn: Focus on fine- to mid-gauge lambswool with natural felting properties, RWS merino extra-fine worsteds, and traceable alpaca and cashmere. Ecological polyamide blends allow lightness in lofty, compact and bouclé yarns.

Construction: Develop simple techniques that emphasise cosiness, such as needle punching, boiled and felted wools, and tailored, double-faced and bonded qualities.

Relevant for: outerwear coats and jackets, tailored jackets, roll- and funnel-necks, crew- and V-necks, accessories

Figure 96. WGSN Women's Knit & Jersey Trend Concepts A/W 21/22: Conscious Clarity – Soft Blurred, (Casey, 2020b)

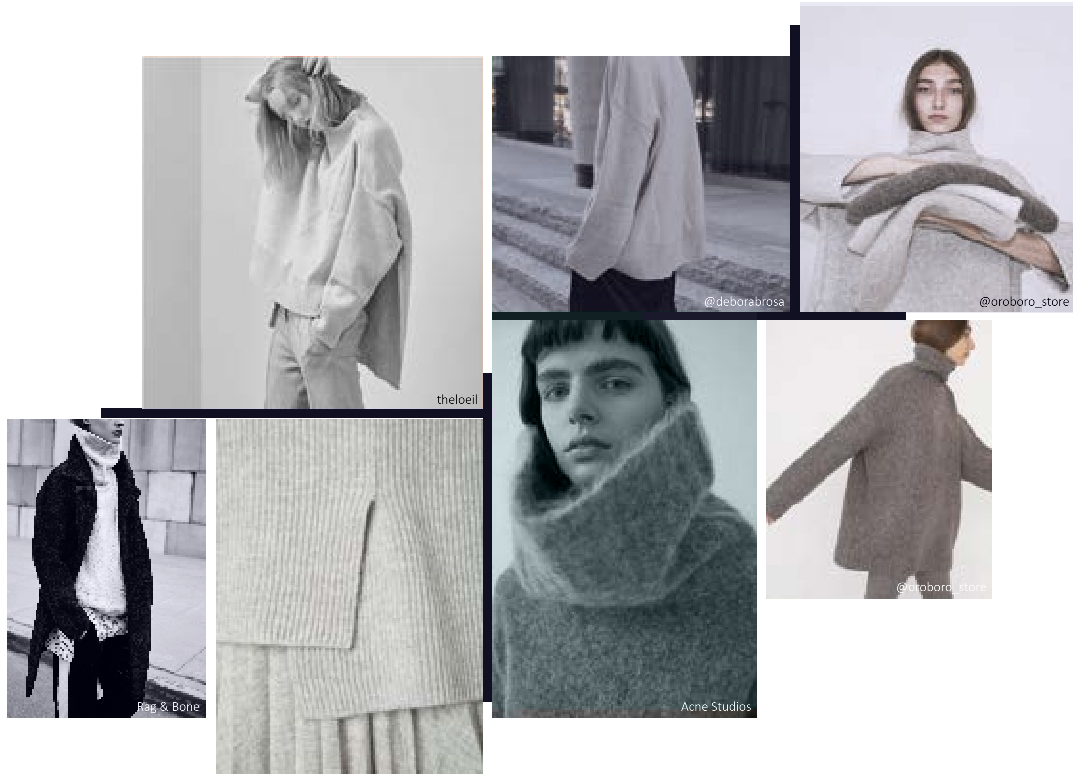
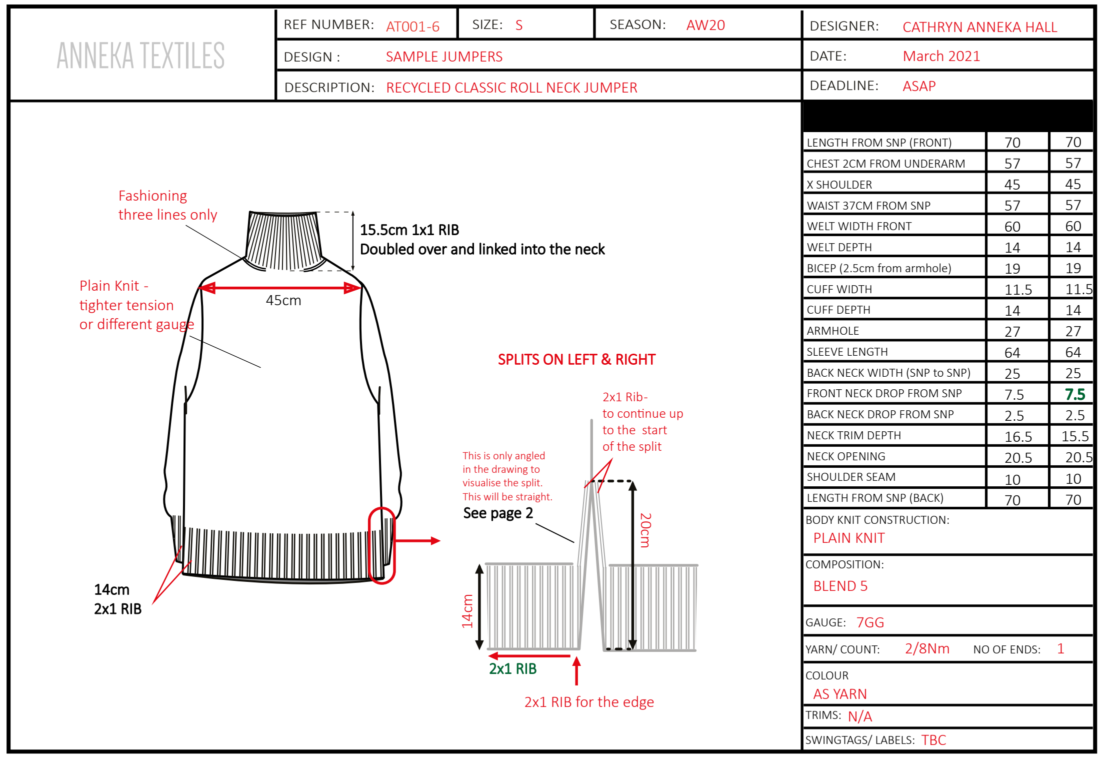


Figure 97. Inspirational mood board created to summarise the design research for the direction of the project.



ANNEKA TEXTILES

REF NUMBER: AT001-6
SIZE: S
SEASON: AW20
DESIGNER: CATHRYN ANNEKA HALL
DESIGN : SAMPLE JUMPERS
DATE: March 2021
DESCRIPTION: RECYCLED CLASSIC ROLL NECK JUMPER
DEADLINE: ASAP

LENGTH FROM SNP (FRONT)	70	70
CHEST 2CM FROM UNDERARM	57	57
X SHOULDER	45	45
WAIST 37CM FROM SNP	57	57
WELT WIDTH FRONT	60	60
WELT DEPTH	14	14
BICEP (2.5cm from armhole)	19	19
CUFF WIDTH	11.5	11.5
CUFF DEPTH	14	14
ARMHOLE	27	27
SLEEVE LENGTH	64	64
BACK NECK WIDTH (SNP to SNP)	25	25
FRONT NECK DROP FROM SNP	7.5	7.5
BACK NECK DROP FROM SNP	2.5	2.5
NECK TRIM DEPTH	16.5	15.5
NECK OPENING	20.5	20.5
SHOULDER SEAM	10	10
LENGTH FROM SNP (BACK)	70	70

BODY KNIT CONSTRUCTION: PLAIN KNIT
COMPOSITION: BLEND 5
GAUGE: 7GG
YARN/ COUNT: 2/8Nm NO OF ENDS: 1
COLOUR AS YARN
TRIMS: N/A
SWINGTAGS/ LABELS: TBC

Figure 98. Final Design specification

physical research placed particular focus on the composition of yarns used in knitwear. Knitwear containing acrylic was found across a range of brands and sold at a variety of price points. Where blended with wool, the wool content varied. In general, it was found that the higher the wool content, the higher the price. It was also noted that the high wool-content garments tended to be classic design shapes. However, wool content did not necessarily dictate the price level, since there are other factors at play such as manufacturing quality and the design or lifestyle attributes of individual brands. A cross section of the scoping exercise can be seen in Figure 94.

As highlighted in WGSN's report, 'Knitwear: Core Item Updates A/W 21/22', the scoping also identified the 'roll neck' silhouette as a key core shape. WGSN's update suggestions for this particular shape directly informed the creative design brief, in which over-sized silhouettes, deep rib cuffs and split-seam details were included (see circled key words in Figure 95).

Beyond the shape and update features, the yarn blend also must be designed. Returning to WGSN's 'Conscious Clarity' trend report, in combination with the researcher's own scoping, a trend for soft tactile yarns with a 'blurred' aesthetic was highlighted. In particular, wool content in a mid-gauge yarn was a key focus of the WGSN trend (Figure 96).

To summarise this trend/market research, a mood board was created bringing together inspirational images as a focus for the creative design (Figure 97). From this, the final design and specification was created ready for the yarns to be developed (Figure 98).

10.3 DESIGNING & MAKING THE YARNS

Once a design brief had been created, the yarns could then be designed and developed. Prior to sourcing recycled fibre, a collaboration needed to be agreed with a spinner to spin yarns using both recycled content and synthetic materials. A range of spinning companies were approached that were willing but ultimately unable to help with the research. Barriers that were cited included size, time, cost and contamination. For example, one company explained that the size of the project was too small; another wasn't able to spare the time to work on the project outside of its current production; a third costed the project and at the scale required the costs exceeded the researcher's funding and finally many companies considered the potential contamination of synthetic fibre to their primarily wool production too great a risk.

However, an agreement was finally settled with a small commission spinner using a woollen system to produce ring-spun yarns. Previously, multiple visits to this facility had taken place, and at one of these visits the researcher's test experiment, Practice 7, had been conducted. A good working relationship was developed between the researcher and the spinning engineer during the whole process, and their very different expertise were bought together to create a positive and fruitful collaboration. The research was only able to take place if certain conditions were met, namely complying with the minimum order quantities (MOQs) of 50Kg per yarn (significantly smaller than others that had been approached) and obtaining seam-cleaned acrylic fibre to reduce the contamination during production. The spinner explained that cleaning was a vital step for them in the recycling system because the strong synthetics threads often used in the construction of knitwear causes breakages in the spinning process. Thus, fibres are released into the air which in turn could contaminate other production. Therefore, the next step was to source cleaned recycled acrylic fibre.

10.3.1 SOURCING THE RECYCLED ACRYLIC FIBRE

It had been assumed by the researcher that recycled acrylic, seam cleaned, sorted by colour and pulled/shredded back to fibre, would be easy to obtain. While waste acrylic knitwear is an abundant resource in Europe, finding this waste source that was both colour-sorted and recycled back to fibre proved difficult. This was because acrylic knits in Europe usually flow into mixed colour recycling streams for non-woven materials. Furthermore, many of the European companies able to supply the required fibre could only do so with MOQs of a scale beyond the budget of this research.

A working relationship with an Italian recycling company had been established during Practice 1. As a favour, this company agreed to sell and ship a small quantity of recycled acrylic fibre to the spinner in Yorkshire. The conversation and interview with the Italian recycling company regarding the sourcing of this material led to insights about the sorting system (Appendix 14.1, page 341). As they primarily recycled wool/acrylic blends rather than the desired 100% acrylic, the fibre was only available in navy and black. As with all mechanically recycled fibre, and in line with the interviews conducted with the Italian recycler, the composition of the '100% acrylic' purchased could in fact contain a small percentage of other fibres (section 8.4.2, page 207).

10.3.2 DESIGNING THE YARNS

Once the challenges of obtaining seam-cleaned acrylic fibre had been overcome, a formal meeting was set up to discuss the yarn design. As the company was small, all the research was conducted with the owner who has a vast experience of working in the industry and on the factory floor. This not only gave him the experience to problem-solve, but as the owner he also had the power to make quick decisions. For the remainder of the discussion, he will be referred to as the engineer.

The Italian company providing the acrylic had sent samples of two different qualities of fibre, which were brought to the spinner to assess. The first fibre sample had been pulled to create a better-quality fibre, however as this has been pulled more thoroughly the fibre length was reduced. The second had been 'worked/pulled less' and therefore was expected to be of lower quality but had longer fibre length. The first sample was singled out as most effective for the woollen spinning method the company employed, and this sample fibre was then used to create mini test blend pads. Rather than create the pads using a test machine (as in Practice 7, page 169), a quicker method using hand combing brushes was used to explore many ideas in a short time frame.

Two physical meetings were conducted. For the sake of clarity, the meetings have been described by breaking down the activities into four stages: discussion, exploration, blend testing and design confirmation. While the practice is presented in an obvious chronological order, many of the stages overlapped or happened in parallel to one another. Conversations, for example, were often half finished and returned to at another stage in the same session.

STAGE ONE – DISCUSSION

The meeting started with the company owner in his office and initially the conditions of the research project were established. Namely, this was to use the recycled acrylic as a base fibre, blending with a minimum of 30% wool and spinning for a knitted application. In response, the engineer laid out his own conditions. For example, based on previous experience he was only prepared to produce a yarn with up to 50% recycled acrylic content. This was to ensure ease of manufacture and avoid problems that could lead to a lower yield and higher costs. A further condition relating to the use of shorter recycled fibres meant than there was a limit to how fine the yarns could be. Clearly, a significant amount of co-operation and communication was required to balance the interests of both parties.

These conditions led to some discussion. The designer-researcher explained that in a previous test (Practice 0) 70% recycled content had been used, but in this case the yield had been reduced with more wastage from the process. The engineer was surprised but insisted, based on his knowledge, that a 50% recycled acrylic maximum would be beneficial for the manufacture and final product. This was then agreed.

Further discussion also ensued around the minimum thickness of the yarns. An example yarn was brought into the room to illustrate the engineer's technical explanations. He suggested that we processed the recycled fibres for a knitted application at 2/8Nm yarn count (Figure 101). He added that creating a finer yarn could cause complications in the manufacture. This in turn could affect the cost. If a finer yarn was required, the engineer explained, the blend would have to be adapted, reducing the recycled content. In the end,

Figure 99. The fibres available for blending.

Figure 100. Selecting wool colours

Figure 101. Example yarn brought into the room for context

the minimum yarn count (2/8Nm) met the creative brief for a mid-gauge yarn. These initial conversations about the brief and manufacturability were vital to lay the groundwork for the next three stages.

STAGE TWO – EXPLORATION

The next stage was to decide on a blend for the yarn. The 50% recycled acrylic had already been confirmed and the content of the other 50% was yet to be decided. One of the conditions of the research was to include 30% wool in the yarn, but this still left a range of wool options to consider. Wool is available in many different forms, for example lamb's wool, merino wool and cashmere, and all of these could be used within the experiment. With the overarching aim of the research being to design for recycling value, the recycling system would equally accommodate other protein-based fibres such as yak, mohair or angora. The 30% wool content, therefore, could be comprised of a variety of combinations. However, given the constraint of large MOQs for purchasing most fibre types and colour ways, this limited the fibre choice to those held in stock by the spinning company (Figure 99).

The remaining 20% of the blend could be made up of any material as long as the design did not negatively impact onward recyclability. During this decision-making process the merits of including man-made fibres were debated. The engineer was very knowledgeable about the origins of the different fibres, their performance/function and cost. For example, nylon was described as very strong and soft but could only be added in small quantities to this particular spinning process (woollens) because, as the engineer advised, it would cause problems during manufacturing. Polyester again was strong but had a harsher "squeaky" hand feel and, as the engineer explained, polyester is more prone to pilling in the final material. He also highlighted that unlike yarns used for the warp in woven applications, where synthetic content would be added for strength, this was not an issue for a knitted application. However, synthetic content is often added to yarns for knitwear because of their cost benefits, with polyester being the cheapest fibre available.

A further consideration made when selecting materials for blending was the impact they would have on the texture and hand-feel of the yarns. While the recycled acrylic fibres felt very soft in fibre form, as discovered in Practice 0 and 7, this softness disappears when spun into yarn. The engineer explained, however, that during the spinning process finer fibres (such as acrylic) are forced to the middle of the yarn and coarser fibres (such as wool) would be brought to the outside. The condition of blending 30% or more wool would overcome some of these issues. The remaining part of the blend, therefore, needed to be considered carefully. This level of expertise and collaboration significantly helped to narrow the designer-researcher's final choices.

Colour was another aesthetic consideration. Choosing colours to blend together at fibre level was more complex and entirely different to the design-researcher's previous experience in selecting colour palettes for textiles or a garment collection. The process of blending colour at yarn level is more akin to the painter's experience of mixing paint. In order to explore how this worked the engineer suggested the conversation moved upstairs to the factory floor. Here, he showed a blend of fibres waiting to be carded and spun: mainly beige with streaks of deep brown, white, bright yellow and orange (Figure 102) that would be used to create a uniform beige shade (Figure 103). This illustrated what the engineer had been trying to explain downstairs.

It was during this time on the factory floor that the possibilities for blending expanded. Discussion ensued amongst the rattles of the machines about the priority of sustainability within the project. Keen to know whether other recycled content would meet the research conditions, the engineer suggested some pre-consumer cashmere waste could be used. In earlier visits to this and other companies, the designer-researcher had been advised that using pre-consumer waste was not a viable option due to limited quantities of any single colour. This engineer's suggestion therefore pleasantly contradicted his previous reluctance to use anything but virgin materials. This meant that with the relatively small-scale (in industry terms) of the research project, using the pre-consumer waste would be possible.

From his back-storage room the engineer produced a box of pink and brown 'roving' cashmere waste. This type of waste is the product of the roving stage that occurs after carding and before spinning. Although previously considered to be too costly, the engineer suggested this might be used in a small quantity in a blend to improve the hand feel. Using the waste cashmere was thus a mutually beneficial proposition. While using a waste product cut the cost of cashmere content by a third for the designer-researcher, for the engineer, it was making good use of waste that was too small in quantity for a production run of its own. The engineer was quick to point out, however, that if it was to be used as a blend for this research, repeatability might be an issue. While the brown could be easily replicated by taking lighter coloured cashmere waste and overdyeing it, this would not be an option with the lighter shade of pink.

Out of this exploration with the engineer and the variety of blending options discussed, the designer-researcher concluded that a small range of yarns should be produced and compared to establish best practice. At this stage it was thought that three different yarn blends would provide sufficient comparison. A final discussion regarding the cost of the resulting yarns verses the aims of the experiment was not as easy to resolve. Given the designer-researcher's aim was to create a wool blend yarn suitable for the mass market the experiment's relatively small production size meant it would not be comparable. While the research would not be able to draw any formal conclusions on cost it was concluded that the range of yarns proposed for the research should be designed to represent the different market levels (standard to luxury). This would ensure that cost aspect of designing was not completely removed from the discussion.

Figure 102. Fibre blend - beige, brown yellow and white - waiting to be processed

Figure 103. Carding process combing the fibres ready for spinning.

STAGE THREE – BLEND TESTING

BLEND 1

The third stage of the experiment was conducted in the testing room. This held the small-scale carding machine which had been used as part of Practice 7. On this occasion hand carding brushes were used to simulate the process of combining fibres (Figure 106). The exact amount of fibre to be blended was calculated on an old set of miniature scales (Figure 105). The process created a small blended fibre pad which could be mock spun in order to visualise the yarn (Figure 107).

The blend testing started simply and built up to the more complex blends. The first blend was comprised of the agreed 50% recycled acrylic and minimum 30% wool. The remaining 20% would consist of a cheaper man-made fibre. This represented the most standard blend type within the conditions of the test. When designing the colour of the yarn, the engineer recommended extremely bright and more contrasting colours to produce a more dramatic final yarn. From the available stock colours, the designer researcher selected two bright shades, a blue and a turquoise to complement the navy acrylic (Figure 104). Without any samples of synthetic fibre in stock, black wool was used as a substitute. The final synthetic content would be decided later in the process. The result of using brightly coloured wool yarns highlighted their coarser textured appearance against the finer acrylic. The result met the creative 'soft blurred' brief and the colour and composition was confirmed as the first yarn blend.

Figure 104. Blend 1: blending test fibre combinations

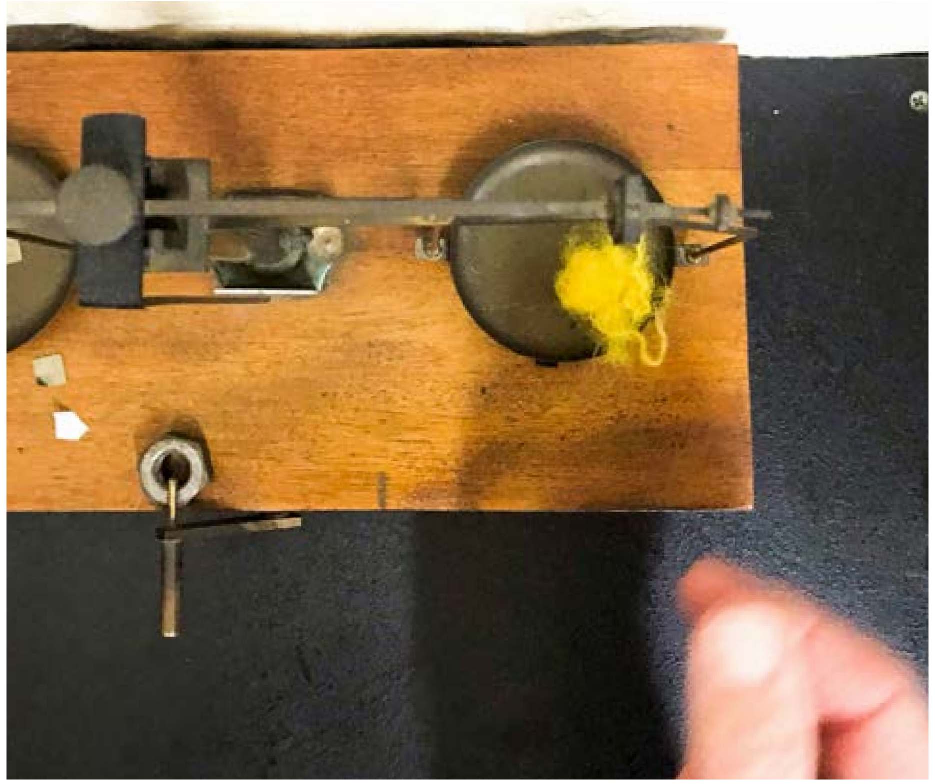


Figure 105. Scales used to weigh out the fibres for a small blend test

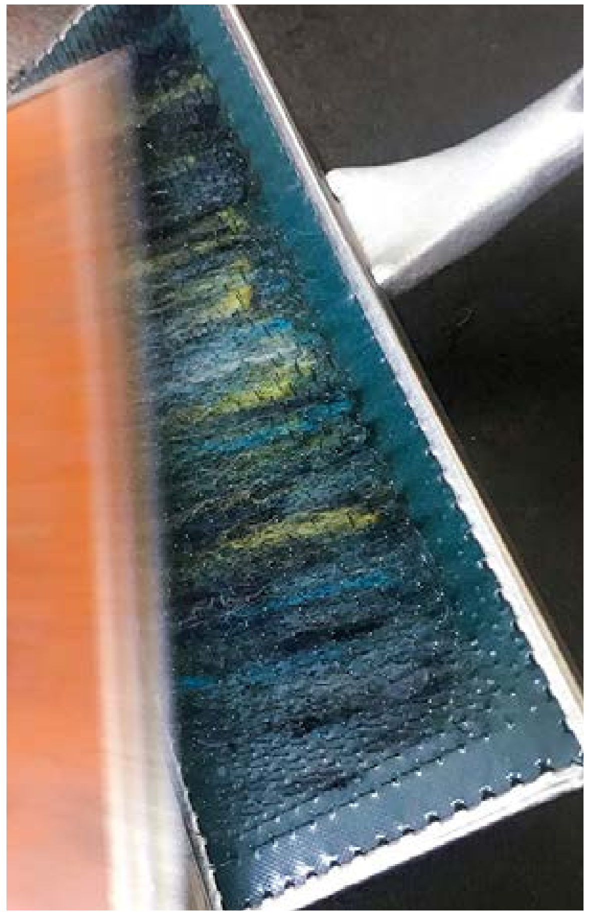


Figure 106. Hand carding brush used to comb the fibres and blend them together

Figure 107. Blend 1: blended fibre pad and mock yarn

Figure 108. Blend 2: blending test fibre combinations

Figure 109. Blend 3: blend test with brown cashmere and blue/grey silk neps

Figure 110. Blend 3:Blending test with cashmere and silk

BLEND 2

The second blending test was conducted in response to the market research findings. During one of the retail visits it had been noted that many of the knits contained a percentage of luxury fibres. The luxury content of these jumpers were marketed with labels such as 'cashmere mix' or 'mohair blend'. The long fibre quality of mohair in particular was used by brands to create a more dramatic textured appearance. As the engineer explained, mohair would be difficult to obtain in small quantities, although in this instance he was able to offer a mohair blend (mohair, cashmere and wool) leftover from a larger order. This was formed of tropical colours (honey bird and lemon shades) to which some stock white mohair could be added to make up the total 'luxury' content required for the final yarn. In combination, these colours were not dissimilar to the Blend 1 and would provide a good visual comparison (Figure 108).

To fulfil the aim of creating a small range of yarns to compare, the designer-researcher decided to increase the wool/other animal-based fibres content of Blend 2 from 30% to 50%. Without the addition of any synthetic material, Blend 2 would therefore represent a more luxury yarn in line with the market research.

BLEND 3

As the blending tests progressed it was clear the engineer had a preference for luxury fibres. These would make what he described as 'beautiful' or 'quality' yarns. It was partly for this reason that waste cashmere (as previously described) was suggested to be used for the research. In addition to cashmere, silk was also advocated. The engineer explained that using silk would create a smooth feel to the fibres. Also if a mix of three or four colours were incorporated, some of the silk would form multi-coloured neps in the final yarn. To demonstrate this, the engineer selected a range of colours (green, red and blue) and started blending these with the pink cashmere and navy acrylic. The designer-researcher was concerned about this suggestion for two reasons. First, silk was not strictly suitable for the wool recycling process she was designing for. Second, the colours were not harmonious and her tacit knowledge as a designer meant she took an instant dislike to the combination. In addition, as a researcher she was concerned for the impact of the colour contamination for the future sorting and recycling processes. However, this form of quick experimentation was a useful tool for taking risks and so she stood back and waited for the result. Ironically, the resulting fibre had a distinct 'recycled' aesthetic. The engineer agreed that the combination of navy and pink created a sludgy purple base and the mixed coloured neps looked like a more uniform colour contamination (Figure 110).

A second attempt was made to create a silk/cashmere blend. This time the brown cashmere waste was used, and the designer-researcher requested permission to select a range of harmonious colours - grey and light blue (Figure 109). The result was much more appealing, however, the researchers concern for onward recyclability was enough to drop this blend from the range. Additionally, she concluded that the inclusion of silk had not been seen during the market or trend research. In this specific instance, the blend was unsuitable.

A final version of Blend 3 was tested removing the silk content. The aims of the research were at the forefront of the designer-researcher's mind during the selection process. She reflected on the composition of both Blend's 1 and 2 and how these represented standard (30% wool) and luxury (50% wool) approaches to blending. To produce a range of options, Blend 3 would therefore need to be designed halfway between the two. To achieve this, Blend 3 used the composition structure of Blend 1 (50%, 30% 20%), but incorporated a small amount of luxury content more akin to Blend 2. The resulting composition was 50% recycled acrylic, 20% cashmere, 10% wool (forming the desired 30%) and 20% additional synthetic. Once again for the test, black wool was used in lieu of the unavailable synthetic fibre.

The colours in this case were dictated mainly by the availability of fibres. For example, navy had been pre-chosen for the recycled acrylic; pre-consumer waste cashmere was provided in brown and small quantities of synthetic materials could only be obtained in black or white. Black had been selected for all the yarns to deepen rather than lighten the yarn shades. An exception was the 10% wool content, and this could be selected from range of stock colours. A 'slate' blue was chosen to compliment this dark colour range (Figure 111). This resulted in a deep but grungy blur of colour suitable for the brief.

Figure 111. Final colours and components of Blend 3

STAGE FOUR – DESIGN CONFIRMATION

The final stage of the design process was to finalise all the blending decisions for production. This occurred both at the end of the first meeting and during a second meeting a few weeks later. The conversation focused on the type of synthetic that would be used in the blends. The discussion went back and forth between the different synthetic materials which could be used. Firstly, nylon (also known as polyamide) was discussed. This was highlighted by the designer-researcher as a popular blending agent seen during the market research. Furthermore, in the recycling industry both nylon and polyester are known to be used when creating yarns in Prato. For onward recyclability, neither material type was deemed problematic as both these types of fibre were most likely present in the recycled acrylic-mix being used in the test.

The engineer explained that the major differences between the two fibres were hand feel and cost. He brought out two examples of test yarns for comparison; one blended with a small amount of polyester and the other with a small amount of nylon. After studying the yarns, the designer-researcher established that there was only a small difference between the feel of yarns, the nylon being slightly softer. Yet, the cost was more dramatic; the nylon fibre was almost double that of the polyester.

Figure 112. Commercial wool blends one with polyester and one with nylon

BLEND 4 & 5

During this discussion, the designer-researcher decided that it would be prudent to spin a 'control' yarn without any wool content for a direct comparison. In line with all the other blends this would contain the same 50% recycled acrylic but would be blended with 50% synthetic. At this point the engineer pointed out nylon could not be used in such high quantities in the woollen spinning process. Therefore, for the sake of consistency the use of nylon was discounted from the research. Virgin acrylic was also put forward as an option. This was appealing as it would increase the acrylic content making the final yarns more mono material, but the researcher also had concerns from a sustainability standpoint and using this virgin material might encourage further a very harsh, chemical based virgin production process. However, the MOQs for acrylic were significantly large to prohibit its use in the test. Thus, the decision was taken out of the designer-researcher's hands and polyester was confirmed for all blends requiring synthetic content. In the spirit of experimenting with recycled materials, the engineer advised he was able to source a recycled polyester fibre produced from plastic bottles. The use of recycled polyester in this form is very commonplace within the mass market.

The addition of the control yarn, which represented the most basic blend, lead the designer-researcher to reflect on how the yarns might be analysed. Solely from the perspective of composition, the three blends and the control provided a good range to be compared. However, visual comparisons might be limited as the control yarn would only be comprised of navy (recycled acrylic) and black (recycled polyester), rather than a blend made up of numerous shades (as in Blend 1, 2 and to a lesser extent 3). To overcome this barrier a repeat of Blend 1 was confirmed, replacing the bright coloured wool with black to ensure a visually unbiased comparison could be made. This repeat of Blend 1 in an alternate colourway was confirmed as Blend 4 and the control yarn was confirmed as Blend 5. It was considered necessary by the designer that the original coloured blends remained in the range as this also might yield results during the comparisons of the materials.

BLEND 6

Finally, a sixth yarn was added to complete the range. This was to have a thicker yarn count (2/4.25Nm), which would be produced to establish if yarn count affected yarn quality, yield and manufacture. All the blends up until this point had been designed at the finest count the engineer was willing to manufacture when incorporating 50% recycled content (2/8Nm). Once again for a direct comparison a repeat of a previous blend was used (Blend1). Blend 6 was confirmed, and this finalised the six yarns to be produced.

10.4 SIX BLENDS – SIX YARNS

Table 16. Six Yarns

	%	TYPE	FIBRE	COLOUR	COUNT	CLASSIFICATION
1	50%	Recycled	Acrylic	50% Navy	2/8Nm	Standard
	30%	Virgin	Wool	30% Black		
	20%	Recycled	Polyester	20% Black		
2	50%	Recycled	Acrylic	50% Navy	2/8Nm	Super Lux
	17%	Virgin	Mohair	17% White		
	24%	Virgin	Mohair/ Wool/ Cashmere	12% Lemon 12% Honey Bird		
	9%	Virgin	Wool	9% Black		
3	50%	Recycled	Acrylic	50% Navy	2/8Nm	Lux
	20%	Recycled	Cashmere	20% Brown		
	20%	Recycled	Polyester	20% Black		
	10%	Virgin	Wool	10% Slate		
4	50%	Recycled	Acrylic	50% Navy	2/8Nm	Standard
	30%	Virgin	Wool	10% Black 10% Green 10% Turq		
	20%	Recycled	Polyester	20% Black		
5	50%	Recycled	Acrylic	50% Navy	2/8Nm	Basic
	50%	Recycled	Polyester	50% Black		
6	50%	Recycled	Acrylic	50% Navy	2/4Nm	Standard
	30%	Virgin	Wool	10% Black 10% Green 10% Turq		
	20%	Recycled	Polyester	20% Black		

Figure 113. Snapshots of some of the spinning processes. Top from left to right: blended fibre, blended fibre going into the carding machine and the carding process. Bottom left to right: laying the fibres, roving and winding.

Figure 114. Final six yarns

Figure 115. Six Knitted swatches

Figure 116. Prototype garments

Each of the six fibre blends were spun adhering to the spinning company's MOQ (50kg). The engineer advised that while 50kg of fibre would be used at the beginning of the process, the yield (resulting amount of yarn) could be lower depending on the success of processing of each blend type. The total yarn produced for all six yarns was 286Kg. Table 16 summarises the designs of all six yarns which can be seen in Figure 114. Once spun each yarn was sent to a knitting factory to be knitted into swatches (Figure 115) and for prototype garments to be developed (Figure 116).

10.4.1 REFLECTION ON MANUFACTURE

After the production of the yarn and swatches both the spinner and knitter recounted that there had been no major issues in the creation and use of the yarns. The spinner did highlight that some small adjustments to the spinning machinery was required at the start to avoid breakages in the yarns. While he reasoned that this was caused by the short fibres of the recycled content, this issue was easily overcome.

The engineer also noted that when breakages did occur there was some amount of 'fly' (fibres that fly into the air as the yarns break), which can cause cross contamination between spinning batches. This, he explained, was a minor issue and only to be expected with the use of recycled fibres. Furthermore, he added, the winding process had gone smoothly with no more than the expected number of faults.

Most noteworthy from the spinning engineer's feedback was that there had been no discernible difference between the carding and spinning of any of the six yarns. While all the blends contained the same 50% recycled acrylic content, the remainder of each blend ranged from polyester (Blend 5) to wool/cashmere/mohair (Blend 2). This meant that all six yarns proved viable for use in the commercial knitting industry.

The researcher noted that there were variations in the yields of the yarns (Table 17 overleaf). The engineer explained, however, that this was a 'normal' result of the manufacturing process and not in any way related to the differences in yarn content. In a later, more in-depth discussion, he explained these discrepancies. He first pointed out that Blend 3 had the lowest yield (35.70Kg) simply because it had been the first blend put into production. This was used to set up their machine parameters and inevitably created more wastage. Blend 6, on the other hand, had the highest yield (48.90Kg). This was put down to the sequence in which the yarns were processed. Having the same fibre composition and colour as Blend 1, Blend 6 was produced directly after Blend 1 and so incorporated all its spinning and setup wastage.

The next highest yield was Blend 2 (43.9Kg). The engineer put this down its zero polyester content. As he explained, unlike acrylic and wool, polyester takes little or no moisture from the atmosphere and this aids the manufacturing process. Furthermore, he added, man-

Table 17. Six Yarns Yield

	%	TYPE	FIBRE	COLOUR	YIELD (KG)
1	50%	Recycled	Acrylic	50% Navy	**38.90**
				30% Black	
	20%	Recycled	Polyester	20% Black	
2	50%	Recycled	Acrylic	50% Navy	**43.90**
	17%	Virgin	Mohair	17% White	
	24%	Virgin	Mohair/ Wool/ Cashmere	12% Lemon	
				12% Honey Bird	
	9%	Virgin	Wool	9% Black	
3	50%	Recycled	Acrylic	50% Navy	**35.70**
	20%	Recycled	Cashmere	20% Brown	
	20%	Recycled	Polyester	20% Black	
	10%	Virgin	Wool	10% Slate	
4	50%	Recycled	Acrylic	50% Navy	**42.00**
	30%	Virgin	Wool	10% Black	
				10% Green	
				10% Turq	
	20%	Recycled	Polyester	20% Black	
5	50%	Recycled	Acrylic	50% Navy	**41.60**
	50%	Recycled	Polyester	50% Black	
6	50%	Recycled	Acrylic	50% Navy	**48.80**
	30%	Virgin	Wool	10% Black	
				10% Green	
				10% Turq	
	20%	Recycled	Polyester	20% Black	

made fibres such as polyester break less at the carding stage because they are smooth and strong. Nature fibres, in contrast, have many deviances so are more likely to break and generate wastage. This goes some way to explain the middling yield of Blend 5 (41.7Kg) and is perhaps one of the reasons the industry uses synthetics when creating recycled materials.

Despite their different colourways, Blend 4 and Blend 1 had the same fibre composition. Yet their yields varied considerably (42Kg and 38.9Kg respectively). The engineer clarified that the ratio between the weight of the fibre input and the weight of the yarn output would appear more significant in such relatively small batches. As he pointed out, if the experiment had been conducted on a larger scale, such as 500kg, the setup waste (estimated at 4-5kg) and end of batch waste (estimated at 3-4kg) would represent less than 2% total wastage. By contrast in this experiment, the 9kg of estimated waste represented 18% of the 50kg batch. Furthermore, the variation in yields was in no way related to their recycled content.

10.4.2 REFLECTION ON THE DESIGN

This section provides an evaluation of the yarns and garments described from the designer's perspective. The main insights have been divided into three categories: colour, hand-feel and classification. Across these sections the look of the yarns and their tactile qualities, the finishing processes used and the impact of the blending choices will be discussed.

COLOUR

The designer-researcher was aware that the colours selected for the yarns might positively bias her final evaluation. The influence of colour was almost immediately obvious when the swatches were first received. Blend 1 and Blend 2 were the most visually impactful, with their turquoise tones popping brightly against the navy acrylic base. The plainer navy tones of Blend 4 and Blend 5, in contrast, negatively biased her evaluation of their overall quality. This was most noticeable when comparing Blend 1 and Blend 4 (Figure 117 and Figure 118), which had identical fibre composition. Without reading the labels, Blend 1 was automatically preferred as more luxurious-looking. Blend 4, with its mix of only two colours, produced a far flatter appearance.

The range of colours in Blend 2 were most visible, with its mix of navy, blue, yellow and white (Figure 120). Whereas Blend 3 could almost be mistaken for a single shade of navy from afar, despite its subtle depth created by brown and blue tones (Figure 121). This analysis of colour was then taken into account when comparing the yarns for their other qualities.

Removing colour from the equation, Blend 4 and Blend 5 that contained only navy and black fibres were compared. It was surprising to find that there was very little discernible difference between the two. It had been anticipated that Blend 5 (50% recycled acrylic and 50% polyester) would look significantly shinier and flatter than the other yarns which contained wool. However, without the use of colour as a visual tool for comparison, Blend 4, with its additional 30% wool, looked almost the same as Blend 5 (Figure 119). This impression altered, however, when the yarns were viewed as a garment rather than as a swatch. This illustrated the importance of testing through all the stages from yarn to product to establish micro and macro differences in material qualities.

Figure 117. Blend 1 knitted swatch

Figure 118. Blend 4 knitted swatch

Figure 119. Blend 4 (right) and Blend 5 (left) knitted swatches

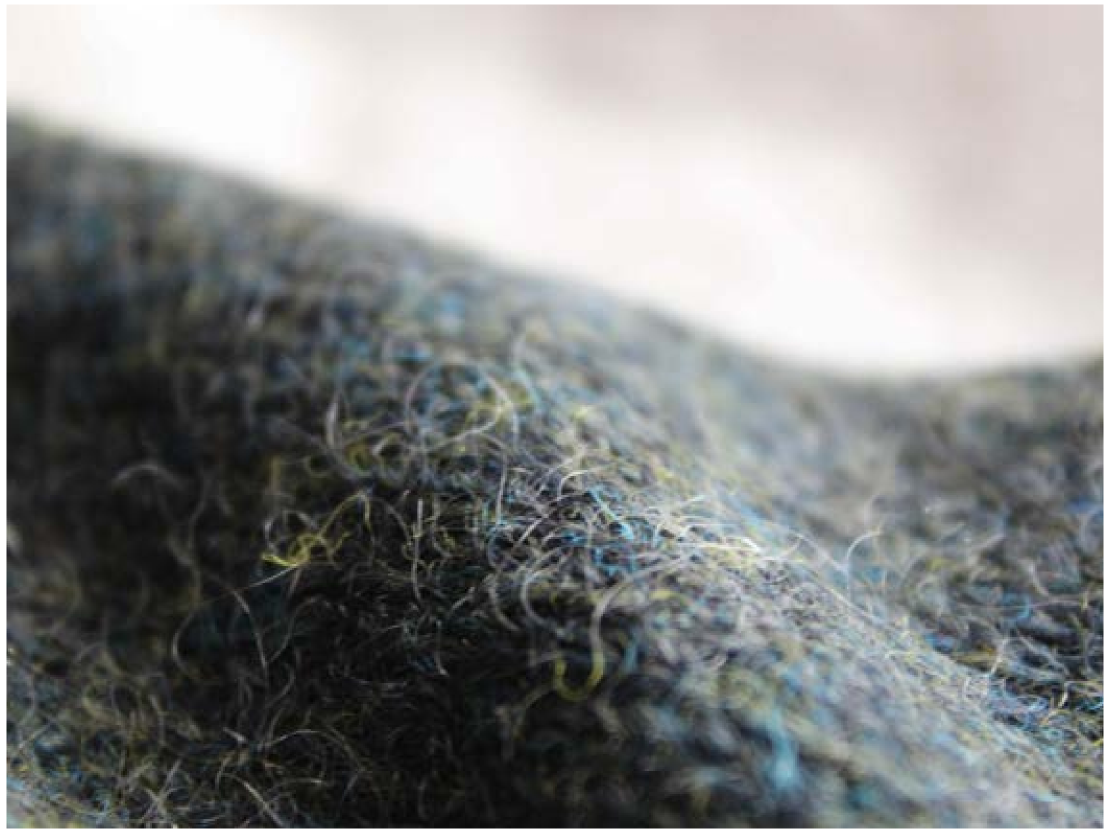


Figure 120. Blend 2 knitted swatch

Figure 121. Blend 3 knitted swatch

HAND-FEEL

All the knitted swatches had been finished by washing and pressing. As expected, the softest swatches were those containing cashmere and mohair (Blend 2 and Blend 3). Once again, the designer-researcher was surprised that the high polyester content of Blend 5 did not produce such a 'squeaky' feel. This was perhaps due to the softness of the recycled acrylic fibre.

Once again, the reflections made on the knitted swatches changed when the knitted prototype was created. First Blend 1 was knitted into the designed funnel neck jumper (Figure 116 on page 249). As the funnel neck sits next to one's skin, the feel of the wool content is apparent, and although not unpleasant to the designer-researcher, when compared to the knitwear products incorporating softer synthetics in the current market, it might feel harsh to some consumers and possibly be problematic for those sensitive to wool against their skin.

From the author's previous experience as a commercial designer, hand-feel is an important attribute to any knitted design. While some textiles demand dry or crisp hand-feel, the wool/acrylic knits demand softness. The attribute 'soft' could make the material more commercial, but often at the expense of durability. While softness can be designed using expensive luxury fibres (such as in Blend 3 with its addition of cashmere), 'softness' can also be added after production in the finishing stages. To address the need for softness, subsequent swatches were actioned using more softener in the washing of the knits. This dramatically improved the hand-feel of the textiles and served to illustrate that attributes can be designed into textiles at any point in the manufacturing process. This is particularly relevant for overcoming the challenges of using recycled content and highlights that solutions can be found at any stage from yarn through to final garment.

CLASSIFICATION

The yarns themselves had been designed and classified to reflect the value they would obtain as products (see Table 16 on page 244). For example, Blend 2 with its 50% wool/cashmere/mohair content was classified as 'super lux'. At the next level down Blend 3 was classified as 'lux' due to the 20% cashmere content. This was followed by Blend 1, Blend 4 and Blend 6 being classified as 'standard' with their 30% wool content and finally the most basic blend, Blend 5, which contained only synthetic fibres. However, when these products enter the sorting systems, they are valued strictly according to their fibre content. In particular, wool is valued above synthetic content. This highlights the widening gap between the way we design our textiles into products for market value and the recycling value of these resources at the end of life.

10.5 TESTING RECYCLING VALUE

The final element of the research was to test the six yarns in the form of knitted swatches with automated recycling (Fibersort machine) and hand sorters within the textile industry. This was to establish if the materials had increased in value when they re-entered the acrylic/wool recycling system. It should be noted that this testing did not take place to establish how accurate both the hand sorters and the Fibersort machine were in their assessments. This would be impossible without a comprehensive composition test of each yarn to confirm their content. However, as this research has been conducted to understand how to design with tricky and often unknown compositions of waste, obtaining an exact composition would not be representative of how the materials are sorted in industry. The aim of these two tests, therefore, was to explore the realities of sorting and the challenges and opportunities this presents for designers. Hand sorting and automated sorting were both selected to understand the differences between the traditional and newer methods used to sort post-consumer textiles.

To accomplish this, six knitted swatches were sent to both hand and automated sorting facilities to ascertain the generic recycling grades they would now flow into. For the hand sorting evaluation, a visual-tactile approach (Kitaguchi et al., 2017) drawing on the tacit knowledge of the expert hand sorters was used to ascertain the percentage of wool present (Botticello, 2012). In addition, the swatches would be tested by automated sorting machinery to compare the recycled swatches with the library of known fibre blends (Circle Economy, 2019).

For the sake of continuity, the owner of the hand sorting business 'Recycle Wool' based in Pakistan, Hasnain Lilani, previously interviewed regarding sorting grades (section 8.4.1, page 199), was sent the swatches to test. The content of the yarns was not disclosed and could only be identified with a number (1-6). Five sorters with various areas of expertise were asked to identify the assumed compositions of the material and determine which sorting grade they should enter into.

Furthermore, six duplicate swatches were sent to be tested using the automated textile sorting machine, the 'Fibersort'. The Fibersort was selected for the test because the findings of the Circle Economy (2019) that had tested the machine had also been used to inform the generic sorting grades (section 8.4.1, page 203). Again, the assumed composition of the swatches was undisclosed prior to the test.

10.5.1 AUTOMATED SORTING TESTING RESULTS

The first test saw six swatches sent to Belgium to be scanned by the Fibersort automated sorting machine. The results of the first attempt were unreadable, leading to the Fibersort project engineer enquiring if any coatings had been used in the development of the swatches. This, he explained, could interfere with the results. As no coatings had been applied it was speculated that the softener used at the finishing stage might be the cause. In addition, the designer-researcher explained that the yarns contained percentages of virgin and recycled fibres that had been dyed, such as the virgin wool fibres or the recycled polyester from plastic bottle sourced in black. In return, the Fibersort project engineer highlighted that normal inputs were very old garments (ready for recycling) that would have been washed many times. It was concluded that hand washing the swatches, multiple times, before re-testing might help to replicate this quality. The results of the second test are presented in Table 18.

Table 18. Fibersort testing results of all six swatches after hand washing and which fractions previously established (Circle Economy, 2019) they would flow into.

SWATCH	ACTUAL	PREDICTION			FIBERSORT FRACTION
	WOOL %	WOOL %	ACRYLIC %	OTHER %	
1	30	40	60		Wool 30, Acrylic 70
2	50	8	92		
3	30	40	55	5% Nylon	Wool 30, Acrylic 70
4	30	40	60		Wool 30, Acrylic 70
5	0		INCONCLUSIVE		
6	30	20	80		Wool 30, Acrylic 70

There were two anomalies in the results. As Table 18 demonstrates the results of Blend 5 were inconclusive. While it had been first speculated that the cause for this was possibly the dyed polyester present, it was later established that the recycled acrylic fibre could have been put through an overdyeing process (see Interview with Recycler X Appendix 14.4, page 348). Further testing would need to be conducted to establish the exact reason for this result, but this fell outside the scope of this research. The results for Blend 2 were significantly different to the actual composition. In particular, the 'wool content' comprised mohair (26%), pure wool (23%) and cashmere (2%). The results, therefore, could have been skewed by the high percentage of mohair fibre which in this research has been classed as 'wool'. However, again no full conclusions could be drawn without further testing.

All the other blends (Blend 1, 3, 4 and 6) fell just within a 10% tolerance. Blend 1, 3 and 4 results indicated 10% more wool than was actually present. Blends 1 and 4 had identical compositions with 30% wool, whereas Blend 3 was made up of both wool (10%) and cashmere (20%). The results suggested that all three of these blends (1, 3 and 4) contained 40% wool. This percentage sits on the edge of two sorting thresholds established in the Fibersort sorting accuracy test conducted by the Circle Economy (Table 19). While technically this result is not over 40%, which is the requirement for the garments to enter the 'Wool 50, Acrylic 50' fraction, the result is very close. However, it does confirm that as designed the materials have moved into the 'Wool 30, Acrylic 70' fraction and therefore have increased in value at the sorting stage.

Table 19. Wool/Acrylic blends Fibersort sorting accuracy results used to compare with the results of Fibersort test in this thesis (Circle Economy, 2019:2)

FRACTION %	THRESHOLD %	COMPOSITION %
Acrylic 100	>95	97
wool 50, Acrylic 50	>40, >40	42; 58
wool 30; Acrylic 70	>20; >60	27; 73

As all the yarns also contained 50% recycled acrylic fibre this may offer an explanation for this elevated wool percentage. Recycler X, who supplied the acrylic fibre, explained in his interview that when you are sorting for high acrylic content, you might "find 95%, 90% or 85% acrylic and 5% or 10% or 15% wool - it depends" (Appendix 14.1, page 341). Therefore, the final yarns could contain a higher content of wool than originally designed. By Recycler X's estimations this could be as much as 15% acrylic content. As the acrylic represents 50% of all the blends, this would equate to up to 7.5% additional wool content in each yarn. If this was the case it easily could explain the results of Blend 1, 3 and 4. However, the lower wool content results for Blend 6 does not fit this pattern. Blend 6 was a thicker yarn with a lower yarn count, and this may have had an effect on the readings. While no formal conclusions could be drawn without additional testing, it does serve to illustrate the complexity of sorting waste textiles.

This 'unknown' element of Designing for Recycling Knitwear provides the challenge when using recycled content. This is often stated as the reason why the fashion industry avoids using recycled fibres in production (Elander and Ljungkvist 2016). However, as it has been demonstrated by this sorting test the materials are not completely unknown, they just fit into wider thresholds than the virgin production industry is used to dealing with. The issue isn't the material's content, rather how we can design using these fibres to create yarns, materials and products. In turn, these products are designed for specific markets and it is these markets that are the crux of the problem:

> The Fibersort sorts for these fibre categories, or grades, because these are the post-consumer textiles that have an end market and can be used for textile-to-textile recycling purposes, currently or in the near-term. Additional grades may be added and sorted for in the future depending on market demand (Fibersort, 2018a:4).

The market for which a fibre should flow into is also a matter of perspective. According to the fractions offered by the Fibersort research, there currently is a gap in sorting for any

Figure 122. Hand Sorters touching the swatches to assess the wool content, Image Credit: Hasnain Lilani

material that contains between 5% and 20% wool (Circle Economy, 2019). We can assume no market was found for them within the scope of the Circle Economy's research. The challenge for designers Designing for Recycling Knitwear is to use these complex fibres and design pathways to alternative markets.

10.5.2 HAND SORTING TESTING RESULTS

Five sorters (A-E) from the 'Recycle Wool' sorting facility were selected to assess the knitted swatches. Sorter A was the team leader and had the most experience; sorters B and C were experts in sorting cashmere; sorters D and E had the least experience and had been working for a little over two years.

Sorting by hand is not an exact science and therefore accurate results were not expected. Once again, as with the automated testing, the swatches were sent in their 'new' state and did not represent old garments that had been washed many times. This may go some way in explaining some of the inaccuracies in results. However, the results shown in Table 20 (overleaf) highlight that on four occasions the swatches were accurately identified by three of the sorters (A, B and E). The most accurate results were produced by the team leader (Sorter A) who holds the most experience.

As the data shows, on the whole, Sorters B to E over-estimated the wool content of all six swatches. In all but two cases, they

Table 20. Hand Sorters (A-E) wool content estimations for knitted swatches 1-6. Estimations in bold have been correctly identified.

WOOL CONTENT %		A	B	C	D	E
BLEND 1	30	15	70	100	70	80
BLEND 2	50	30	**50**	80	100	80
BLEND 3	30	15	90	80	70	100
BLEND 4	30	**30**	100	70	50	80
BLEND 5	0	30	30	70	70	**0**
BLEND 6	30	**30**	70	80	100	90

placed them in sorting grades of 50% wool or more. While the yarn blends 1,3, 4 and 6 were specifically designed to up-value the recycled acrylic fibre into the 30% wool category, in this test, the sorters' estimations doubled, and in some cases tripled, their wool value. In contrast, Sorter A made lower, and far more accurate, evaluations of wool content. This highlighted the importance of skill and experience in the sorting process. For this reason, the evaluations of only Sorter A will be considered going forward.

As it can be seen in Table 20, Sorter A's correctly identified the wool content of Blends 4 and 6, while in Blends 1,2 and 3, he under-estimated the wool content. Finally, Sorter A inaccurately assessed the presence of 30% wool in Blend 5 where there was none. As described before, there could be up to 7.5% wool content in this blend, but this is far below the estimated composition. This could be an anomaly but also goes some way to explain the need for thresholds around the sorting grades provided in Chapter 8 (section 8.4.3, page 208). It supports the inconsistences in sorting described by Recycler X (Appendix 14.1, page 341) which need to be understood and harnessed in order to appropriately design recycled materials going forward.

The aims of this research have been to design a yarn that combines low value recycled acrylic fibre with wool in order to raise the value of the acrylic fibre at the sorting stage. Judging all six blends as containing at least some percentage of wool therefore, seems to largely fulfil this aim. However, Hasnain Lilani's recycled wool sorting company only value 50% wool or above. Therefore, regardless of Sorter A's classifications, all swatches fall into a general low wool category. While this does sit above 100% acrylic, further understanding of the swatches' value in the recycling system needs to be established.

10.5.3 SORTING IN DETAIL

To understand the implications of these sorting results a second interview with Hasnain Lilani (2020b) was conducted (see Appendix 14.3, page 344). During the interview Lilani illuminated that while the focus of his business is on high-percentage (50% and above) wool waste, he had recently expanded into low percentage wool because of market demand. He continued to explain that this lower value wool waste would be used by his clients (recyclers) to reduce the price of the yarns and materials they were producing. Lilani confirms what Recycler X suggested in his first interview (Appendix 14.1, page 341), that the blending of different sorted grades as a method to amend value does not occur during the sorting stage but during the manufacturing/blending stage. Lilani explained that combining different grades at the sorting stage would cause problems for his facility's quality standards.

Alternatively, as Lilani expands, this grade could also be used for pillows or blankets. Here Lilani is describing two different markets. First as flocking for the inside of cushions and yarns for use in blankets, which are both supplied to markets in Pakistan/India. Second as relief blankets for the charity sector. These represent what is generally considered the range of low value options for low-wool content textiles and this also extends to recycled acrylic. While Lilani describes 100% acrylic as 'completely wasted', this comes from the perspective of a sorter of wool. As the literature has illuminated recycled acrylic does hold some value - even if it is very little - and is used for the same markets as the low-wool grades Lilani describes. Therefore, the results from Sorter A have demonstrated that through design, acrylic has been blended and spun into a new yarn which not only has moved up a step in the resource spiral (acrylic to low-wool), but has been directed towards an entirely new market (knitted clothing). Further discussion can be found in Chapter 11 (section 11.1, page 265).

In addition to his comments regarding fibre type, colour was also discussed in relation to the swatches. Lilani illuminates that three of the yarn swatches would be categorised as 'melange' yarns. Yarn 1 and 6 combined turquoise, green and black with the recycled navy to produce a deep turquoise melange. Yarn 2 took an even bolder approach to colour, combining white, lemon (yellow), honey bird (bright turquoise) and black with the navy to create a bright turquoise melange with pops of yellow. The remaining three yarns would all be considered 'solid' colours as the colour combination were very subtle. For example, Yarn 3 combined brown, black and slate (grey/blue) with the navy, whereas Yarn 4 and 5 blended black and navy to produce a very deep navy shade. While sorting solid colours is desirable, melange garments can also be sorted into 'double tone' grades. Lilani warns, however, that there is not always enough quality to create a full batch. Solid colours therefore hold the highest value, acting as a reminder that value is not only attached to the fibre type of the garments. This point was emphasised by Lilani at the end of the interview in which he explained the following:

> "There are people that prefer to use this fancy material in local market products....most of the customers want to take these materials because they are less expensive. The quality is really good because most of the fancy sweaters come in heavy sweaters and mostly pure wool and the quality is super super nice. For recycling it is worth nothing, it has low value and no quality....but this is the market trend and the norm. We have to go with the market." (Lilani, 2020b, see Appendix 14.3, page 344)

Here, Lilani reminds us that value in the sorting stage is found in the balance between many design decisions. In his example, the colours designed into the jumpers at material level cause them to be sorted into the fancy sorting grade, those with many colours and patterns, resulting in a reduction of value. Whereas the loose structure of a heavy knit (easy to recycle) and purest 100% wool fibre type are the most desirable qualities in recycling industry. However, the combination of these three design decisions result in an undesirable low value waste stream for the recycling industry. As Lilani expresses, this is only used in the local markets for hidden applications. However, where value is only reduced in one aspect this highlights the need for design intervention to maintain or increase the value of this waste (further discussion in Section 11.1, page 265).

In order to understand the implication of colour, a second interview with Recycler X was conducted to maintain a recycler's perspective (Appendix 14.4, page 348). Recycler X explained non-solid coloured waste textiles must be dealt with differently. While solid colours are used by recyclers, as Lilani (2020b) confirms, "to make their own blend recipes", melange and fancy waste streams have more limited pathways. Jumpers with melange colours are used to re-create melange shades but are not suitable for solid shades. While melange may hold value, they are not as useful as solid colours, which can be used to produce both solid and melange yarns.

Fancy fabrics, Recycler X illuminates, can be recycled into yarns through overdyeing in dark colours. However, the ability to over-dye the fibre is dependent on the composition. If the composition can be assessed as a particular group, such as wool/acrylic, wool/nylon, wool/polyester or better still a pure wool or pure acrylic, then overdyeing can be conducted more easily. However, if the rough composition cannot be assessed then overdyeing is not practical. It is then downcycled into hidden applications such as felt insulation etc...

The complexity of the sorting industry correlates directly with the complexity of the products to be sorted. For example, the fancy sorting category is used to describe patterned textiles and textiles produced from fancy yarns containing contrasting colours. This type of waste can be utilised when spinning yarns with neps. However, Recycler X explained, if textiles are created with many different coloured neps these are then considered contaminants at the end of use and cannot be recycled again. Additionally, when it comes to more subtle colour combinations in textiles, the structure of the material also has an impact on the recyclability. For example, a navy and black patterned textile, if it is knitted, can be easily recycled as Recycler X explains:

> "if it is a knitted jumper with dark blue and black you can put it in either the blue or the black sorting category. A little navy in the black is not a problem." (Recycler X, 2021, see Appendix 14.4, page 348)

However, if the same colours are found in a woven material, then this is considered too low quality for recycling. The overall conclusion is the composition is the priority. If the composition can be roughly established but it has a mix of colours, the composition allows the fibres to be overdyed for yarn spinning. If left undyed, the fibres can only be downcycled for non-woven insulation felt. For this research concerned with understanding how to Design for Recycling Knitwear, the relationship between all these sorting methods must be understood (further discussion in Section 11.1, page 265).

10.6 SUMMARY

This chapter describes the final body of practice in this thesis. Following the previous chapter in which spiralling, blending and sorting have been brought together, the practice research was conducted to test these combined ideas towards understanding the Design for Recycling wool/acrylic knitted textile spiral. To begin, both a research design brief and creative industry design brief were developed. The research brief provided the conditions for creating recycled value, namely, using recycled acrylic fibre, using a minimum of 30% wool in the blends and that the yarn produced needed to be suitable for a knitted garment. The creative design brief drew on trend and market research to direct the aesthetic, function and cost aspects of the design.

The practice experiment was then described, starting with the challenges of finding a partner spinning company and sourcing the colour sorted recycled acrylic fibre which had to comply with the spinner's conditions, namely that the seams were cleaned from the waste. The chapter recounts two meetings with the spinning engineer in which the six yarn blends where designed and specified. Decisions centred around composition, colour, recycled content, manufacturability, hand feel and cost. It was noted that a balance between the engineer's requirements and the designer-researcher's had to be found. The six yarns were spun and knitted into swatches and prototype jumpers. The swatches were sent to both a hand and automated sorter to establish if they had increased in recycled value at the sorting stage. The aim of this test was not to establish the exact composition of the swatches but to explore the realities of sorting and the challenges and opportunities this presents for designers.

The testing itself illustrated the complexities facing the sorting industries across hand and automated systems. While both tests illustrated that the recycled resources would have increased in value, the pathways for these fibres were less clear. The automated sorting highlighted that the challenge for the designer is to create markets for all waste types as this directly impacts the sorting criteria. The hand sorting results lead to a second interview and a more detailed understanding of sorting from the perspectives of colour. While composition was found to be the priority, the effect of structure and colour are also important factors. To successfully Design for Recycling Knitwear, the relationship between all the different sorting methods needs to be understood and this will be addressed in the next chapter.

11 DISCUSSION AND INSIGHTS

11.1 REFLECTIONS ON THE PRACTICE

This research set out to explore Design for Recycling Knitwear, namely how design can be used to aid the use of recycled fibres in textiles (re-active design approach) and their onward recyclability (pro-active design approach). In order to accomplish this, the researcher first explored the recycling system from the point of disposal through the recovery of fibres and on to the creation of products (Practice 10, page 225). Across this thesis, particularly in Practice 1 (page 79), four areas were established in which design intervention could occur: sorting, blending, processing (spinning), end product/market (weave/knit through to product). These 'areas for intervention', or 'hotspots', have been discussed in the author's conference paper 'MIXING IT UP IN PRATO: identifying innovation hotspots within mechanical textile recycling' (Hall, 2018, Appendix 14.8.1, page 405). Throughout this research each of these hotspots have been explored through the various practice experiments (Practice 0-9), which are brought together in Practice 10. It is therefore under each of these themes that the research in this thesis will be reflected on to draw the conclusions of this study and demonstrate original contributions to knowledge.

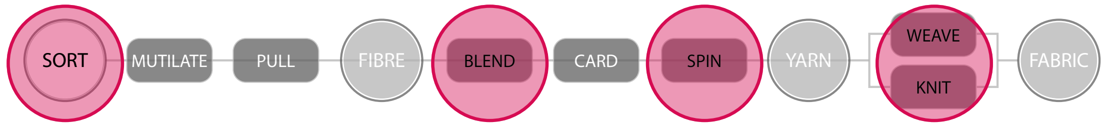


Figure 123. Hotspots for innovation within the processes of recycling textiles, (Hall, 2018)

11.1.1 SORT

This first hotspot outlined in Practice 1 was the sorting stage. Only in 2020 has Niinimäki and Karell made the connection between designing textiles and the end-of-use sorting processes. They point out that if textiles cannot be correctly identified at the sorting stage, it is impossible to direct them to the appropriate recycling process (Chapter 8.3, page 198). Taking this one step further, without effective sorting, the mixed materials produced by recyclers would only be suitable for low-value end-markets. The value of resources is therefore determined at the sorting stage. This value and how it embodies itself through the design choices has been unpicked through the lens of 'Design for Sorting'. This was first coined by Niinimäki and Karell (2020) and following their recommendation it was explored in three steps:

1. Understanding the elements of the textiles to be identified in the sorting process
2. Identifing what grades the textiles are generally sorted into and for what purpose
3. Ascertaining the general limitations and possibilities of textile-to-textile recycling technologies

STEP 1

The first step was explored in section 8.3.1 (page 199) in which findings from Practices 1,2 and 4 resulted in three elements for sorting being established: structure, colour and fibre type. In addition, cleaning was highlighted as an important step overlooked by Niinimäki and Karell.

First, sorting by structure (namely knit and weave) is vital for the physical recycling process, especially if you require high quality recycled fibres as an output. It is generally accepted that woven materials produce shorter fibres in the recycling process than their knitted counter parts due to the density of their structure making it difficult to tease the fibres out for re-use. After Practice 2 (page 111) had taken place, where a woven fabric was created from recycled yarns, the researcher reflected on the weave technician's comments regarding the 'looser' tension of the weave. The technician explained that the tension for a commercial weave would usually have been tighter, yet for the designer in this instance it was inconsequential for the application of a cushion. The tighter tension was an unnecessary property in this design, and if added, could have had a negative impact later in the recycling process. In this instance the looser tension was unrequired and therefore adjusting the tension would be inappropriate. Conversely, reducing the tension of another woven textile designed to be highly durable might result in its quicker return to the recycling system. Needless attributes should, therefore, be designed out of textiles to balance function and recyclability.

Colour is one of the most well-known sorting categories for recycling and is often claimed as one of the mechanical recycling industry's 'environmentally friendly' attributes. This is because the colour from the waste textile is re-used in its next life. This presents a creative challenge for designers when designing for mechanical recycling, as they design for a system which attaches value to single colour inputs. One prominent solution is designing textiles for disassembly (Forst, 2020), in which the coloured sections on materials and garments can be separated at the end-of-use. However, within mechanical recycling at fibre level, this is not possible. Outside of the scope of this thesis, chemical recycling does offer a potential solution for this problem but only for certain fibre types. In an attempt to combat this challenge, joined up thinking between the sorting and the blending stages was explored in Practice 4 (page 147). Here, the idea of designing textiles in specific colour combinations was suggested to create blended shades during the recycling process, such as a red and blue garment creating a purple fibre after recycling. However, as the focus of the research was on the composition of the yarns, this idea and any further understanding of the complexities of sorting and processing mixed colour textiles was only explored during the testing in Practice 10 (further discussion on page 289).

Cleaning is a vital step in the recycling process which has been overlooked in literature. Here elements of materials or products which would cause the colour of fibre type contamination have to be removed. Therefore, as designers there appears to be three options: designing out these elements, considering their placement with care for their easy unskilled removal or enabling them to be fully disassembled. Ultimately these contaminants are blends in the most macro form and materialise themselves at material and garment level (section 7.7, page 181). In this research, Practice 1 uncovered systems created to utilise the cleaning of waste. Here, the cleaned seams from cashmere recycling were sold to another recycling facility to benefit from the mixed cashmere fibre. The designer, therefore, needs to both consider Design for Recycling for both the main body of the textile/garment as well as the parts that are to be cleaned (the extras).

However, while it is nice to think of all our materials such as those from the 'main body' and the 'extras' circulating in high-value closed-loops, this is not always realistic. In Practice 1, for example, the seam waste from the cashmere recycler was not able to be recycled to the same quality as the main body material (page 79). Therefore, this provided an opportunity to feed lower value loops into the resource spiral. The method of cleaning ensures the whole textile is not needlessly lowered in value and that even the cleaned 'extras' can extend their lives in new loops.

Finally, the industry also sorts by fibre type. While it has been discussed in Chapter 3.3.3 (page 77) that the recycling industry as a whole is divided into processing very broad material types, such as wool, cotton and polyester, it is the particular categorisation that each individual recycling sectors uses that needs to be understood. This addresses Niinimäki and Karell's (2020) second step and is discussed in detail below.

STEP 2

The second step as proposed by Niinimäki and Karell (2020) was the identification of sorting grades and their specific purpose. In the context of this research, it is the grades and purpose of the wool recycling system with acrylic as its contaminant that has been explored. While the ideas for this investigation came from field investigation and practice, the grades were primary established through literature review and interviews (section 8.4, page 202). Four main grades of wool/acrylic textiles were found: 100% wool, 80% wool, 50% wool and 100% acrylic. These percentages are not representative of each individual textile's wool content but rather is the average percentage of wool content within a batch. For example, an 80% wool batch may contain textiles with 100% wool content and those that contain 70% wool content. Overall, the batch is estimated to be 80% wool which gives it its name.

However, as current textile sorting is conducted by hand a further layer of complexity is added. While a batch may be named after the general percentage it represents, it is impossible to be precise when using hand sorting methods and this means that the name of the batch can mis- represent the content. For example, the 100% acrylic grade may contain as much as 15% wool, illustrating this misrepresentation of the batch. This has created a need for lower and upper thresholds of each grade for which there is certainly an overlap, such as any 100% wool textiles could be placed in both an 80% wool grade to ensure the overall wool composition reaches the required 80%, as well as the 100% wool grade. It is this complexity which results in what could be explained as 'blurred' grading categories. In this research these are described as 'generic' grades and thresholds for Design for Sorting.

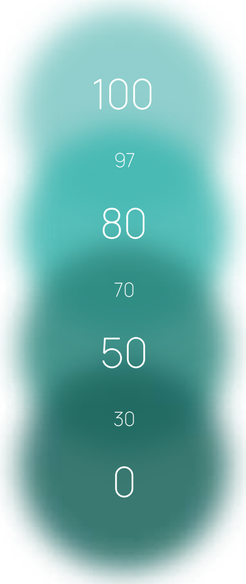


Figure 124. Wool/acrylic sorting grades and thresholds visualised to represent the blurred boundaries between the sorting categories

The purpose of these grades is a little more difficult to establish. The sorting industry, like any other, is constrained by the clients and markets to which they can sell. This means sorting practices alter depending on a client demands (Lilani, 2020a). Generally, the end markets are split between high-value end-uses, which normally refers to using the recycled fibres in yarn form for either knit or woven materials, or lower-value end-uses, normally referring to either non-woven or amorphous materials.

However, there isn't always one single purpose for a sorting grade. For example, the textiles that fall into the 100% acrylic grade can be utilised across both higher and lower value applications. Either they are sorted as 'jazz' for non-woven flocking (Thompson, Willis and Morley, 2012), or spun into yarns in locations such as India to be used in blankets for the local market or as relief blankets for foreign aid (Norris, 2012c). Relief blankets, Norris (2012c) explains, are renowned of being very low quality and this demonstrates that while the creation of yarns from recycled materials is generally associated with high-value product applications this is not always the case. This example illustrates the more nuanced relationships between recycled resources and the designed products they create.

In Practice 10 of this research, design was used to divert '100% acrylic' grade fibres, generally considered worthless material (Lilani, 2020b see Appendix 14.2, page 343), to be used outside of its normal 'purpose'. Here, a new product pathway has been designed by returning the acrylic into a knitwear product for the European marketplace. The lowest value fibre grade (100% acrylic) was selected to create a proof-of-concept yarn through to a garment; not only to increase the value of the resource by design (discussed in 11.1.2, page 269), but to design increased value into the product (discussed further in 11.1.4, page 279).

STEP 3

The final and third step offered by Niinimäki and Karell (2020), explored throughout this research, is to understand challenges for textile-to-textile recycling processes. This research specifically investigated the challenges of the mechanical recycling system. While this has been explored throughout the thesis it was primarily explored in Practice 10. Here the challenges of both sourcing recycling fibres and working with the additional priorities of other stakeholders, such as a spinning engineer, were addressed. Specifically, it was through conducting the research in an industry setting that these insights were found and will be further discussed in Section 11.1.3 (page 276).

11.1.2 BLEND

With the rise of concerns for our planet's resources and the publication of 'Cradle to Cradle' and the circular economy model (Braungart and McDonough, 2002; EMF, 2013), the concept of blending different materials has been demonised - specifically combining materials from the biological and technical spheres. The current design solutions for blending at the end-of-use has been reduced down to two strategies: designing for mono-materiality (designing without blends from the beginning) and design for disassembly (to separate the blends into mono-materials). However, there are many reasons we use blending within textile design, such as for added function, appearance and reduction of cost of our materials.

When it comes to recycling the reasons for blending are shared with those of virgin production. For example, recyclers will compensate for the shorter recycled fibres by blending them with longer virgin fibres. This can aid the efficiency of manufacture and lead to less waste, more cost effectiveness and, depending on the blend, could produce a more functional final material. What needs to be avoided is the trade-off between durability in use and the recovery potential (Tanttu, Kohtala and Niinimäki, 2016). However, when textiles containing blended fibres enter the recovery stage of the lifecycle, it is not the physical recycling process, shedding or pulling the fibre from the cloth, that is the problem. Rather it is the quality of these fibres for the design of new textiles which is problematic (Langley, Kim and Lewis, 2000). Therefore, understanding how we can Design for Recycling Knitwear is vital.

METHODS OF BLENDING

Throughout this thesis the knowledge around blending within the mechanical wool recycling industry has been expanded. Historically, as explored in Practice 6 (page 161) and Chapter 7 (section 7.4, page 160), the wool recycling industry has used a variety of blending methods in order to create textile materials for a range of end-markets. While, blending techniques in recycling have adapted creatively to overcome their own set of challenges, there is still some overlap with the virgin textile industry. For example, the most common method of blending is to combine different fibre types, which is followed by combining different coloured fibres. In addition, the recycling industry extends its blending repertoire to include blending recycled and virgin fibre, pre- and post-consumer waste types and finally different structured wastes together (Table 21 on page 271). Regardless which creative methods the recycling industry uses, these blending techniques are applied for the same reasons that we blend virgin materials: function, cost and appearance.

During Practice 10 most of these different methods of blending were used (Table 22 on page 271). First, virgin and recycled materials were combined in different quantities. All the yarns produced (1-6) contained 50% recycled acrylic, but the virgin content varied in percentage. For example, Yarn 2 blended 50% recycled acrylic with a virgin blend of wool/mohair/cashmere, whereas Yarns 1, 4 and 6 all contained 30% virgin wool and 20% recycled polyester originating from plastic bottles. These different methods of blending were each

Table 21. Blending methods used in recycled and virgin industries.

	BLENDING METHODS	
	RECYCLED	VIRGIN
Recycled & Virgin	X	X
Pre-&Post-Consume	X	
Structure	X	
Fibre Type	X	X
Colour	X	X

Table 22. Different blending methods of the six yarns in Practice 10

	%	TYPE	FIBRE	RECYCLED %	POST-CONSUMER %	PRE-CONSUMER %	STRUCTURE
1	50%	Recycled	Acrylic	70	70	0	KNIT
	20%	Recycled	Polyester				BOTTLES
2	50%	Recycled	Acrylic	50	50	0	KNIT
	17%	Virgin	Mohair				-
	24%	Virgin	Mohair/ Wool/ Cashmere				- -
	9%	Virgin	Wool				-
3	50%	Recycled	Acrylic	90	70	20	KNIT
	20%	Recycled	Cashmere				KNIT
	20%	Recycled	Polyester				BOTTLES
	10%	Virgin	Wool				-
4	50%	Recycled	Acrylic	70	70	0	KNIT
							-
	30%	Virgin	Wool				-
							-
	20%	Recycled	Polyester				BOTTLES
5	50%	Recycled	Acrylic	100	100	0	KNIT
	50%	Recycled	Polyester				BOTTLES
6	50%	Recycled	Acrylic	70	70	0	KNIT
							-
	30%	Virgin	Wool				-
							-
	20%	Recycled	Polyester				BOTTLES

constructed for different reasons and markets (see Section 11.1.4, page 279 for further discussion).

The recycled polyester component used across all the yarns (with the exception of Yarn 2) was sourced from plastic bottles originating from outside of the textile industry. This recycled polyester fibre is still considered a form of post-consumer waste as the bottles have been used by consumers before being recycled. There was only one example, Yarn 3, which contained both pre- and post-consumer waste in the blend. This is because Yarn 3 sourced waste cashmere from the spinning facility itself and was a waste from a previous spinning production. This method of blending occurred to reduce the cost of using this luxury fibre, it also had the added benefit of producing a softer yarn/textile. Finally, blending in this way, combining recycled post-consumer acrylic, recycled polyester and pre-consumer cashmere, enabled a high percentage (90%) of recycled content in the yarn. If maximising recycled material is the end goal, this form of blending is an optimal way to achieve this.

Notably there is a correlation between the highest percentages of recycled content and the use of polyester (specifically polyethylene terephthalate – PET). For example, Yarn 5 reached 100% recycled content using only recycled acrylic and recycled PET, which was chosen specifically due to its strength (function) and economic price point (cost). Virgin PET is a very strong fibre and can be recycled to a good standard mechanically, or alternatively if chemically recycled, the PET returns to near virgin quality. The recycling of PET plastic bottles faces similar challenges in that it requires rigorous sorting and cleaning to avoid contaminants (Sarioğlu and Kaynak, 2018). However, we regularly find the textile industry utilising PET from plastic bottles and not from PET textiles. This is put down to the added complexity of our textiles, with many components, compared to the relatively simple design of plastic products (Payne, 2015). This makes it an easier waste stream to capture and convert. However, if we continue to use PET from plastic bottles which will enter the textile recycling systems only to be wasted by speedily downcycling, then we cannot fully transition to a circular economy.

Out of the all the different methods of blending highlighted in this PhD, blending using structure was explored least in practice. In all the yarn blends, the recycled acrylic content was sourced from knitted waste only. While the recycling industry is known to blend shorter recycled woven fibres with recycled knitted ones, it was not possible to replicate this in the research due to limited time and difficulty sourcing the material.

The final two methods of blending identified in this research cross over with the blending that occurs in virgin production, namely fibre type and colour. Colour was used in the research as a design tool so that the final yarns would fit the specific design brief created. Yarns 3, 4 and 5 blended the navy acrylic fibre to create solid or very subtle blends. These are valued very highly in the sorting process as they can be first sorted into family colours and then into specific shades and tones. After this waste has been recycled into fibre, the different shades and tones are mixed to create new colour blends. This form of colour blending was used in three of the yarn blends in which the navy recycled acrylic was blended with brighter coloured virgin wool fibres to create aesthetically pleasing yarns suitable for knitted garments. When different coloured fibres are combined together, they produce melange tones, such as the deep turquoise/navy shade created in Yarn 1 and the brighter turquoise shade created using turquoise (honeybird), yellow (lemon) and navy in Yarn 2. These new shades still hold value in the sorting process, but as these have to be sorted into specific melange tones and are trickier to categorise (Lilani, 2020b).

Finally, blending different fibre types has been used across all the yarns in Practice 10. The aim of the test was to increase the value of recycled acrylic fibre (a known contaminant of wool recycling), by blending with wool so it could move up a grade at the sorting stage and at the end-of-use. Due to limitations of the spinning process only 50% recycled acrylic could be used in the manufacture. Three different percentages of wool, or fibres similar to wool (such as mohair), were designed into the yarns: 0%, 30% and 50%. If 0% or 30% wool was used in a blend with the 50% recycled acrylic this left either 20% or 50% of another fibre type to be chosen.

First, virgin acrylic fibre was considered as a blending agent to create a mono-material yarn. However, due to MOQ limitations it could not be sourced, which happily avoided further demand for virgin acrylic - problematic due to the chemical based process this man-made fibre goes through to be produced (Fletcher, 2008). Nylon could not be used across all the blend designs due to limitations on its use in the spinning process (20% and below) and was therefore discounted. This left polyester, of which a recycled version could be sourced. Much of the wool recycling industry uses either polyester or nylon to make the yarns for woven fabrics stronger and therefore more durable during their use. For knitwear, polyester was not necessary for the performance of the yarn but provided a more economic element. The decision on any blend compositions were not, however, purely based on the cost of the individual materials . In addition it was important to understand how the fibre choices affect: the speed at which the fibres can be processed, the yield (amount of yarn produced minus the wastage) and the thickness/count of the yarn.

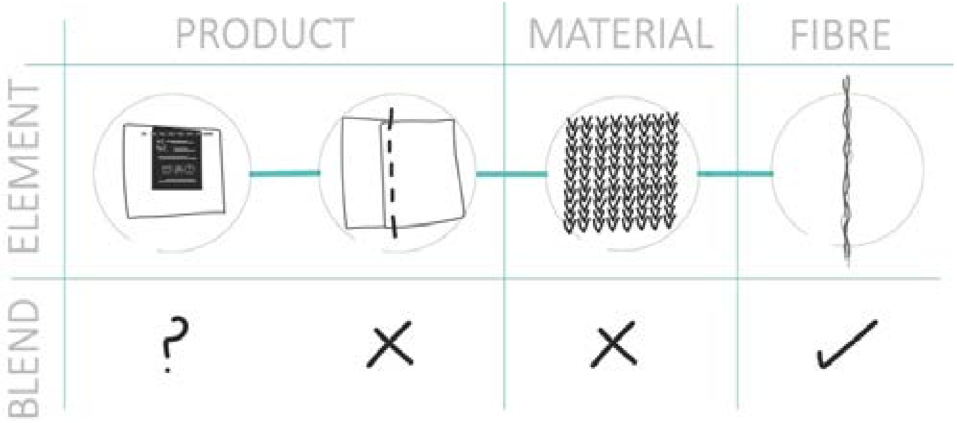
The fibre choices also impact the recovery potential of the textile. At the sorting stage, the polyester content would be considered a contaminant in exactly the same way as the recycled acrylic. Value, at the sorting stage, is only attributed to the percentage of wool. In Practice 10, Yarn 1's composition was 50% recycled acrylic/20% polyester/30% wool. Therefore, after manufacture, as demonstrated when sending this swatch to hand and automated sorters, it was considered approximately 70% 'mostly acrylic' and 30% wool and would be recycled as such. While blending with polyester in this instance just adds to an already complicated fibre blend, this does not provide licence for designers to create blends from virgin materials without any consideration for the consequences. The context of this research needs to be highlighted, where it aims to address the complexity

of blended resources that already exist. In this case specifically, polyester is being added to an already synthetic content which otherwise would become a wasted resource. Polyester was therefore deemed to be an appropriate material.

BLENDING LEVELS & RATIO'S

While the methods for blending recycled fibres have been split into five categories (discussed above), these can also be conducted over three levels: yarn, material and product. This research has focused in on blending at yarn level, thus blending at both material and product level was purposefully designed out. Each of the six yarns developed in Practice 10 were designed and used for a knitted material in the creation of a funnel neck jumper. At both material and product level, each yarn was used alone to create the six jumper prototypes. This meant that each garments' piece was made of the same material, such as arms, body, trims etc… and was linked at the seams with self-yarn to avoid further contamination. The final ratio of fibre type created across yarn, material and product remained at the same percentage as the yarn itself. Therefore, the recycled value designed into the yarn represented the value that the product would hold at the sorting stage (Table 23).

Table 23. The different elements used in the design of Practice 10 – blending was designed to only be conducted at the fibre level.



Similarly, colour blending was also avoided at material level (i.e. using two different coloured yarns to create a pattern), and at product level (i.e. creating contrasting colour blocking for certain elements of the garment). Design decisions such as these make it necessary for these mixed coloured parts of the garment to be cut out or cleaned. Particularly at material level, the coloured patterns in garments are sorted into a grade described as 'fancy' and can only increase in value through overdyeing. It was noted later in the research that the acrylic fibre sourced for Practice 10 might have originally been multi-coloured acrylic waste that had been overdyed.

As the jumpers were not made commercially, care and brand labels were not required as part of the design. These are usually made of cheap woven polyester materials in white or black, potentially causing a mixture of fibre and colour contamination. And if these had been required then this could have caused blending at product level. This type of blending can be disassembled or cleaned away and therefore is not as problematic as other levels of blending. However, it still represents value depletion as any form of cleaning is a laborious and costly step that needs to be accounted for.

DESIGN FOR SORTING USING BLENDING

While blending textiles can be conducted in different ways and at different levels, blending for increased value at the recycling stage has been investigated in this research as a tool for Designing for Sorting. The research draws on Carlsson et al's (2017) incremental updating strategy and reframes it in the context of developing yarns. In line with Carlsson et al's strategy, the aim of this research is to increase longevity of recycled fibres by incrementally blending them with other high-value materials. As Roos et al. (2019b) describe it, adding a percentage of recycled fibres in all fabrics provides an opportunity to increase the use of recycled fibres and thus extend their lifetimes. Therefore, if the blend is used to create longevity of a resource and doesn't result in further waste, then it accomplishes its aim.

To explore this idea, six yarns were designed and blended in Practice 10. These were knitted into swatches and sent to both hand and automated textile sorting companies to establish what value they held by understanding which sorting grade they would fall into. While each of these sorting methods has its own challenges, such as human error or a limited material library respectively, the test demonstrated that the recycled materials would have generally increased in value, falling into the 30% threshold between 0% wool and 50% wool. One of the yarns (Yarn 5) was designed to remain in the 0% wool category and another (Yarn 2) was designed to move up to the 50% wool category (using both wool and mohair). The results indicated it was possible that both of these textiles could also fall into this middle 30% threshold. While the test illustrated the difficulties in sorting with complete accuracy, for designers this research has demonstrated that value can be designed into our textiles over wider thresholds. As more accurate sorting technologies develop, this design approach could become even more useful.

While this research took a focused look at fibre type blending, this approach could be harnessed for other types of blending including colour and structure. In addition, this research specifically designed using the lowest value resource type, 0% wool. This design approach could also be applied to the higher-value fibres in the sorting grade hierarchy, such as 50% wool/50% acrylic. Therefore, by demonstrating that the lowest value resources can be used for high-value applications this could result in the '0% wool' sorting grade itself increasing in value. Design, in this case, would provide a new pathway for these low-value fibres to flow into.

11.1.3 PROCESS

The process investigated in this research is the spinning of recycled fibres into yarns. As this research was conducted from the point of view of the designer, this hotspot does not refer to the technical innovation possible in the recycling of fibres, such as those currently being conducted by Lindström et al.(2019). From a designer's perspective, the processing of recycled fibres can refer to these technical processes such as pulling or shedding of fibres, carding, spinning of yarns, needle felting for non-woven materials, knitting, weaving and garment production and so on. As it was concluded by the author in the 'Mixing it up in Prato' research paper, only by fully understanding these processes and pushing our boundaries can we design innovative recycled products (Hall 2018). In order for the designer to achieve this, collaboration with stakeholders at the processing stages is vital.

The role of the designer-researcher spanned across the many stages to act as a bridge and connector between the processes and stakeholders. While Toomey and Kapsali (2014) advocate for engineers and industry designers to work together across many stages, in reality these roles are still separated. Therefore, in this research the dual role of academic researcher with industry design experience was combined to create a new boundary spanning role (Rieple, Haberberg and Gander, 2010), enabling insights from the research to be translated for the industry designer to understand (Hornbuckle, 2013) (Figure 125).

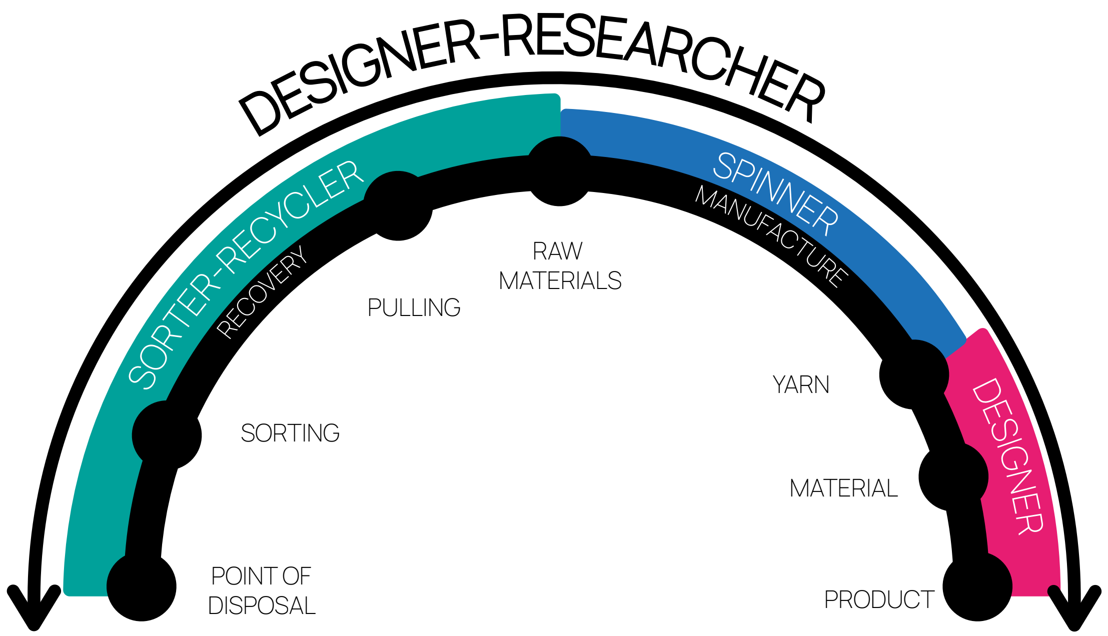


Figure 125. The expanded role of designer researcher in this research from point of disposal to product working with sorter-recycler experts, spinning expert and as drawing from author's own experience as an industry designer

Throughout the practice in this research, a variety of research methods have been used to gain insights into the technical processes of the recycling system. For example, Practice 6 was formed of an interview in the field surrounded by fibre samples, exploring the historical methods of recycling and blending wool fibres; Practice 1 used field research to explore the present-day wool recycling industry and Practices 3,5,7,9 and 10 all demonstrated collaboration with spinning facilities to test new ideas towards a future of Designing for Recycling Knitwear.

RELATIONSHIPS

As suggested by Franco (2017), implementation of circular and sustainable development in the textile industry is made easier depending on how developed/strong the relationships between stakeholders are. The relationships between the researcher and industry experts in this research, such as a spinning engineer, supported Franco's finding as it was one of the most vital elements in the research project. Challenges and opportunities in the collaboration were encountered at the different stages of the research and to varying degrees. Throughout Practices 0-9 (prior to the final Practice test), a network of companies was developed through field research, interviews and small-scale experiments. In particular, conducting small scale experiments prior to larger scale testing benefited this relationship building. Notably, Practice 7 and 10 were conducted with the same company with whom a relationship was built in the first instance (Practice 7), leading to the larger test taking place.

It was through directly interacting with a range of stakeholders at all levels (owners, engineers and managers) that the designer-researcher understood the value in ensuring different types of collaboration occurred with the most appropriate person. For example, asking more technical questions with employees of bigger firms who actively worked on the factory floor with the machines was of great value. They were able to directly answer and explain if design ideas would or would not work and why. Negotiations with employees at management or owner level was also necessary to arrange active experiments. However, for Practice 10 the biggest benefit was found when collaborating with a smaller company. In this instance the manager/owner would most likely spend some of his day with the machinery and have a current knowledge of how the process worked, removing the need to speak to multiple people. A full reflection on the research collaboration process is discussed in section 11.2 (page 295).

CHALLENGES CONDUCTING RESEARCH IN INDUSTRY

Beyond smaller experiments, the main challenge encountered during this research emerged during the organisation of Practice 10. Prior to the experiment that is described in this thesis, a range of companies were contacted to establish a potential partnership.

Common challenges cited by the companies related to time, cost and size. For example, companies cited they did not have time to accommodate the experiment. Alternatively, the cost quoted for the experiment was too high for the research budget. This was often the result of high minimum order quantities (MOQs) and thus the scale of the experiment was deemed too small.

These challenges were experienced across all the recycling processes. For example, when sourcing the recycled fibres, companies were often only prepared to sell the fibres in high volumes beyond what was required and at great expense. Therefore, a number of compromises occurred in order for Practice 10 to take place. For example, while the experiment was relatively large-scale from the perspective of the researcher, it was small compared to other production at the facility. It was agreed with the spinning engineer that the experiment would only meet the MOQs for each yarn and it would be of lower priority, fitting in around larger production runs.

Another challenge faced was the issue of using synthetic materials. Working specifically with the UK wool industry, many companies refused to work with this type of fibre. Many managers were enthused by the sustainable aims of the experiment but would not risk the recycled acrylic fibres contaminating their wool-based yarn production. When Practice 10 was finally agreed, this was on the condition that the recycled fibres were produced from fully cleaned textile waste, removing any synthetic seams. This seam waste was an issue known by the spinning engineer from his previous experience working with recycled material. If the seams were kept in the garments, they were known to cause yarn breakages and send fibres into the air, thus contaminating other orders and delaying production.

Prior to the development of Practice 10, the experiment had at first intended to cover five processes: collection, sorting, recycling, spinning and knitting. However, the cost, time and varying MOQ demands at each stage meant this became unrealistic. While a designer can be central to a recycling network (Kriwet, Zussman and Seliger, 1995; Cleveland, 2018), it raises the question; does the designer needs to be involved at every stage? In the context of this experiment the designer-research omitted the physical collection and sorting stages. While these stages had been explored in detail through the literature and in the field, the design innovation was primarily occurring at the spinning stage. Once this was established, the design research was able to take a much more focused approach.

Practice 10, however, still had to balance the logistics of three separate stages: sourcing recycled fibres, spinning fibres into yarns and knitting the yarns into swatches and garments. While some companies were able to complete one or two stages, no single company could do all three. Ultimately, this meant coordinating with three individual companies in three different locations: Italy, UK – Huddersfield and UK- London. Simple communication issues resulted in delays and confusion that had knock-on effects on subsequent stages. This was caused not only by language barriers when working outside of the UK, but also by continually switching between individual styles and preferred modes of communication (email, telephone, in person conversations and WhatsApp) at various points in the research.

Here, the designer's role is exhibited as a 'boundary spanner' or 'material translator' (Rieple, Haberberg and Gander, 2010; Hornbuckle, 2018) across the three stages. Returning to the aim of the research to Design for Recycling Knitwear (both designing from and for recycling), we can see that the designer role is crucial in joining the dots between recovery and manufacture. Design, as Hornbuckle (2018) has suggested, provides a bridge between the designers demanding quality recycled materials and the complexities in manufacturing faced by the material developers using recycled content. Using this role throughout the research has allowed for the challenges present to be designed around. This was by no means an easy task and is shrouded in complexity. The methodology developed from this thesis demonstrates the push and pull of priorities from all stakeholders when conducting research between academia and industry. This is further expanded in Section 11.2 (page 295).

11.1.4 PRODUCT/MARKET

The product or market for which recycled materials come from and flow into was not the focus of the research. However, the importance of designing and ensuring appropriate design choices are made beyond yarn level became clear during experiments prior to Practice 10, in which a design brief was never set. For example, in Practices 5 and 9 yarn blends were designed with fire retardancy properties. This is a function required for commercial interior textiles but not for fashion and therefore the design of the blend would differ significantly depending on the resulting product.

In addition, when both commercial design conditions and Design for Recycling Knitwear conditions were employed during Practice 10, this provided a wider context for the design decisions to be made. Here the push and pull of researcher (concerned for the recovery of the resources) and designer (ensuring the successful manufacture for commercial success) was acted out to demonstrate the challenges faced when Designing for Recycling Knitwear.

In the recycling system, the product is the vehicle in which a resource is contained and travels through the use phase before it enters recovery phase at the point of disposal. Here, the product is to be transformed back into a resource as it transitions towards its next life as a new product. The value, during recovery – at the sorting stage – is accounted for by two factors: the previous decisions made when combining and processing the resources into the product, and secondly how the resources can now be combined and processed for the same or new product market.

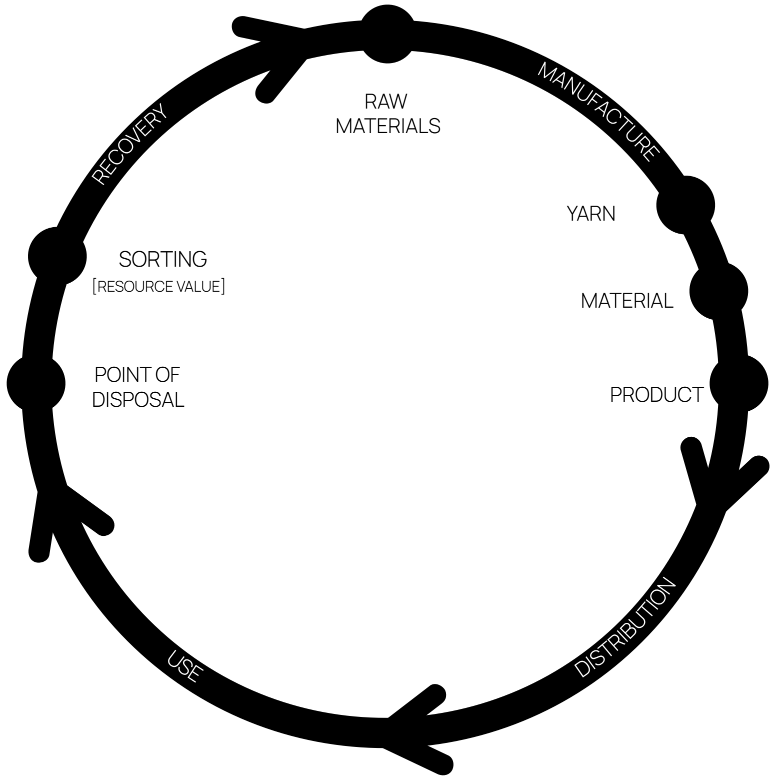
The current pathways for the wool and acrylic recycling system were explored throughout this research. As Gupta (2014:10) explains, "woollen shoddy was normally used for making readymade garments; whereas synthetic shoddy (acrylic component) is mainly suited for blankets" and specifically are usually blankets for charitable aid (Norris, 2005). However, it is not as simple as dividing the recycling industry into wool and synthetic sectors. For example, in Practice 1 (page 79) Company D, a firm in Italy, demonstrated a successful business producing yarns with low-wool but high-synthetic in an industry which is known for high-wool content recycling. Furthermore, the traditional route when recycling textiles takes knit or woven materials and recycles them into woven or non-woven materials. As Lilani (2020a) articulates recyclers "prefer the knits. They are using knit material and turning it into woven". While knitted products produce longer fibres in recovery because of their loftier more open yarn and material structures, the opposite is true of more tightly woven materials. Therefore, intervention into these current pathways to ensure maximum longevity of our resources it vital. This was demonstrated during Practice 10, where recycled acrylic fibres were obtained to be designed and blended in different ways to produce knitted products for the European marketplace.

The missing link here is the design of these pathways. While it has been proposed by Cleveland (2018) that the designer should sit at the centre of system, this research presents design as having a more strategetic intervening role at specifc points in the recycling system. This was achieved not by the designer taking on the individual processes in the system as Cleveland did, conducting sorting and cleaning herself, but rather harnessing the current methods of sorting and blending to create new pathways to produce alternative products/markets for the fibres. Ultimately, as Norris (2012d:140) expresses, if we are to create value from waste textiles we need "to keep it moving, keep sorting and recombining it, imagining new contexts and creating those pathways".

11.1.5 DESIGN FOR RECYCLING KNITWEAR - WHY, HOW AND WHAT?

WHY?

The aim of this research is to retain resource value (Design for Recycling) rather than product value (Design for Re-use). As Goldsworthy (2017:4) reminds us "we must stop viewing the product as the ultimate vehicle for longevity and start to see the materials themselves as holding the true value". Design is therefore challenged to retain this value at the point of disposal (after product longevity is exhausted). Value here is defined as 'recycled value' (section 5.2.2, page 118) and is determined at the sorting stage. Design must intervene to create pathways for these resources to flow in and out of products for the longest time possible. This is modelled in a spiral in which resources can flow up and



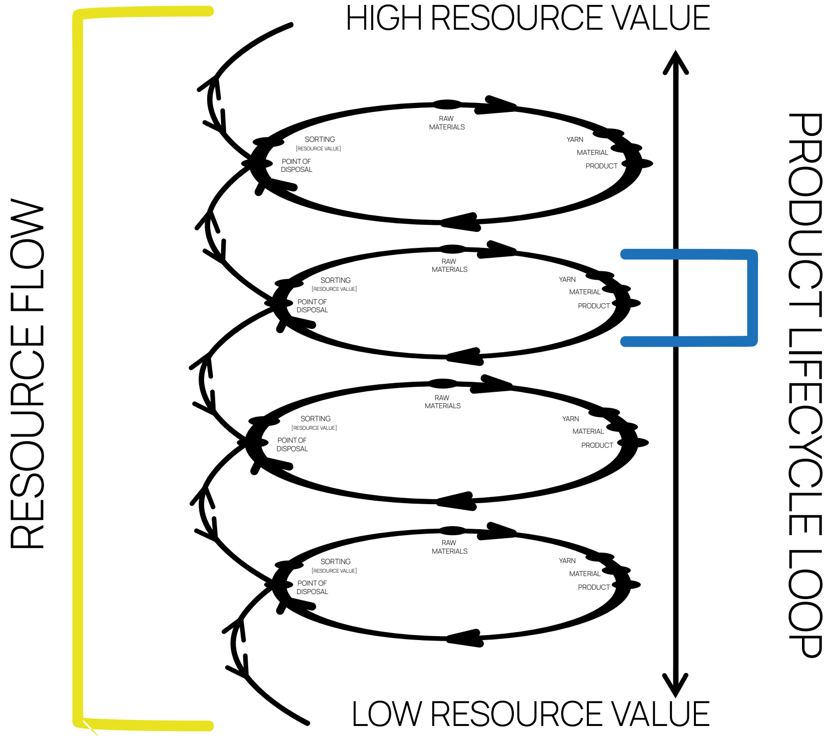


Figure 126. Resource Spiral – multiple product lifecycle loops (as above) connected by a resources flow - up and down

down (Figure 126). Why would we Design for Recycling Knitwear? To maximise the time these resources, spend in the spiral.

DESIGNING SPIRALS

To fully understand how this spiral works we must first address how our resources currently flow through the spiral. As Thackara (2006:31) reminds us, if we speed through the use of our products, we will then pay the price of wasting our resources. This is the current approach we wish to avoid, it is described by Fletcher (2008) as the immediate downcycling of textiles into low value applications (section 6.3.2, page 140). For example, currently a knitted jumper (higher recycled value) may flow straight from a garment into a non-woven insulation material for the construction industry (lower recycled value). This approach to recycling speeds through the spiral with a reduced number of product loops (Figure 127 - left hand spiral). This is generally referred to as downcycling but in fact describes downcycling in its worst form, producing a quick reduction in value that often ends in waste. Alternatively, an incremental approach can be useful. If designers can design additional product lifecycles into the spiral this could provide maximum longevity described by EMF (2013) as 'the power of cascaded use' (Figure 127 - right hand spiral).

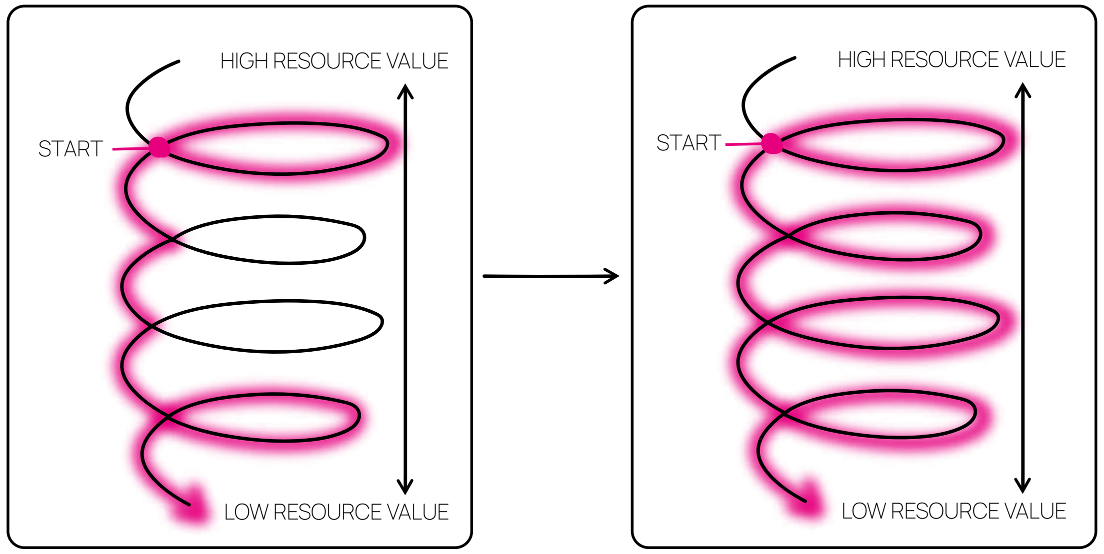


Figure 127. Common downcycling approach in which textiles resources moves quickly between very limited product loops (left) and preferred method slower spirally of many loops (right)

In contrast upcycling is hailed at the design-led approach (Earley, 2010). However, this is often driven with a desire to only increase product value. This is a valid and worthwhile approach but as with many (but not all) upcycling approaches, if the design makes recycling more challenging at the point of disposal the resource value reduces. Even when upcycling approaches design with recovery in mind, if no-one has ever designed the intended pathway using the materials from the specific recycling stream, there is no guarantee the material will be recycled as intended. Without a detailed understanding of the required design intervention to enable new resource pathways, longevity cannot be maximised and could remain limited to extending a single product lifecycle (Figure 128).

In contrast this research suggests methods to design more complex pathways, upcycling and downcycling our resources within the mechanical recycling system. An illustration of how resources might flow through a spiral is depicted in Figure 129. This incorporation of downcycling is important as resources within the mechanical recycling system cannot be infinitely used. And in this case, we are not starting with virgin or the highest value resources and therefore cannot expect them to continually rise in value exponentially. Additionally, we require a variety of products for our resources to be used within and not all of them require the highest value resources.

Designing pathways in a spiral has been explored through this research in the context of mechanical recycling of acrylic fibres in a wool recycling system. Down-cycling in this industry is commonplace but up-cycling at yarn level has thus far not been explored. This research has specifically targeted recycled acrylic, the lowest value sorting grade, and has provided an up-cycling method in which value can be designed into the resource through blending. The yarns and garments created during Practice 10 were proof of concept of this. By using the lowest value fibre type it is anticipated that the same approach could be applied to any other fibre. In addition, while only mechanical textile-to-textile pathways have been explored in this thesis, future research might consider textile-to-non-textile pathways as well as chemical recycling processes being incorporated.

HOW?

The resource spiral provides a context for 'why' this research is important – to create longevity of our resources. The 'how' is provided by Design for Recycling Knitwear Framework (Figure 132 on page 293) combining re-active and pro-active design approaches (see also Section 4.2.2, page 102). This Design for Recycling Knitwear research took first a re-active design approach that sought to address the complex waste textile resources that already exist. In doing this a wider understanding of designing for recovery is uncovered beyond mono-materiality and disassembly which the current waste does not fit into. To begin, a waste source needed to be established and in this research waste acrylic fibres were sourced. Second the processing, blending and product/market options available were outlined. Throughout this research both spinning and non-woven processes were investigated. However, it was spinning that was explored in further detail during Practice 10. Above and beyond creating a yarn, testing the Design for Recycling wool/acrylic knitted textiles model (Figure 90 on page 216) explored the whole design process from yarn into a knitted garment application.

In order to understand the impact of these design choices for maximum resource longevity the designer returned to the recovery system where the recycled materials originated. Here

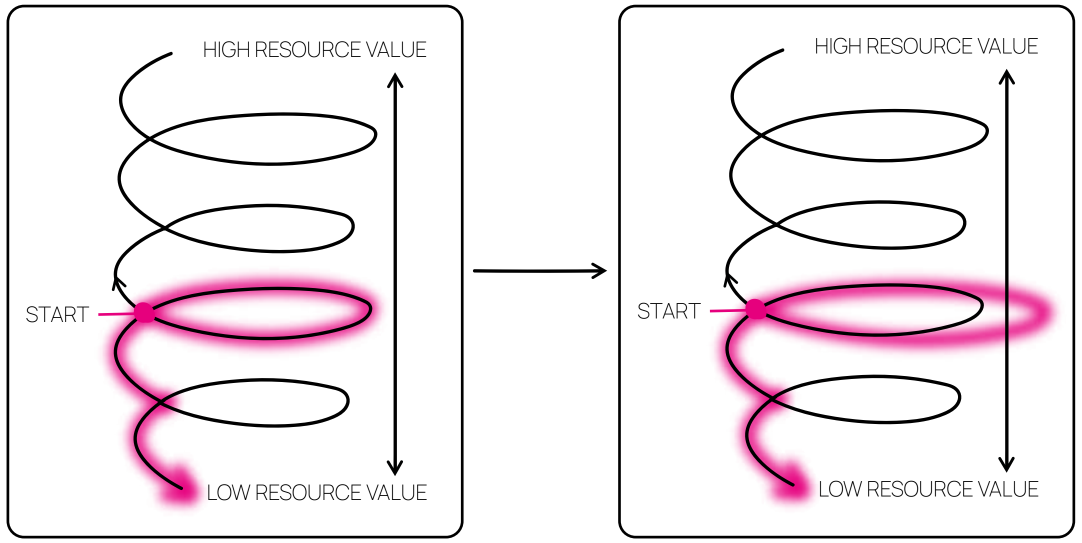


Figure 128. Upcycling approach focusing on increasing longevity of a product. Resource value is not always considered and therefore at the point of disposal the resource continues to follow ta raditional downcycling route.

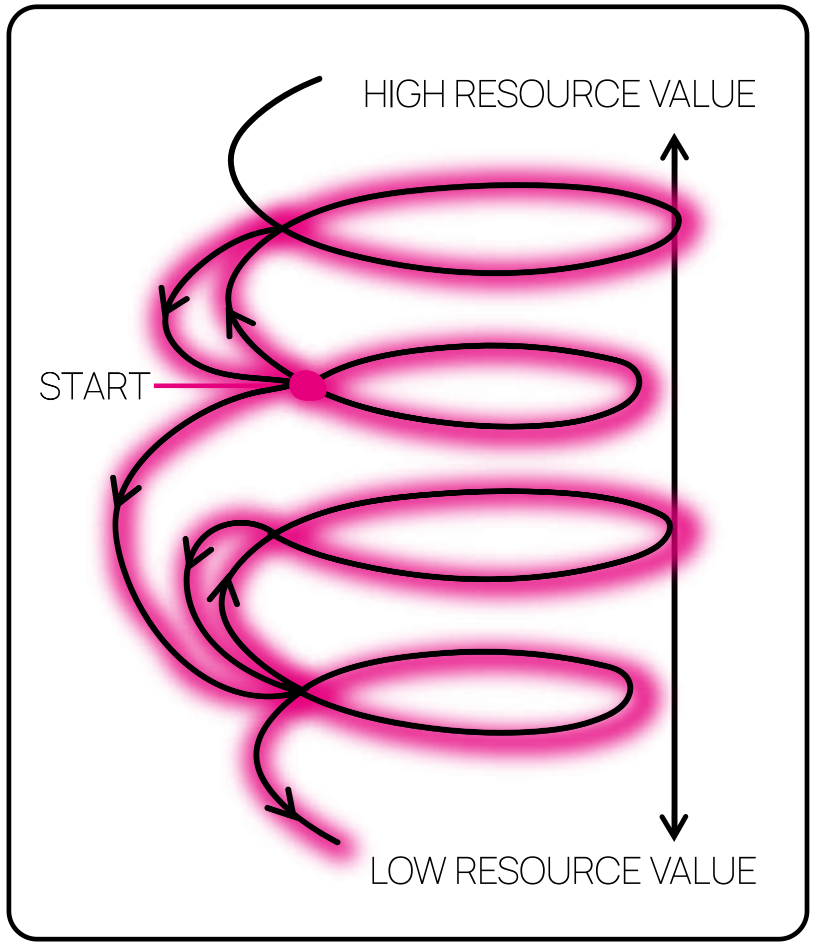


Figure 129. Example of how designing both up- and down-cycling in a resource spiral can create longevity of resources.

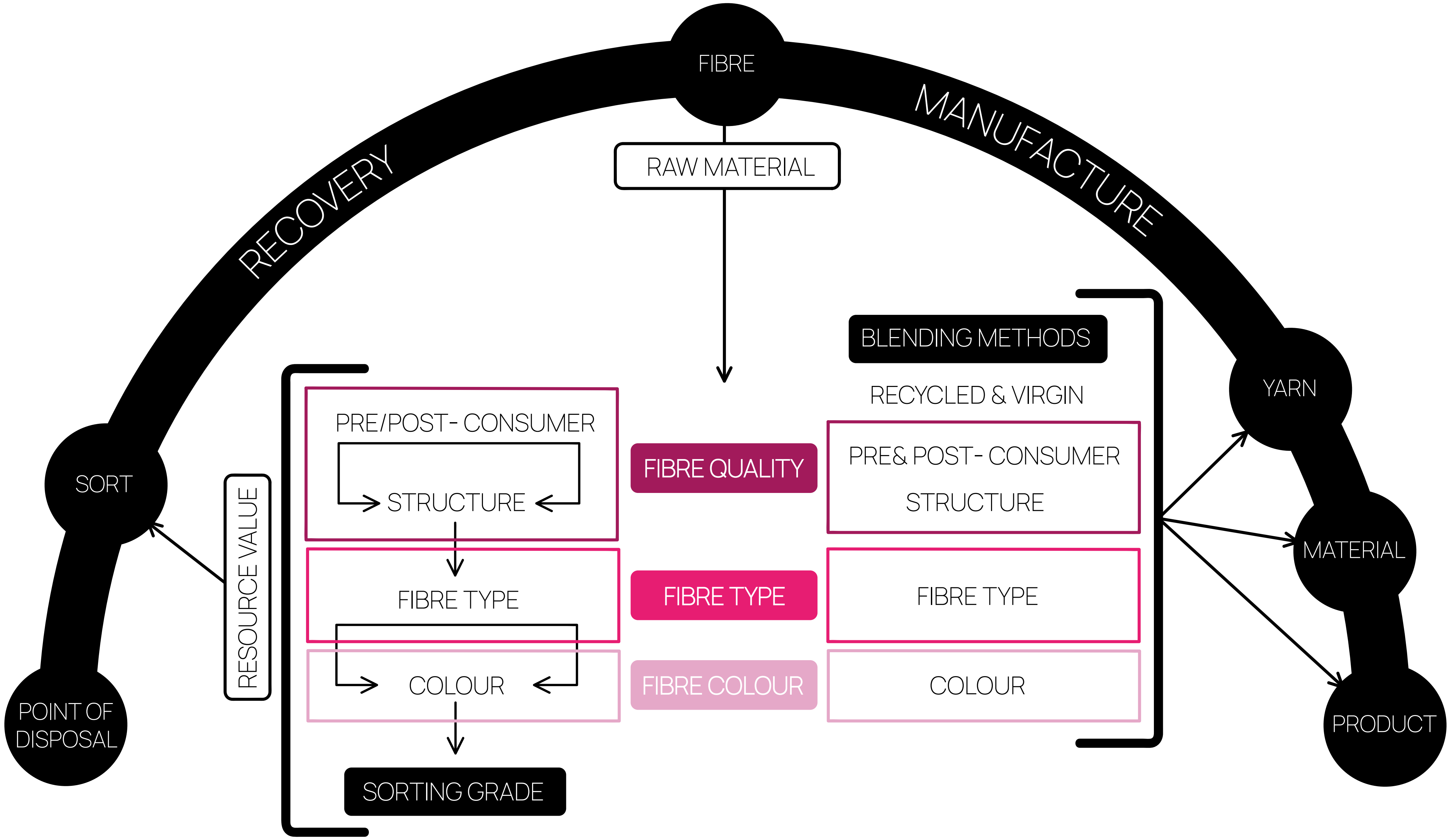


Figure 130. From recovery to manufacture - the correlations between sorting and blending via three fibre categories: quality, type and colour.

the pathways for recycled fibres were understood and in doing this, a pro-active design approach was started. Rather than apply this knowledge to virgin fibre production it was now applied to the recycled fibres and thus the Design for Recycling Knitwear framework emerged (Figure 132 on page 293).

Without the re-active design approach, it is easy to overlook the fact that not all recycling methods produce virgin quality materials. If we continue to design only using virgin resources, we cannot transition to a circular economy, but by undertaking both re-active and pro-active design strategies (designing recycled fibres in a way that allows them to be recycled in the future) then we can ensure the maximum circulation of our resources (section 4.2.3, page 102).

WHAT?

Finally, after the 'why' and the 'how' this research has established 'what' designers need to know when Designing for Recycling Knitwear (Figure 130). The answer to this question is found is in the relationship between blending (during manufacture) and sorting (during recovery). This research has provided granularity on both blending and sorting, such as how blending is conducted across the levels of production: yarn, material and product, in which this research has taken a specific focus on yarn level blending. In addition, it has outlined the variety of sorting methods used to categorise and combine waste textiles, with a specific focus on wool/acrylic fibres.

At yarn level there are five methods of blending used when manufacturing recycled fibres. These blending methods are used to effect three elements. First the fibre quality, such as combining shorter recycled fibres with longer virgin ones, combining the different qualities found in pre-/post-consumer fibres and/or different fibre length from different structured textiles. Second, the different fibre types and finally the different colours can be blended to create a yarn. These three elements of blending: fibre quality, fibre type and fibre colour directly correlate to ways that textiles are sorted - for the quality of the fibres after recycling, fibre type and fibre colour (Figure 130). Each of these categories has been expanded below.

FIBRE QUALITY

Fibre quality is one of the biggest challenges for the manufacture of recycled materials. Quality, here, refers to fibre length obtained after shredding but could have an expanded definition to include attributes which occur after other processes such as yarn spinning. For example, the yarn tenacity, thick or thin areas, neps and hairiness etc…(Vadicherla and Saravanan, 2017). In the recovery phase, sorting waste textiles for fibre quality is conducted in two sorting methods: pre/post-consumer textiles and structure.

Waste textiles are generated from two different systems, pre-consumer and post-consumer waste. Pre-consumer usually create higher quality fibres during recycling because they have either been processed less or they have no degradation due to wear. For example, spinning waste is easier to shred as it has not been knitted or woven into a textile. In addition, material production offcuts can be easier to obtain fibres from, unlike for example, an old, felted wool jumper accidentally washed at too high a temperature. This a simplified view of the pre-consumer recycling system which is much more complex (Runnel et al., 2017). Understanding the intimate detail of these pre-consumer waste flows falls outside the scope of this PhD, however, if collected straight from the factory, pre-consumer waste, has the potential to have increased fibre quality (Fontell and Heikkilä, 2017). This approach is made easier if recyclers are situated close to the virgin manufacturing facilities to gain easy access to the local industry waste (Roos et al., 2019b). In addition, relevant to the next two categories, pre-consumer waste also requires minimal sorting to ensure fibre type and colour are maintained, as the waste is collected from the production of large quantities of the same manufactured products (Fontell and Heikkilä, 2017).

Post-consumer textile waste, on the other hand, are sorted for quality via structure. This is primarily done for re-use markets in which garments are sorted into clothing categories such as trousers, which tend to be woven, or jumpers, which tend to be knitted. These structures dictate fibre length. For example, it is easier to tease fibres from knitted textiles created from less tightly spun yarns knitted into looser textiles. Easier still is obtaining fibre quality from heavier knits that are produced from looser spun yarns. In contrast, woven materials, created using a tighter construction and often requiring stronger more tightly spun yarn, are more difficult to gain longer fibres from during recovery.

In manufacture, at yarn level the designer can blend different fibres (short and long) to ensure longevity of all resources and not just the highest quality ones. For future recycling, it also illustrates that the choices made by the designer regarding the construction of the textile across yarn, material and product level also impact recovery. For example, the value of fibre quality will be affected by how tight the yarn is spun (yarn level), how tightly the knit of weave is produced (material level) and finally how different structured materials are combined, such as in a coat with an outer shell and an inner lining (product level) which creates a need to disassemble/clean. Each of these represent several design decisions that will impact the recycled value of the resource in its next life.

For the designer, this knowledge of quality value and how it materialises itself is the key to design intervention. Armed with the wider view of the spiral, in which traditional routes for resources in and out of products can be mapped, this provides designers with a breeding ground for new pathways to be created from more tricky waste types. In this research, proof of concept was offered using recycled fibres from knitted structures (high value) and diverting them away from woven goods into yarns for knitwear (maintaining value). Armed with the knowledge of the resource spiral, this enables designers to establish gaps in the spiral's pathway for design to intervene and create new ways of using these fibres to maximise use.

FIBRE TYPE

Mixed fibres is another one of the biggest challenges facing the recycling industries. Addressing this challenge through design was the focus of this research, specifically designing with low value mixed fibre waste. In the recovery stage, this research has unpicked the complexity of defining recycled materials composition. For example, the sorting grade called '100% acrylic' often contains other synthetics and wool. Mono materiality in these situations is impossible without chemical separation. The highest value, therefore, in the wool recycling system, is assigned to the purest recycled wool fibres (mainly but not completely pure wool) and lowest value to most synthetic content (mainly but not completely pure acrylic), with a range of blends falling between these two.

At the manufacturing stage, while it is easy to utilise the highest value recycled fibres (100% wool grade), this research illustrates that it is possible to also use the lowest value fibres (100% acrylic grade). This research provides proof of concept by blending these already mixed fibres and provides an opportunity to design functional yarns and textiles that can incrementally increase in value at point of disposal, such as in Practice 10 adding wool to recycled acrylic fibres to move it up a sorting grade. The aim of this approach ultimately is to enable the use of recycled fibres – the waste that already exists – to replace virgin production.

While this research focused on blending for sorting of fibre type at yarn level, blending at material level, such as combining two yarns of different compositions, and product level, such as combining multiple materials with different compositions together, was purposefully designed out. For the designer it is vital to understand how blending of fibre types across yarn, material and product levels combine to create a blend ratio as this could affect the value at the sorting stage.

FIBRE COLOUR

Sorting for colour is a cornerstone of the mechanical recycling industry as the colour is carried forward into its next life. Colour sorting is meticulously conducted as a method to increase value during the recovery phase, such as into family colours, shades etc... There is a mismatch, however, between the efforts made in recovery to keep these colours pure and the blending of these fibres during the manufacture of yarns.

While solid or pure colours hold the highest value other types of colour blending produce an array of values just as with fibre type. Colour blending at yarn level is used to produce melange yarns, which if found in big enough volumes can hold high value when sorted into 'double tones' (Lilani, 2020b). Colour blending at material level materialises in the form of patterns and have the potential for the biggest reduction in value. The more intricate the pattern and more contrasting the colours, the more problematic for the recycling industry. This type of waste is categorised as the 'fancy' grade. At product level, different colours present themselves across different elements of the garment, such as different coloured arms to the body, or different coloured trims. This type of colour blending offers the potential for cleaning the contrasting-coloured sections away from the others so that both parts can be sorted into solid colour grades.

However, for the multi-coloured material level blends there are two types: subtle and bold. More subtle combinations can avoid value degradation, for example black and dark navy pattern knits could be sorted into either a navy or a black sorting grade. Unfortunately, this does not always apply to woven materials as these are lower value. Bolder, more brightly coloured patterned textiles often automatically loose value and are downcycled into non-woven applications. Alternatively, they can be overdyed with a darker colour, such as black, brown or navy to be used as a solid colour alone or in a blend.

This method of overdyeing fancy wastes may have been used for the acrylic fibre sourced in Practice 10 prior to the recycling company purchasing it and suppling it for this research. Value, in this case is added by returning the waste to the desired solid colour. However, overdyeing is only conducted on certain types of waste and judgements on structure and fibre type must be made first. For example, woven waste is less valuable than knitted and might not be considered worthy of the additional cost and effort of overdyeing. Most importantly, the composition of the garment needs to be approximately known, such as wool/acrylic, wool/polyester etc... because truly 'mixed fibres' are problematic to overdye back to a solid colour (Recycler X, Appendix 14.4, page 348).

As with fibre type, design intervention can provide methods for all manner of fibre colour waste to be utilised effectively. In the same way as designing to incrementally increase the value of fibre type, the value of fibre colour could be harnessed. Further research building on the insights presented here should be undertaken for designers to understand this approach in more detail.

DESIGN FOR RECYCLING KNITWEAR

For designers, this research has expanded understanding of the bridge between design in manufacture and the sorting systems within textile recovery. Armed with this knowledge, design can intervene across these three categories to both design from recycled wastes and influence the resource pathways for onward recyclability, thus Designing for Recycling Knitwear framework emerged (Figure 132 on page 293).

These three value categories (quality, type and colour) do not stand alone in the textile sorting industry. Whether design choices are made to impact fibre quality, fibre type or fibre colour at the sorting stage, all three together create the ultimate value ratio. To illustrate this, the original recycled fibre used in Practice 10 as well as all the jumpers produced during the research were assessed for their value across the three categories (Figure 131 on page 291). The jumpers rather than the yarns from Practice 10 were evaluated as a more realistic representation of how it would enter the recycling system. And thus represented the value across yarn, material and product levels combined.

The original navy recycled fibre was produced from knitwear, and as with most fibre in the recycle industry, it is not known what precise waste source it came from. Therefore, it is assumed that this would have come from a mixture of mid-weight jumpers that were potentially overdyed in navy. Not being from the heaviest weight knitwear, the fibre was valued just to the right of the highest level. At the same time, the fibre was sourced from the 100% acrylic category which represents the lowest value material in the wool recycling system. Finally, as a solid colour, the fibre has very high colour value.

Each of the six jumpers have also been evaluated in the same way. These have been compared against each other and the original fibre. Firstly, the quality of the fibre was assessed, this refers to the quality that is assumed once the six jumpers have been recycled. As knitted structures the quality will be the same as the original. The exception

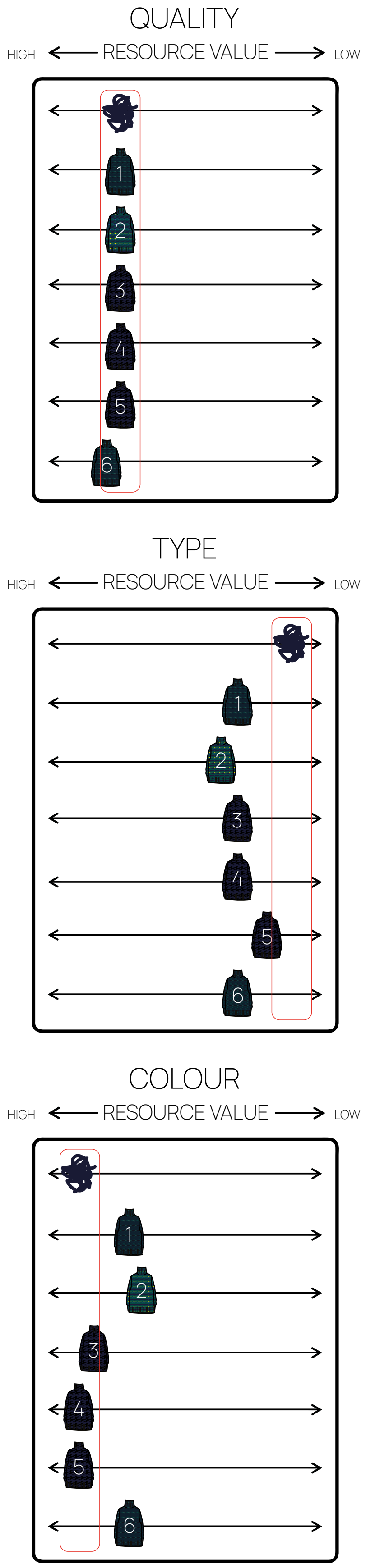


Figure 131. Original recycled Fibre and Jumper 1- 6 from practice 10 evaluated against fibre quality, fibre type, fibre colour value

is Jumper 6 which was knitted from a heavier weight yarn and therefore has the potential to offer longer fibres in pulling process. However, while this might be technically true, the wider thresholds used in sorting makes this very likely that Jumper 6 would be classified and combined together with the others.

The value of fibre type was specifically tested in this PhD and demonstrates through blending with wool that the jumpers would have incrementally increased to a slightly higher value category. The exception is Jumper 5, which had no added wool in the yarn blend. While it should remain at the same value, this research has shown this could have been sorted into a low wool grade. Similarly, Jumper 2's yarn was blended with 50% wool/mohair/cashmere that should have increased its value above all the others. The results of this research were inconclusive and therefore the value has been placed only slightly above the other yarns. This highlights the reality of value judgements at the sorting stage and demonstrates how sorting combines different types of wastes to make approximate batches.

Finally, while the original fibre started as a solid colour, valued very highly at the sorting stage, only two of the jumpers (4 and 5) retained a solid shade. Jumper 3's yarn was designed with a very subtle shade and while the value is represented as very slightly lower, the reality is this jumper would still be considered solid. Jumpers 1, 2 and 6 all decreased their colour value through blending at yarn level resulting in melange shades. Specifically, Jumper 2 was knitted from a yarn that contained five different colours and therefore would be even more difficult to sort into the 'double tone' groups (Lilani, 2020b). However, melange tones and solid colours are sold for similar prices to the recyclers and can be used to create new melange colours. Overall, the six jumpers have been designed to alter the value by minimal amounts. The focus of the design at yarn level was to increase the fibre type value at the sorting stage. However, as we can see from Figure 131, that value can be shifted in different directions depending on an array of design decisions. Where value can be added in one area it is easily decreased in others.

While it would be desirable to use this visual as a tool to convince designers to only design heavy, loose knit products in 100% wool and solid colours, this is far from practical. This stands to illustrate why the highest value resources are the most sought after. However, these mono-coloured, mono- fibres textiles constructed from loose structures are also the easiest to downcycle. Design for Recycling Knitwear challenges the designer to intervene and create new pathways (up and down) using the whole spectrum of wastes in order to maximise the longevity of our resources. Without first designing recycled fibres into products and without second understanding how blending and processing at yarn, material and product level impacts the value at the sorting stage, this is an impossible task. If designers can use this knowledge, we can meet this challenge of designing with the full spectrum of waste to create a multitude of textiles for every kind of application and successfully Design for Recycling Knitwear (Figure 132 on page 293).

PRACTICE FRAMEWORK

DESIGN FOR RECYCLING KNITWEAR

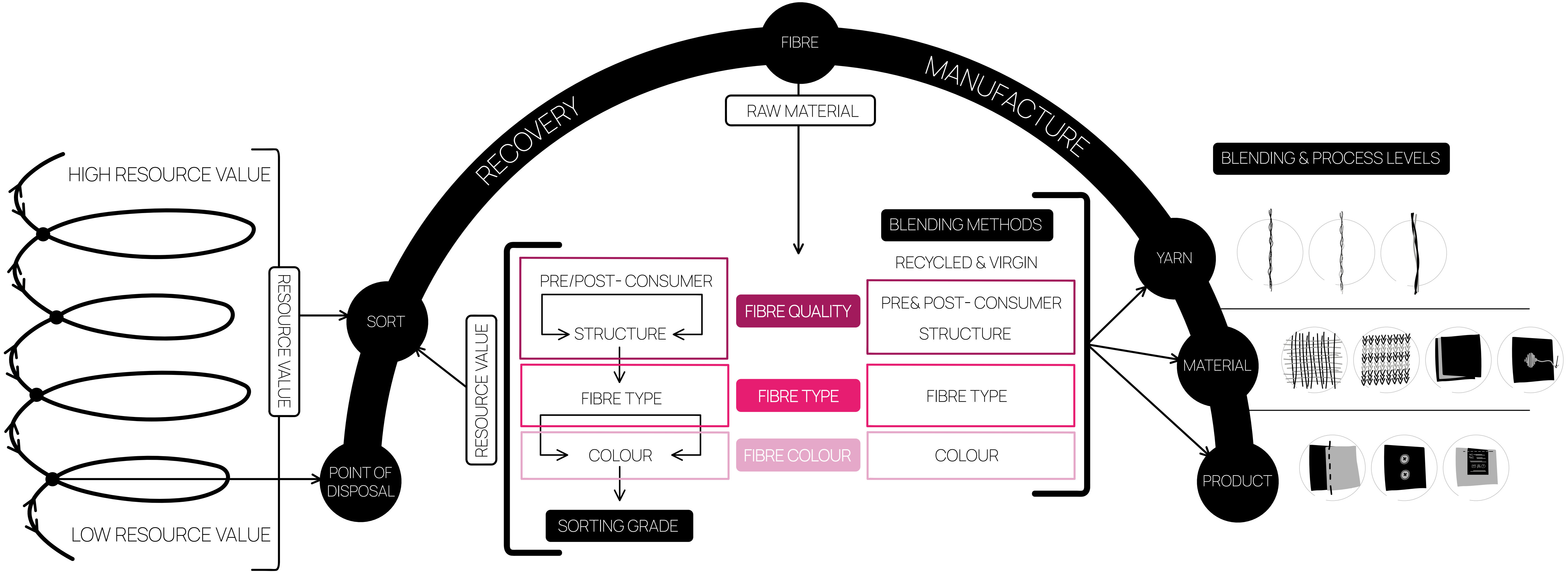


Figure 132. Design for Recycling Knitwear framework

11.2 REFLECTING ON THE RESEARCH PROCESS

11.2.1 THE DESIGNER AND THE RESEARCHER

Throughout this research the author of this text has intentionally referred to herself as a 'designer-researcher'. As indicated in the preface (page iv), this hybrid title accounts for her education and experience in industry as a designer-specifier (Hornbuckle, 2018) as well as her research in sustainable and circular textile design for her Master's degree (Practice 0, on page 59) followed by her work at the Centre for Circular Design. The expertise of both designer and researcher have been brought together for this PhD study. However, while they have overlapped and worked in tandem throughout this project, the role of the designer-researcher and that of the industry designer are discrete and need to be distinguished.

In broad terms, the realms of industry and academia use very similar methods but with different goals and objectives. They ask similar questions, but while industry focuses on the 'know-how', academia focuses on the 'know-why' (Mujumdar, 2004). In the field of interaction design, understanding the complexity and combination of academia and industry methods has been explored by Fallman (2008, see also section 2.5.2, page 49). In his model, he first describes the activity 'design practice' as an industry endeavour that is a very similar method used by designer-researchers when working for a commercial design company. This industry-based design practice, Fallman explains, needs to represent the realities of the industry, such as cost, time to market, sales figures etc… This is supported by Kimbell (2011) who advocates for more attention to be paid to the creation of practice by the 'situated' professional designer rather than solely 'design thinking' – the problem-solving method used in innovation (Brown, 2008). In contrast Fallman (2008) distinguishes 'design studies' as an academic activity which is used to build on an accumulated body of knowledge. These two contrasting methods form two points of his triangle shaped model (Figure 21 in section 2.5.2, page 49).

The reason to combine both academic and industry methods and vitally move between the two is advocated by Fallman to gain a change in perspective. This, he describes, is like "using a different set of goggles" (Fallman, 2008:10) and is very similar to the 'changing hat' metaphor in the author's co-written journal article 'Divide, Switch, Blend' (Hall and Earley, 2019, see Appendix 14.8.2, page 423). This dual perspective provided by the two activities (industry and academia), Fallman explains, is vital as they often support each other. And explicitly knowing and understanding which perspective is being taken is key to conducting design research. This is supported by the author's 'Divide, Switch, Blend' methods which describes the specific ways academic and industry hats interact. 'Divide' entails wearing both hats separately on different occasions; 'Switch' is having both hats to hand ready for swift interchange on the same occasion; and 'Blend' refers to the wearing of both hats simultaneously. Specifically, it is vital to identify the dominant hat for both fluidity and ultimately the generation of broader and deeper insights (Hall and Earley, 2019).

Putting this idea to use,Table 24 identifies and maps how the author's roles have interacted across the research as a whole. It highlights where the researcher or the designer role was dominant and where, in some cases, there was an equal balance.

In cases where one role was dominant, such as Practices 1, 2, 4, 5, 6, 8, and i (interviews), it is important to note that the non-dominant role was never entirely absent. In these cases, dividing and switching between roles occurred, while in the other cases (Practices 0, 3, 7, 9 and 10) the roles were blended. As discussed later, the dynamic/interaction in each individual case is dependent on the context and the roles played by other individuals involved.

Table 24. Dominant role/hat (researcher or designer) mapped against the practice research elements in this thesis

	0	1	2	3	4	5	6	7	8	9	i	10
RESEARCHER	X	X		X	X		X	X	X	X	X	X
DESIGNER	X		X	X		X		X		X		X

DIVIDE

In Practice 2 (page 111), the designer role was dominant when working with a weave technician to produce a recycled woven fabric. Here, in this design-led experiment the hats were 'divided'. It was only after the experiment that the researcher reflected on what had occurred, namely that this division created insights into design choices for recyclability.

SWITCH

In Practice 4 (page 147), although both hats were active, the researcher role was dominant when facilitating workshops that explored design for cascading. The 'switching' back and forth with the designer hat, however, was crucial in providing a current industry perspective to the research. This was demonstrated by the designer creating a 'how will it work' worksheet.

BLEND

Finally, during Practice 7 (page 169) the hats 'blended', working in continuous dialogue with one another to conduct tests into repetitive blending of recycled fibres. The designer hat provided knowledge of commercial design conditions, while the researcher hat considered the implications for Design for Recycling.

These three examples highlight that when a single person takes on two roles, added value is created to generate deeper insights.

DESIGN EXPLORATION

The two roles of industry designer and academic researcher have worked hand-in-hand throughout this research across Practices 0-10. These practices have been described as 'design explorations', a term also used to refer to the third element in Fallman's (2008) triangle shaped model (Figure 21, section 2.5.2, page 49). In this section, how this term is defined by Fallman and interacts with the other elements of his model is examined. This discussion will be used to clarify the similarities and contrasting approaches proposed in this thesis.

Fallman (2008) expresses 'design exploration' as the process through which the researcher brings forth a product or a service. This, however, is very similar to 'design practice' without the clients and markets. The resounding difference in design exploration, Fallman explains, is the role of the researcher. Here the activity is only concerned with the research agenda and vitally allows the researcher to ask 'what if?' and challenge what is possible. In doing so, the researcher often uses creative problem-solving methods, such as creating a problem space or frame (Moxey, 2000; Cross, 2011). However, the methods used in this PhD research diverge from Fallman's thinking to create a differently configured model. While Fallman acknowledges the flow between the three activities, he views them as entirely discrete. This thesis, in contrast, proposes a layered approach in which all three activities are brought together.

Unlike this research, Fallman's model does not explicitly define activities by role (or hat). These roles are, nonetheless, clearly evident. His terms 'design exploration' and 'design studies', for example, both correspond to what this study calls academic research, while his 'design practice' corresponds to what this study would identify as industry design. In this research both theory and exploration are understood as activities or roles and distinctions between them are not considered necessary. The main contrast to Fallman's model, however, is that the designer and researcher roles continually divide, switch and blend. This way of working promotes knowledge exchange that generates new insights, between the academic researcher and industry designer, whether they be a single person wearing two hats or two individuals collaborating. It is the convergence of these roles in an industry context which is fundamental, and this will be discussed in detail in the next section.

CONTEXT

The context of any given situation is vital for our understanding of the world (Papanek, 2019). Following Kimbell's (2011) suggestion that more focus should be placed on the creation of practice by the 'situated' professional designer, this can be addressed by research occurring in the space between academia and industry. Therefore, to meet this challenge in this research a reflection was made on the different designer and researcher roles in a specific context, namely Practice 10, which took place at an industrial yarn spinning facility (see Chapter 10, page 225). Here, the author drew on previous experience and expertise as a designer in industry (as opposed to that of a craft-based designer), and as an academic PhD researcher. Taking on the roles of both designer and researcher, she was dealing with two distinct sets of priorities.

These priorities were distinguished most clearly when introducing a design brief. A design brief is described by Sinclair (2014) as a 'research for design' method and offers commercial fashion design direction. In Practice 10, in her role as a designer, the author created what Carlsson et al. (2017) refer to as a set of design conditions. In parallel, in her researcher role, she included a set of Design for Recycling conditions. It is through layering these design and research conditions within a single context (in this case, an industrial spinning facility) that insights could be maximised.

Using an annotated portfolio method (Gaver and Bowers, 2012, Hall, 2020b) the written description of Practice 10 (in Chapter 10) was highlighted and annotated (Appendix 14.7, page 399). This fully demonstrated the continual interchange of roles from designer to researcher with their contrasting and complementary priorities. An example of this is shown in Figure 133 (page 300) where designing Blend 3 is described. Here, the designer and researcher hats switched and blended during experimentation with silk fibres. First, in her designer hat, she was concerned about the aesthetics of the final yarn, such as colour, and the suitability of using silk fibres for the design brief. Switching to her researcher hat, she then focused on the impact of silk on future recyclability in a wool recycling system.

Thereafter, the author took a blended approach, wearing her researcher and designer hats together over the development of a range of yarns for different markets. The final decision was to blend the recycled fibre with both luxury virgin fibres as well as less expensive fibre types. As a designer, she recognised the usual practice of creating a range of options during the design process, and the potential of each option to have a use in a different final market. Simultaneously, as a researcher, she acknowledged the need to generate a range of yarns to be tested for Design for Recycling across different market levels. Thus, the priorities of each role were matched, and a range was created. From this example, we can start to see how the priorities of each role are used and how they come together to forge the direction of the yarn development.

Further understanding can be gained from instances where the researcher and designer priorities did not align so conveniently. For example, during stages 3 and 4 of the practice, colour posed issues for both the researcher and designer, but for different reasons. The designer was more concerned about the end-result for the market, whereas the researcher only considered colour as an aid for comparison. During stage 3 of the practice, as a purely design-driven concern, turquoise and yellow were used to create yarns that fit in with the design brief. In contrast, at stage four, when the decision was made to create a control yarn, colour became a problem from the researcher perspective. The two core components of this control yarn, 50% recycled acrylic and 50% polyester, could only be sourced in navy and black respectively. The limited colours would potentially cause problems at the analysis stage when comparing the control yarn to the brighter samples that had been designed previously. This resulted in the researcher creating a navy and black duplicate of the designer's brighter yarn. It is through the combination of both researcher and designer roles that this expanded range of yarns was created.

The point of the above examples is to demonstrate the importance of a specific context. In this case, the context was an industrial spinning facility selected to explore 'Design for Recycling Knitwear' in practice. The dual presence of the researcher and the designer in this industrial setting highlights the nuanced conflicts between their respective research and commercial concerns. By involving both roles of within this context, richer insights can emerge into how far and in what situations the designer is able to push their priorities forward, and how far the researcher can question or push back. It is specifically at the intersections of industry (designers' remit) and academia (researchers' remit), set within a context, that insights can be uncovered (Figure 134).

11.2.2 THE EXPERT

Omitted from the discussion, until now, is the presence of a third role. Unlike the designer and the researcher roles, taken in this research by a single person, this third role resides within the industry context as a collaborator and expert in the field. This role is born out of the wider context exploring 'wool/acrylic textile recycling'. However, more specifically in Practice 10 the expert was a spinning engineer in the UK wool textile industry approached to create a recycled (research priority) yarn for the commercial market (designer priority). As with any new role, the expert also brings new priorities, and these have to be balanced with those already at play.

These additional priorities were also evidenced in Practice 10 in which the complete yarn

Figure X. Third blend test with cashmere and silk

A second attempt was made to create a silk/cashmere blend. This time the brown cashmere waste was used and the designer-researcher requested permission to select a range of harmonious colours (grey and light blue) and the result was much more appealing. However, the researchers concern for onward recyclability was enough to drop this blend from the range. Additionally, she concluded that the inclusion of silk had not been seen during the market or trend research. In this specific instance, the blend was unsuitable.

Figure X. Blend test four with brown cashmere and blue/grey silk neps

A final version of Blend 3 was tested removing the silk content. The aims of the research were at the forefront of the designer-researchers mind during the selection process. She reflected on the composition of both Blend's 1 and 2 and how these represented standard (30% wool) and luxury (50% wool) approaches to blending. To produce a range of options, Blend 3 would therefore need to be designed halfway between the two. To achieve this Blend 3 used the composition structure of Blend 1 (50%, 30% 20%) but incorporated a small amount of luxury content more akin to Blend 2. The resulting composition was 50% recycled acrylic, 20% cashmere, 10% wool (forming the desired 30%) and 20% additional synthetic. Once again for the test black wool was used in lieu of the unavailable synthetic fibre.

The colours in this case were dictated mainly by the availability of fibres. For example, navy had been pre-chosen for the recycled acrylic; pre-consumer waste cashmere was provided in brown and small quantities of synthetic materials could only be obtained in black or white. Black had been selected for all the yarns to deepen rather than lighten the yarn shades. An exception was the 10% wool content, and this could be selected from range of stock colours. A 'slate' blue was chosen to compliment this dark colour range. This resulted in a deep but grungy blur of colour suitable for the brief.

Figure 133. Annotations and highlighting created on Chapter 10 (see also Appendix 14.7, page 399)

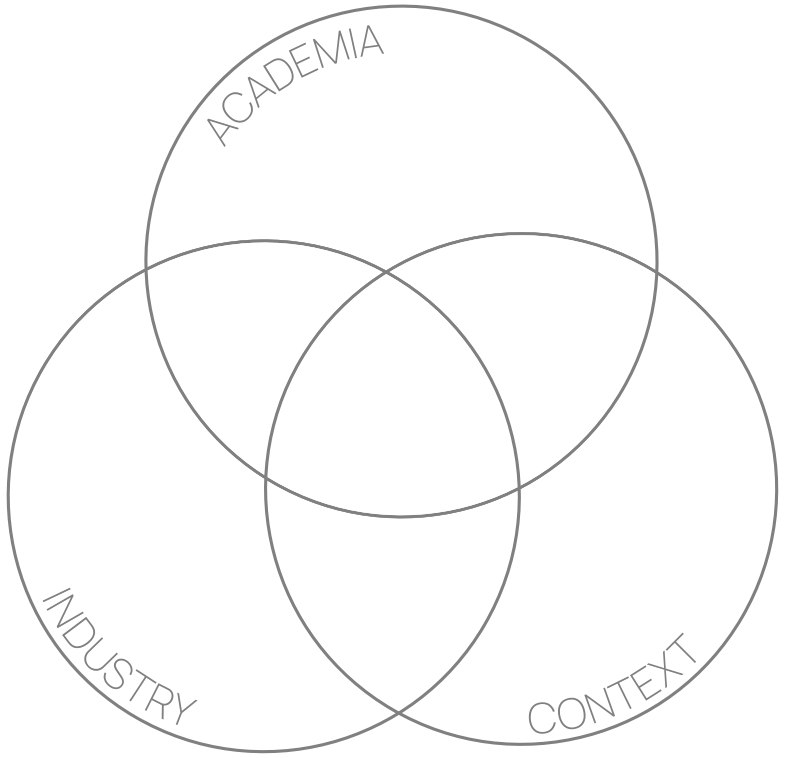


Figure 134. Interactions of the designer, researcher and context for conducting research

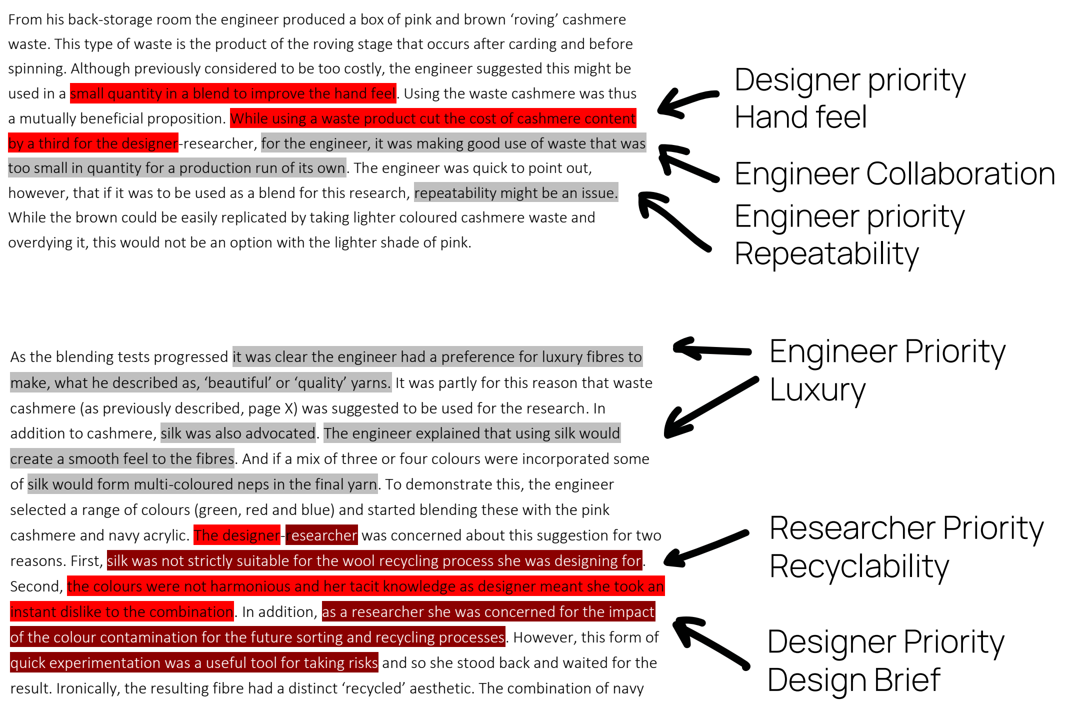
spinning process was undertaken. For example, from the beginning the engineer explained that the collaboration could only take place if the designer-researcher was able to source seam-cleaned recycled acrylic fibre. For the engineer this was vital to avoid contamination caused by the strong synthetic threads breaking in manufacture triggering fibres to fly into the factory air. Here, the engineer's priority was for the smooth running of his business and this provided boundaries for the recycled yarn development. In another example, during Stage 4, when confirming the synthetic content of the yarns the designer-researcher wanted to use synthetic fibre in greater quantities than 20%. Nylon fibre was removed, a choice by the engineer, as this could not be processed by the machinery in large quantities. In both examples the engineering role dominated by setting boundaries.

The engineer role did not always dominate in this manner. In stage 2, when discussing waste cashmere as a blending component, the engineer raised concerns for the repeatability in manufacture. Two shades of waste cashmere, pink and brown, were available and the engineer reasoned that by using brown it could be replicated through overdyeing lighter wastes in the future production. Repeatability had not been considered by either designer or researcher and this illustrated the benefits of collaborating with multiple roles that bring a range of expertise (Figure 135).

Moreover, the engineer's priorities intersected individually with both researcher and designer. As discussed in Chapter 10 (section 10.3.2, page 231), the engineer had a preference for natural luxury fibres. This was because most of his work centred around spinning these types of fibres such as wool, mohair, cashmere and silk. Based on his tacit knowledge, he explained how the silk would affect the look and feel of the final yarn for Blend 3. Here, his priorities were more parallel to those of the designer (Figure 135).

Earlier in Stage 2, when discussing the possible fibre options, the engineer's priorities aligned with the researcher by being perceptive of the researcher's aims. He suggested the use of pre-consumer waste cashmere to increase the waste content of the yarn (Figure 135). This arrangement benefitted the engineer by being able to sell the waste that was too small for most production runs. It also provided the researcher an opportunity to experiment with a waste stream previously thought to be unavailable to her. In addition, the designer also benefited from the lower cost of the waste ordinarily out of reach. All three roles were aligned, and the fibre was used.

Ultimately, as the roles come together, as illustrated by Figure 136, it is the push and pull of priorities at the intersections of roles where insights can be found, and knowledge can be exchanged. As demonstrated in the diagram, the designer brings expertise from having worked in the UK fashion industry as a knitwear designer; the researcher provides the theoretical design context, and the expert provides the know-how for the creation of yarns. It was only in instances where all three roles come together that practice 10 was able to move forward.



From his back-storage room the engineer produced a box of pink and brown 'roving' cashmere waste. This type of waste is the product of the roving stage that occurs after carding and before spinning. Although previously considered to be too costly, the engineer suggested this might be used in a small quantity in a blend to improve the hand feel. Using the waste cashmere was thus a mutually beneficial proposition. While using a waste product cut the cost of cashmere content by a third for the designer-researcher, for the engineer, it was making good use of waste that was too small in quantity for a production run of its own. The engineer was quick to point out, however, that if it was to be used as a blend for this research, repeatability might be an issue. While the brown could be easily replicated by taking lighter coloured cashmere waste and overdying it, this would not be an option with the lighter shade of pink.

Designer priority
Hand feel

Engineer Collaboration

Engineer priority
Repeatability

As the blending tests progressed it was clear the engineer had a preference for luxury fibres to make, what he described as, 'beautiful' or 'quality' yarns. It was partly for this reason that waste cashmere (as previously described, page X) was suggested to be used for the research. In addition to cashmere, silk was also advocated. The engineer explained that using silk would create a smooth feel to the fibres. And if a mix of three or four colours were incorporated some of silk would form multi-coloured neps in the final yarn. To demonstrate this, the engineer selected a range of colours (green, red and blue) and started blending these with the pink cashmere and navy acrylic. The designer-researcher was concerned about this suggestion for two reasons. First, silk was not strictly suitable for the wool recycling process she was designing for. Second, the colours were not harmonious and her tacit knowledge as designer meant she took an instant dislike to the combination. In addition, as a researcher she was concerned for the impact of the colour contamination for the future sorting and recycling processes. However, this form of quick experimentation was a useful tool for taking risks and so she stood back and waited for the result. Ironically, the resulting fibre had a distinct 'recycled' aesthetic. The combination of navy

Engineer Priority
Luxury

Researcher Priority
Recyclability

Designer Priority
Design Brief

Figure 135. Annotations and highlighting of Chapter 10 (see also Appendix 14.7, page 399)

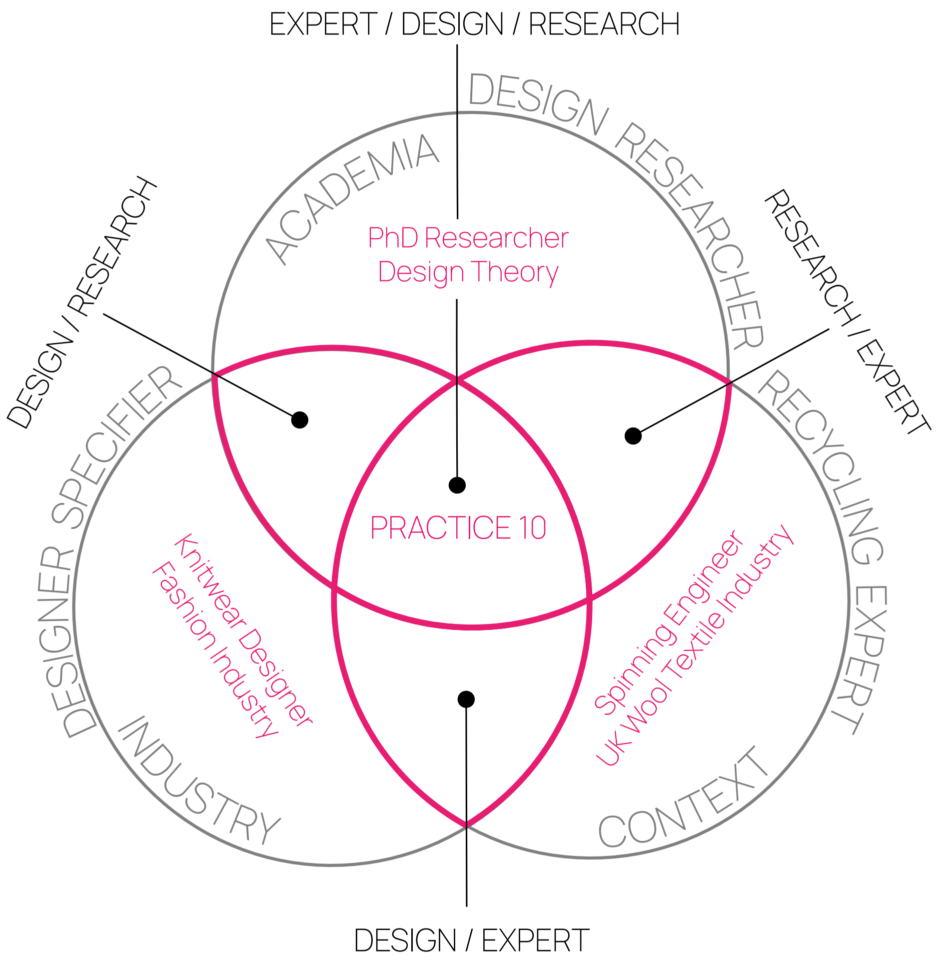


Figure 136. Intersecting roles of Researcher, Designer and Expert in Practice 10

11.2.3 COLLABORATION

Collaboration is defined by Amabile et al. (2001) as "individuals who differ in notable ways sharing information and working toward a particular purpose". Collaboration between researchers and industry is a growing area evidenced by EU funding encouraging collaborative networks between academic institutions and industry (Mønsted and Hansson, 2010). And within the field of design research a push towards industrial collaboration is shown by the Arts and Humanities Research Council AHRC (2018) partnership with Innovate UK to pursue "knowledge transfer partnerships", helping industry access expertise from UK Universities. There is now also an emphasis on Knowledge Exchange, which enables business and design to learn from each other rather just a single sided communication of ideas (Follett and Marra, 2012).

Taking a broader look at the practice conducted in this PhD, beyond a singular reflection on Practice 10, collaborative practice (working with the expert role) is a common thread running through the research. In each situation (with the exception of the workshops in Practice 4) the role of the expert and the specific context to be explored changes, while the overarching investigation of the research remains. The role of designer and researcher provided by the author remains constant as the expert role shifts between collaborators in the variety of situations.

All the practice in this research has been mapped against the intersection of the three roles: industry designer, academic researcher and expert in context (Figure 137). The location of each practice within the Venn diagram has been allocated firstly using the reflections of the dominant hat in each situation, namely designer, researcher or a combination of the two (section 11.2.1, page 295). Secondly, the reflection on the role of the expert within the practice was defined. To do this a description of each expert role was provided relating to individual practice numbers.

This map illustrates the range of practice that has been undertaken in this thesis towards the investigation of Design for Recycling Knitwear theme. Each intersection of the Venn diagram will be discussed below in reference to the practice from this research and the benefits of these different intersections for knowledge exchange.

DESIGNER AND RESEARCHER

In the intersections between the designer and researcher only Practice 4 is present without the input of an expert. Practice 4 (page 147) was formed of a series of workshops created by the researcher role to investigate design for cascading. The workshop, centring around a re-design challenge, started from an understanding of how garments are currently designed in industry (designer role/hat). Building from this, the workshop focused on asking students and industry designers to explore new resource flows beyond the present to imagine new futures (research role/hat). With the introduction of a new worksheet, a switch was made to the industry designer hat, and brought the exploration full circle back into an industry context. This was achieved by asking the participants to establish how their ideas might work in a nearer future considering the systems currently in place.

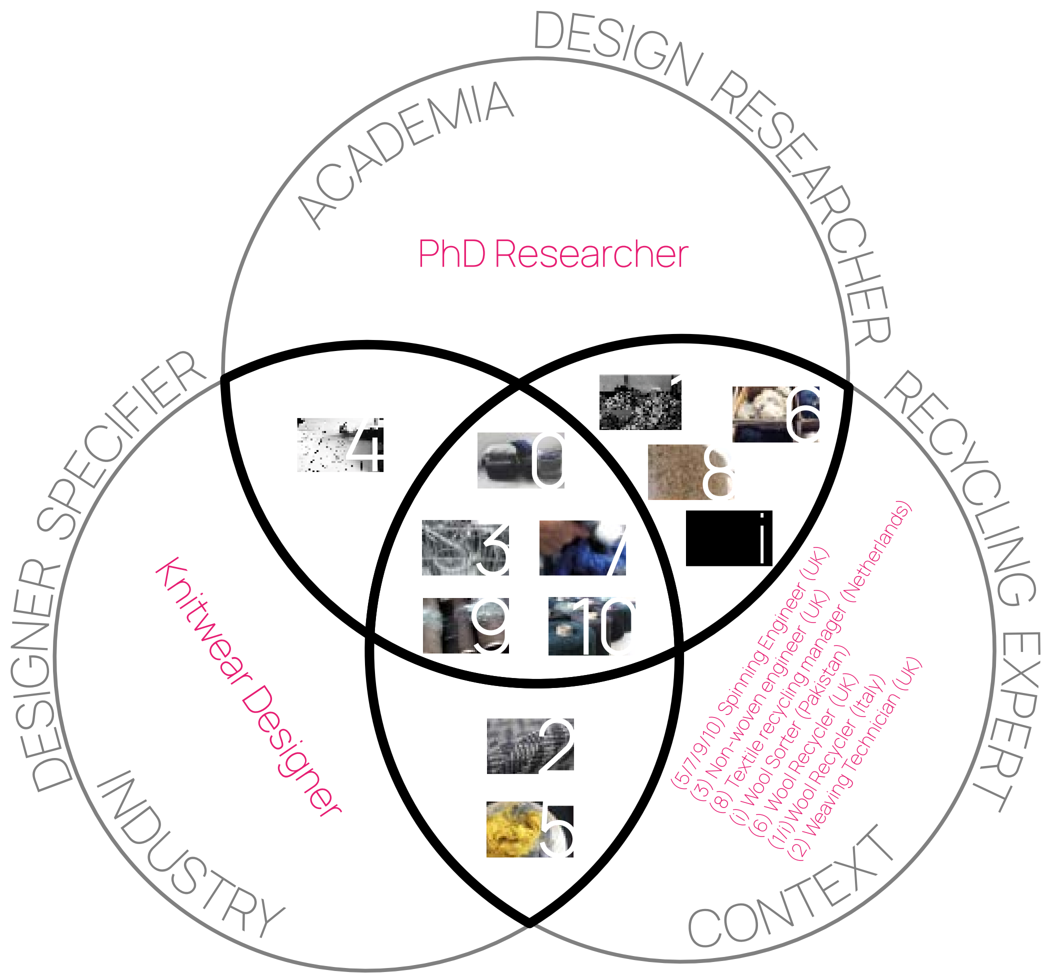


Figure 137. Mapping all the PhD practice against industry, academia and context

RESEARCHER AND EXPERT

Four different practices are situated between the researcher and expert. Three of these took place in the field and workplaces of the experts involved (Practice 1, 6 and 8) and the other was the interviews of experts (section 8.4.1, page 203). Practice 1 (page 79) was conducted as a field research visit to the wool recycling industry in Prato, Italy. Here a range of facilities were visited that make up the recycling industry and later the same expert provided a detailed interview with his perspective on textile sorting. Each of these practices, including the interviews, were used as a method (researcher role) to map and understand the wool/acrylic recycling system. Practice 1 was focused on wool recycling in the current day, Practice 6 (page 161) was concerned with wool recycling from a historical perspective, Practice 8 (page 177) was concerned with innovation in synthetic recycling and the interviews provided a deep dive into sorting activities. The expert role provided the current context of system and the research was able to use this as a base for which new knowledge could be built.

EXPERT AND DESIGNER

Primarily a research project, it might appear strange that practice took place that removed the researcher role (Practice 2 and 5). In these instances, the designer and researcher roles were taken on by the same person and therefore the insights gained from this practice were used by the researcher as a reflection after the event. While the researcher hat was not dominant in these situations, understanding how design ideas (designer role) and materials are produced in a current industry context (expert role) is vital to understand the challenges for the research aims. For example, in Practice 2 (page 111), a woven design was produced from recycled materials in collaboration with a weave technician. This practice was conducted to go through the designer's process of taking a yarn into a material and then a product. The designer role ensured the materials were designed to maximise different fabric options for a range of cushions and this was implemented by the expert. It was long after Practice 2 was complete that the researcher understood the implications for both recycling and blending levels during the activities. This demonstrated how the combined 'expert and designer' collaboration is equally important to the 'expert and research' combination in establishing the current baseline challenges for designing in context.

DESIGNER, RESEARCHER AND EXPERT

Finally, at the central intersection of the Venn diagram all three roles are brought together. Here the practice explorations (0, 3, 7, 9 and 10) actively worked with recycled fibres to be designed (designer role) in collaboration with manufacturing experts (expert role) to explore the research aims (researcher role).

11.2.4 PERSPECTIVES

Navigating practice situated in the space between the three roles (designer, researcher and expert) is demonstrated throughout this research as a tool to create insights. However, the navigation itself can be difficult. While it might seem a logical and well-structured approach to first conduct practice in the outer segments of the Venn diagram working inwards to this central space, this is not conducive to the nature of messy design research (Cleveland, 2018; Mcquillan, 2019). As indicated by the practice numbers, the research moved backwards and forwards between the outer intersections and into the central collaborative space as the ideas changed and progressed.

It is therefore not the path between the practice that is most interesting but rather the perspectives offered by the roles for the subject being investigated and the insights that this generates. As insights are produced, new practice is initiated with the appropriate roles. Reflecting on all ten pieces of practice research it can be seen that each role takes a distinctive perspective: now, near and far (Hall and Earley, 2019).

NOW, NEAR AND FAR

Designers are often propositioned as future thinkers, with a focus on how things might be (Yelavich and Adams, 2014; Simon, 1996), but the designer within academia and within industry have different remits of what they consider 'the future' to be. The design researcher is often concerned with the far future, whereas the industry designer focuses on changing the more immediate future (Hall and Earley, 2019).

In academia, probing and exploring the possibilities of radical transition to a new future is necessary and should be encouraged but does not mean all research is required to be situated as such. Transition design (Irwin, 2015), is a developing discipline advocating for design-led change towards a sustainable future. This transition can happen within a spectrum allowing designers to address the world's complex problems to transition from now to near and far contexts (Goldsworthy, 2012; Centre for Circular Design, 2020).

Returning to Practice 10, positioned in the centre of the Venn diagram, these three perspectives can be clearly demonstrated. For the expert, their priority is the successful production of yarns that aids rather than disrupts business (now). For the industry fashion/textile designer in industry, their priorities are materials for beautiful and practical design of knitwear (near). Finally, for the academic researcher, their priority is both the use of recycled fibres in the near future as well as the future recyclability towards longevity of fibres (far). Together, unrealistic visions of what is possible and the constraints of current technology can be balanced to produce future based ideas and solutions.

These now, near, far perspectives are layered on top of the Venn model in Figure 138 on page 307. Purposefully, the timeline is circular with each timeframe blending into the next. This illustrates the less rigid association of each role to the timeframe closest to them. For example, the researcher role in academia is situated within the 'far' period, however as the researcher collaborated with the other roles they can also consider both the near and now. Therefore, to allow the researcher to apply their ideas within the near and now timeframe, in

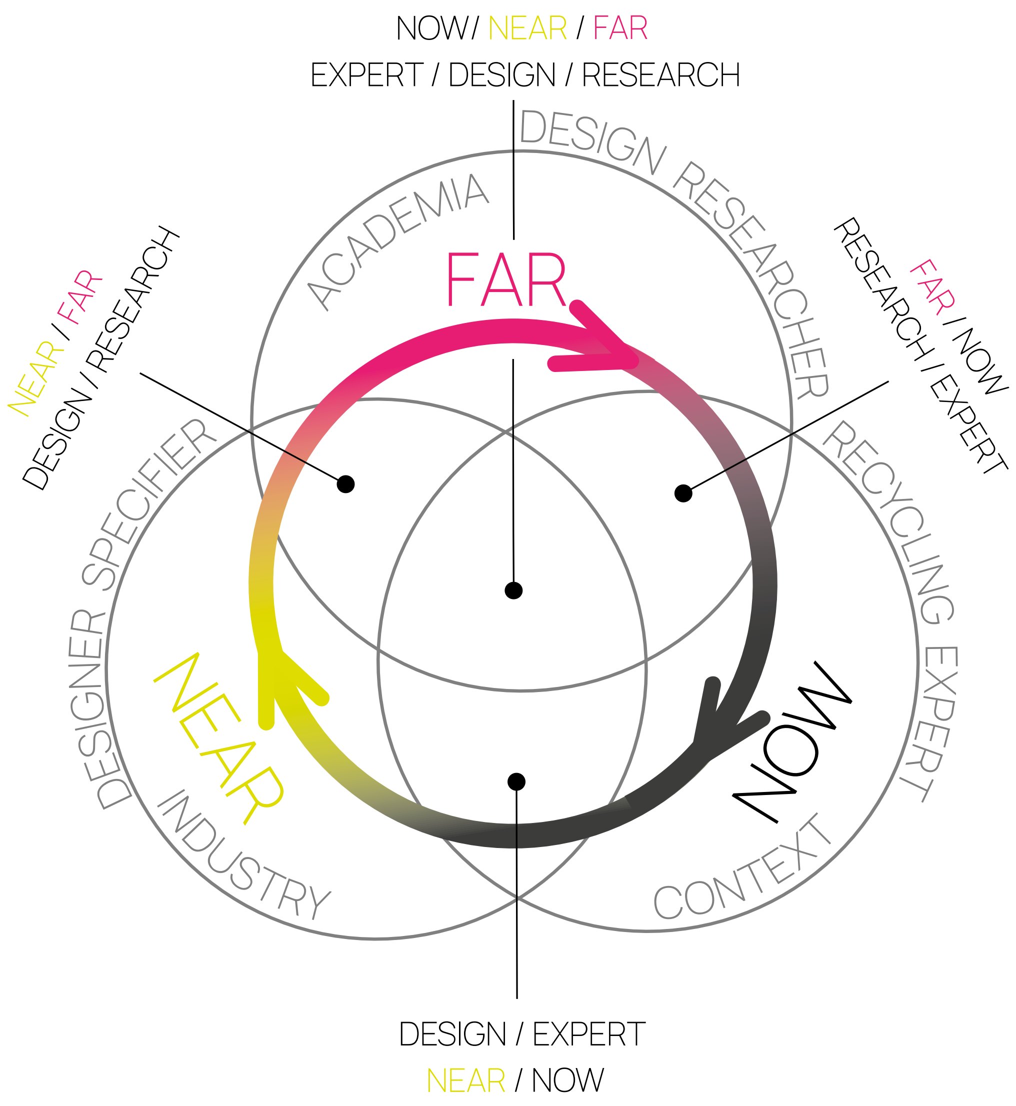


Figure 138. Now, Near and Far timeframes mapped against the three roles (expert, designer and researcher) and their intersections.

which the transition from old practices into new sustainable ones needs to occur, it is vital for the researcher to collaborate to maximise insights created through these alternative perspectives.

Establishing how to navigate between these perspectives allows insights to be generated, knowledge to be exchanged, and impact to be created. In Practice 10, the expert was challenged on the business-as-usual scenario while allowing for them to input their current understanding of process, manufacture and know-how. For the designer, they were challenged by the limitation of the Design for Recycling Knitwear brief and manufacturing whilst adhering to commercial design criteria including aesthetics and cost. Finally, the researcher was challenged by both sets of priorities layered onto the Design for Recycling Knitwear criteria towards sustainable alternatives. Each set of priorities pushed and pulled, resulting in insights and new knowledge.

11.2.5 OVERARCHING METHODOLOGICAL FRAMEWORK

As discussed in Chapter 2, a bricolage of nine methods have been used across four stages of this research: think, explore, test and reflect. As described in detail in section 2.1 (page 19) these stages and methods have be categorised between industry and academia approaches. However, to understand how these methods connect to the insights generated in this PhD a visual thinking mapping exercise was conducted.

This mapping was inspired by the methodology outlined in Forst's (2020) textile design PhD thesis in which she used this visual thinking approach to establish how her original contributions to knowledge had emerged from her own four stages in the research process (scope, make, map and reflect). It is particularly relevant that both this research and Forst's is conducted in the field of circular textile design in which practice is centred "between an understanding of the field and the development of solutions to a circularity challenge" (ibid, 2021:270). Therefore, while our stages have different names (scope, make, map, reflect / think, explore, test, reflect) and the methods used are specific to our research, the physical act of mapping methods in relation to the thesis structure is the same. Vitally this process expounds the relationships between methods and insights and how, when combined, lead to new knowledge (Figure 139).

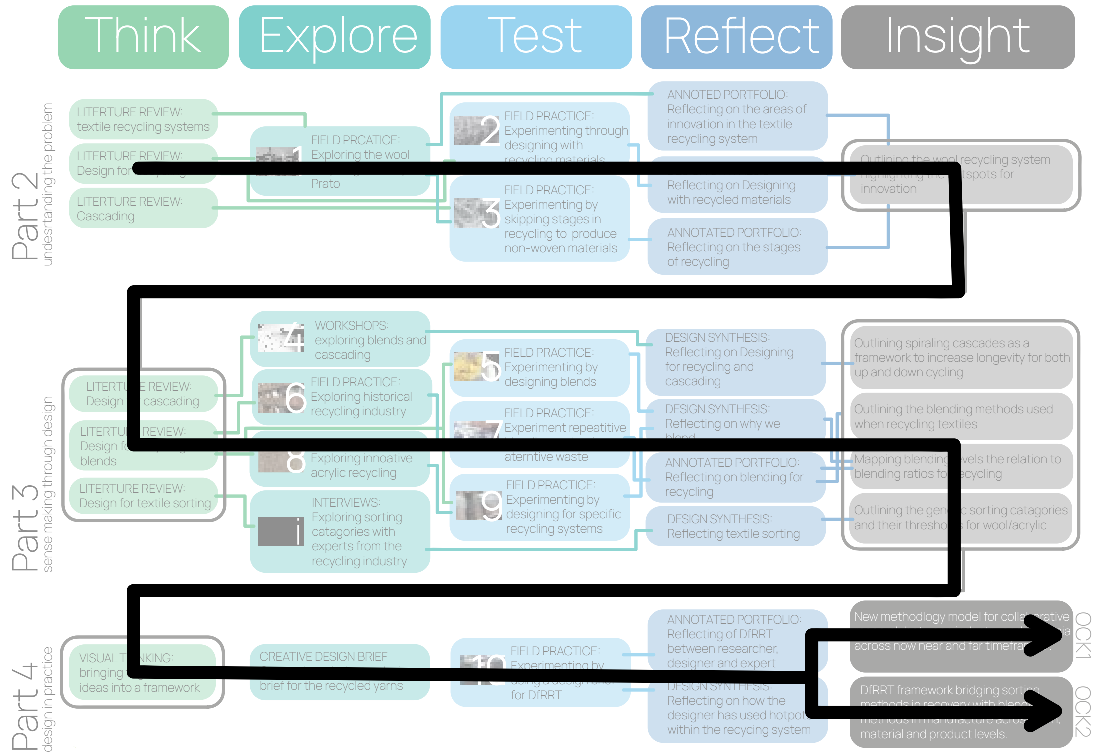


Figure 139. Demonstrating the repetitive cyclical movement through the four stages to the original contributions to knowledge (OCK)

The mapping in Figure 139 is overlayed with arrows highlighting repetitive cyclical movement through the four stages. Starting with 'Think', in which literature review and visual thinking are used as methods, this leads into a period of exploration in the field, workshops or interviews. Ideas from the 'Explore' stage are tested through the field practice experimentation. Finally, reflection on both explore and test stages is conducted through an annotated portfolio and design synthesis. This results in insights being generated and the research returns to the 'Think' stage once again and the cycle continues. At the end of each cycle, the insights build on the previous knowledge created, which ultimately leads to the original contributions to knowledge.

As discussed in Chapter 2 (section 2.5.3, page 50) the methods and stages have been split between academia (think and reflect) and industry (explore and test). Therefore, links between the research process, the use of collaborative roles and their different perspectives can be made. For example, while Think and Reflect are methods used in academia by researchers to consider the future, Explore and Test are methods situated in industry exploring the now and testing the near possibilities. This combination of process and collaboration have been visualised in Figure 140, in which the stage of the research links to a role and a perspective in the cyclic motion.

This model has been expanded further in Figure 141 (page 313) to demonstrate the relationship between the three layers. Particularly, this diagram demonstrates how the roles are sandwiched between the timeframes (perspectives) and the process. It is through the combination of both academia and industry across these three layers that original contributions to knowledge can emerge from the insights.

11.2.6 A MODEL FOR FUTURE RESEARCH

While this methodological framework has emerged from circular textile design PhD research it could also be used or adapted for other PhD researchers conducting practice research between academia and industry. In particular those that have experience that they are bringing to the research from industry themselves. Shaped like a steering wheel, this methodology seeks to provide the tool to steer someone through research of this kind. Rather than create a direct path, the wheel clarifies how the roles overlap, exchange knowledge and consider practice from different perspectives. As the research process circulates between academic thinking and reflection and into industry practice, exploring and testing, it provides the breeding ground for insights which in turn generate original contributions to knowledge.

Additionally, while the author took on both the researcher and designer roles, for other research projects a design-researcher may want to conduct research in collaboration with industry designers and experts and the designer and researcher roles can be separated. In this case, the framework provides a clearer understanding of how knowledge can be exchanged between the stakeholders and the perspectives from which they stand. Beyond this, further research would be required to expand this model beyond three roles, such as including multi-disciplinary researchers, students, educators and different industry professionals.

METHODOLOGICAL FRAMEWORK

INDUSTRY & ACADEMIC STEERING WHEEL

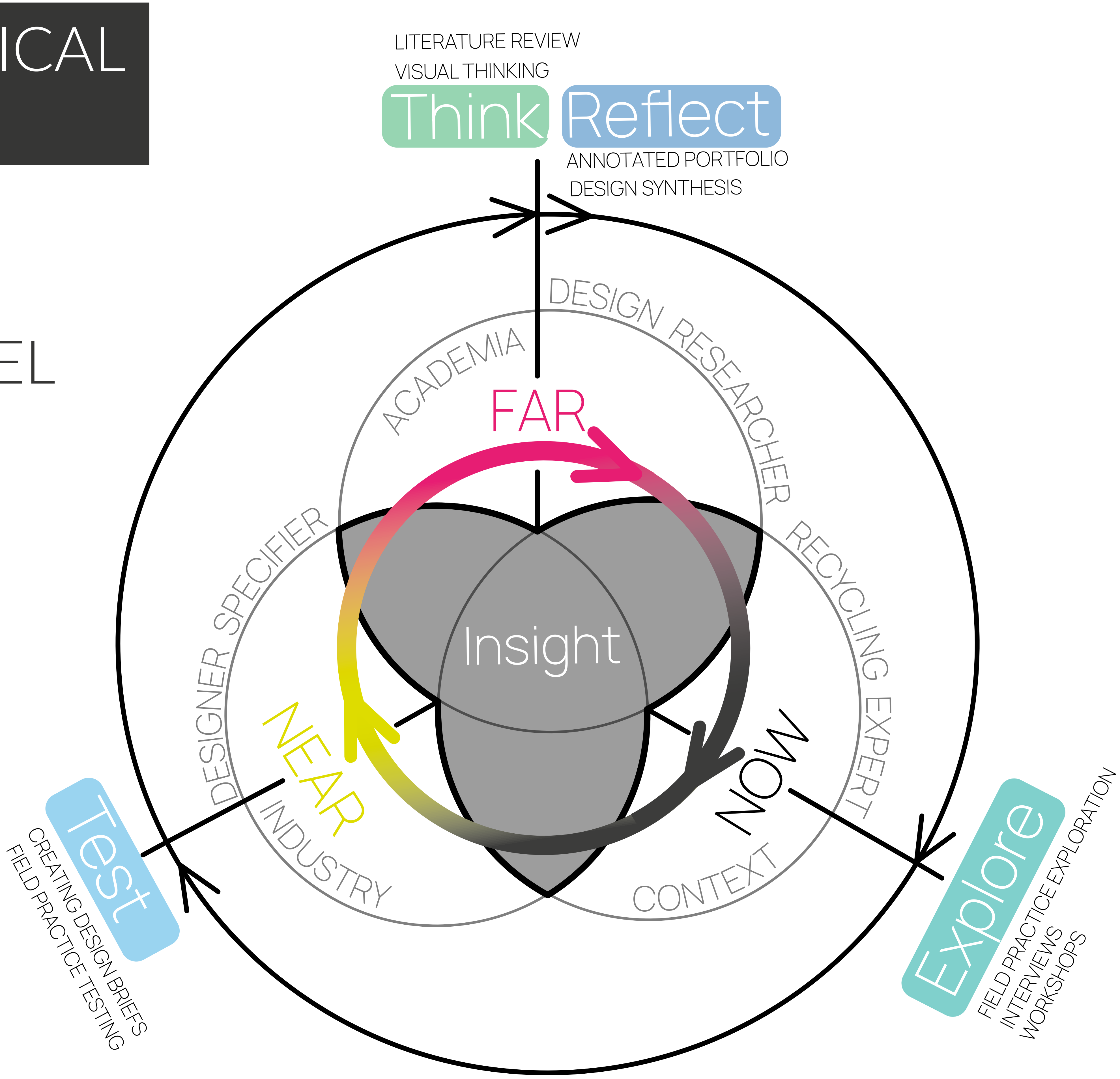


Figure 140. Industry and Academic Steering Wheel – A methodological framework combining four stages: think, explore, test reflect with collaborative roles and perspectives

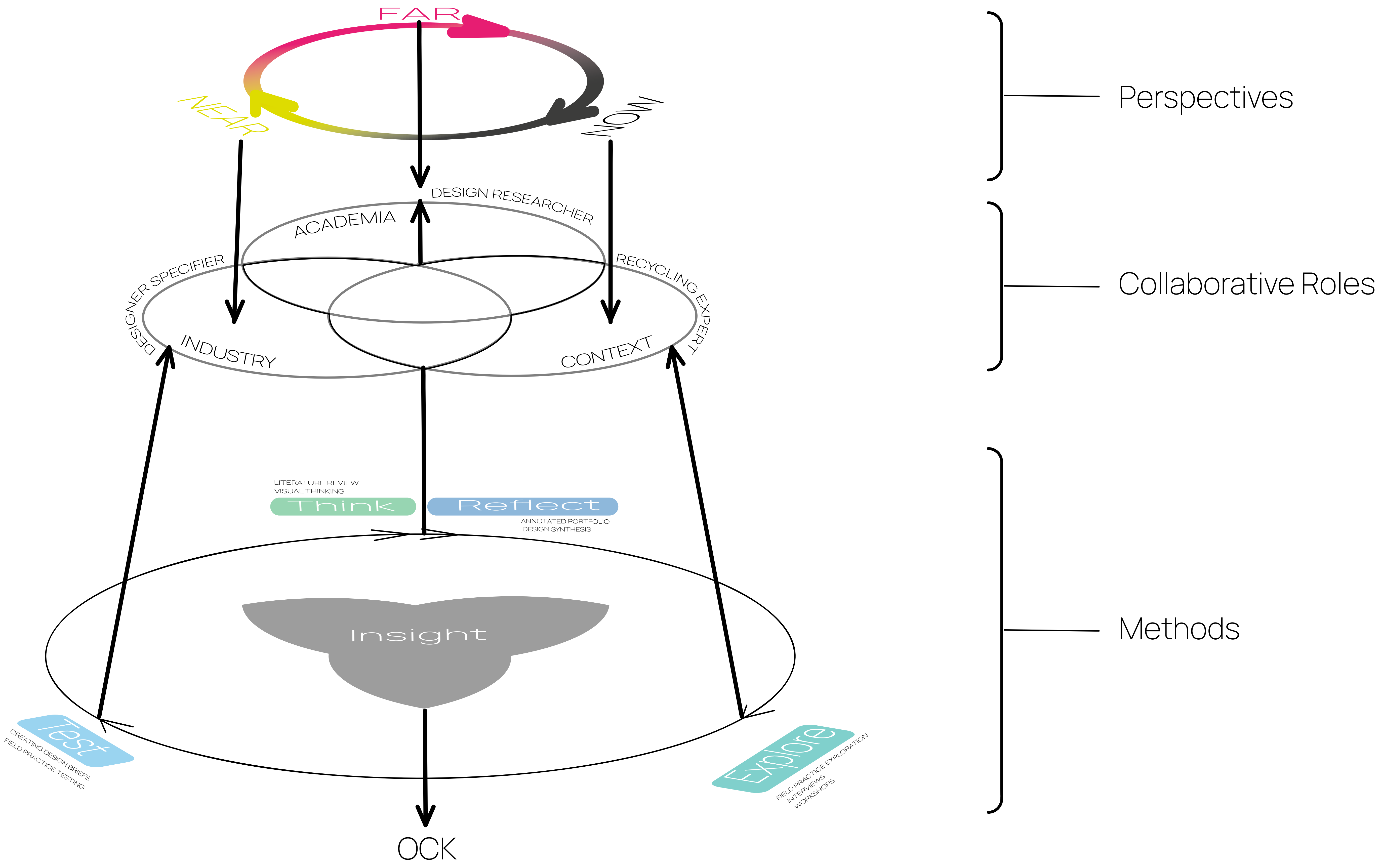


Figure 141. Industry and Academic Steering Wheel – An expanded methodological framework

12 CONCLUSIONS

12.1 SUMMARY OF THE RESEARCH

> the only way to make money out of the used clothing trade is to keep it moving, keep sorting and recombining it, imagining new contexts and creating those pathways (Norris, 2012d:140)

Design for Recycling Knitwear framework has been born from the abundant and complex post-consumer waste textiles that have become a growing problem (EMF, 2017). This research argues that the design strategies we already have, namely Design for Mono-materiality and Design for Disassembly, do not address the complex waste streams that already exist. Design for Recycling Knitwear combines both designing from recycled fibres and designing for cyclability to enable longevity of all forms of textile resources.

To establish this approach, the research has been conducted between the realms of academia and industry and this provides one of the original contributions to knowledge (section 12.2.1, page 317). The approach offers researchers a way of steering themselves through this tricky domain. In using this methodological framework, the practice research has explored the links between cascading (redefined as spiralling), blending and sorting for acrylic/wool knitted textiles. It is through these links that the designer can carve out new pathways, as Norris (2012d) suggests, to re-value waste resources in the mechanical textile recycling system. This research has found that if we are to transition towards a circular economy, we need to find solutions for all waste fibres across the spectrum of qualities, colours and types. It is only by exploring the process from the point of disposal through to manufacture that the designer can truly Design for Recycling Knitwear (section 12.2.2, page 318).

12.1.1 ACHIEVING THE AIMS AND OBJECTIVES

As outlined in the introduction (section 1.2, page 6) the research is made up of three aims and a variety of objectives. The thesis has been structured to address each of the objectives in consecutive chapters. This has been outlined in Table 25.

Table 25. Achieving the aims and objectives

AIM A. To understand both the fields of design for mechanical recycling and design for cascading in the context of post-consumer wool and acrylic textiles.

OBJECTIVES	ACHIEVEMENTS
Conduct a review of the current mechanical recycling industry of wool and acrylic textiles.	**Chapter three** reviews the current mechanical recycling industry of wool and acrylic textiles. This not only provides the context of the post-consumer textile recycling system within the circular economy but will outline the context for using knitted wool and acrylic textiles.
Understand the role of design in current textile recycling industrial systems.	**Chapter four** establishes the role of design in the current textile recycling industrial system. It outlines the problems with the current Design for Recycling approaches and establishes the role the designer might play in finding solutions.
Conduct a review of the current cascading literature in relation to textile design.	**Chapter five** provides a review of the current cascading literature in relation to textile design. This chapter outlines how design for cascading can be combined with the circular economy model.

AIM B. To establish a Design for Recycling wool/acrylic textile model for designing longevity of resources through recycling and bringing together cascading, blending and sorting.

OBJECTIVES	ACHIEVEMENTS
To understand how the field of cascading intersects with design for recycling of post-consumer textile waste.	**Chapter six** explores how textile design and cascading intersect. It specifically considers the differences between product and resources cascades and considers how cascading has been defined as downcycling and upcycling. This chapter provides a new spiral shaped model for combining cascading and circularity which brings together a resource flow and product loops.
Identify the role of blending within virgin and recycled textile production.	**Chapter seven** identifies the role of blending within virgin and recycled textile production. It outlines the reasons for blending in textiles and those used with the textile recycling industry. The chapter provides the designer with three levels of blending: yarn material and product and highlights that understanding the blending ratio across these levels is vital to enable successful textile recyclability.
Investigate the methods of sorting for mechanical recycling of wool and acrylic textiles.	**Chapter eight** investigates the methods of sorting for mechanical recycling of wool and acrylic textiles. It outlines how sorting is generally conducted in the textile recycling industry. In addition, it provides an analysis on the generic sorting grades used for wool/acrylic textiles.
Propose how cascading blending and sorting might be used together to ensure resource longevity of post-consumer wool/acrylic textiles.	**Chapter nine** outlines how the spiralling model (Chapter 6) can incorporate both blending and sorting (Chapter 7 and 8) to extend the lifetimes of textile fibres.

AIM C .To test, through practice, the ideas generated in the previous aims to produce the Design for Recycling Knitwear framework and to establish how the methods have been used across research and industry.

OBJECTIVES	ACHIEVEMENTS
Investigate, and where necessary collaborate with, industrial partners to test the realities of Designing for Recycling Knitwear from yarn to product.	**Chapter ten** describes the how the final practice research (practice 10) and how this was conducted with industrial partners to test Designing for Recycling Knitwear.
Draw insights from the opportunities and challenges of Designing for Recycling Knitwear in industry to establish how designs decisions bridge the recovery and manufacture of textile resources.	**Chapter eleven** establishes opportunities and challenges of Designing for Recycling Knitwear in industry to establish how designs decisions bridge the recovery and manufacture of textile resources.
Draw insights from Designing for Recycling Knitwear in industry to establish a model of how researching between academia and industry can be conducted.	**Chapter eleven** presents the final Design for Recycling Knitwear textile framework as well as the Methodological framework for conducting research between academia and industry. **Chapter twelve** draws together the research as whole to provide original contributions to knowledge and further research opportunities.

12.2 CONTRIBUTIONS TO KNOWLEDGE

This research set out to provide two contributions to knowledge. The first was to provide a methodological framework for researchers working between the realms of academia and industry (12.2.1). The second is to provide the Design for Recycling Knitwear framework which has been created to provide a new perspective building on existing work in the fields of cascading, sorting and blending for the design of recycled textile fibres (12.2.2).

12.2.1 METHODOLOGICAL FRAMEWORK FOR RESEARCHING BETWEEN ACADEMIA AND INDUSTRY

This research offers a new methodological framework which has developed out of the practice research in this study. The framework offers a way of approaching or 'steering' practice design research being undertaken across academia and industry. The research moves cyclically through four stages: think, explore, test and reflect. These represent the overarching purpose for methods used in the research. For example, the annotated portfolio is used as a method for reflection and field exploration is used as a method of exploring etc… However, rather than focus on the stages themselves, the methodology splits the actors of the research into three roles: industry designer-specifier, academic designer-researcher and an expert situated in context. Each of these roles collaborate and overlap. In addition, each role provides different perspectives across now, near and far timeframes. It is the combination of the think, explore, test and reflect methods, collaboration and multiple perspectives that is found to lead to the generation of new knowledge.

12.2.2 DESIGN FOR RECYCLING KNITWEAR FRAMEWORK

This research offers the Design for Recycling Knitwear framework which has formed out of this practice research, exploring design for mechanical recycling of wool/acrylic waste textiles. The framework materialised through the synthesis of three smaller contributions that provide new perspectives on existing work in cascading, blending and sorting by using a design for textile recycling lens. Each of these three contributions are outlined below as well as the final framework which forms the original contribution to knowledge.

NEW PERSPECTIVE ON CASCADING – THE SPIRAL

This research explores the current literature for cascading; discussing and directly relating it to the field of textile recycling in the context of a transition to a circular economy. It builds on the original theory provided by Sirkin and ten Houten (1994), which was developed for product designers (section 5.1, page 115). Cascading has only recently been more broadly synthesised with the circular economy model (Campbell-Johnston et al., 2020) and while the literature has predominantly been utilised for the biomass and wood industries, this research considers its application for circular textile design specifically (section 5.5, page 123).

The research explores and differentiates between the two different types of cascading approach, namely product cascading and resource cascading (section 6.1, page 137). These are synthesised with more commonly discussed concepts in textile recycling: upcycling and downcycling (section 6.3, page 139). By bridging cascading and the circular economy, a new modal is produced: a resource spiral. This spiral is comprised of both a resource flow and product loops. It allows the designer to look beyond a single product and assess how textile resource value changes as it moves in and out of products during the recycling process (section 6.5, page 143).

A NEW PERSPECTIVE ON TEXTILE BLENDING FOR RECYCLING

This research examines the role of blending as a method to aid recyclability in two ways. First, the methods of blending were explored with the recycling industry itself. This is required because of the damage the physical recycling process does to the reclaimed fibres. These five methods: recycled and virgin, pre- and post-consumer wastes, structure, fibre type and colour, provide the wider context for blending within the mechanical recycling system (section 7.4, page 160).

Second, this research builds on both the work of Gulich (2006) and Forst (2020) in articulating how textile combinations can hinder recyclability. This is achieved by re-organising the basic textile blending typologies, previously outlined by Forst, specifically for the context of mechanical textile recycling. This resulted in the presentation of three levels of blending: yarn, material and product (section 7.7, page 181). These levels can be used by the designer to recognise where blending occurs during the design stages. This is translated for the field of Design for Recycling considering the blending ratios between the levels, which directly impact a textile's onward recyclability (section 7.7.1, page 183).

A NEW PERSPECTIVE ON DESIGN FOR TEXTILE SORTING – GRADES AND THRESHOLDS

This research builds on the recent Design for Sorting strategy, outlined for the field of textiles by Niinimäki and Karell (2020). As the textile fibres reach the point of disposal, their value is determined at the sorting stage, and therefore knowledge regarding sorting can be harnessed to design value in and out of textiles. Design for Sorting has been explored from the perspective of knitted wool and acrylic textile waste. Following Niinimäki and Karell's three steps, this research established the elements the sorting industry are concerned with, the grades they are sorted into and finally the limitations and possibilities of textile-to-textile recycling technologies (section 8.3, page 198). To accomplish this, the research brought together literature and expert interviews to understand the interconnected sorting categories (section 8.4.1, page 203). Later in the research the relevance that post-consumer textiles are sorted by fibre quality, fibre type and then fibre colour was understood. At this stage, however, in the context of wool and acrylic textiles (fibre type) the complex methods of sorting and combining wastes were unpicked to create four generic sorting grades. Further still, to account for the complex waste entering the textile recycling system, the wider thresholds which surround these four core grades were determined (section 8.4.3.page 208).

SYNETHISING THE FRAMEWORK

The Design for Recycling Knitwear framework was created by bringing each of these new perspectives of cascading, blending and sorting of waste textiles together. First the resource spiral provides the wider context for how textile fibres can move in and out of products. As they reach the point of disposal their value is determined at the sorting stage. Therefore, by understanding the sorting grades and thresholds designers can design recycled fibres to enter the same or new value grades. This design of recycled fibres, for a specific sorting grade, is only possible by harnessing the knowledge of blending both in the recycling industry and the wider textile industry. It is either by incrementally designing blends into our already complex waste textiles, or incrementally designing them out, that we can Design for Recycling Knitwear. The framework's original contribution specifically bridges sorting and blending knowledges by acknowledging the links between fibre quality, fibre type and fibre colour (section 11.1.5, page 280). This can then be used by the designer to design longevity into our textile resources rather than only our products.

12.3 FURTHER RESEARCH

The two original contributions in the research have already been described in more general terms than the specific context of this study and therefore have the potential to be relevant beyond conducting textile design research and beyond the wool/acrylic mechanical textile recycling industry. However, to strengthen this a range of further research areas have been outlined to be explored.

METHODOLOGICAL RESEARCH BETWEEN ACADEMIC AND INDUSTRY FRAMEWORK

Further research to strengthen and broaden the methodological framework could be conducted by:

- Exploring in more depth how the model can be used if the industry designer and acedemic designer-researcher roles are not understaken by the same actor.
- Expanding the model to include a educator role, such as conducting worksops and generating ideas with students as part of the research.
- Using the model outside of textile design to establish its applicability to other design disciplines.

DESIGN FOR RECYCLING KNITWEAR FRAMEWORK

Further research might be conducted to strengthen and broaden the understanding of designing for spiralling, blending and sorting in textile recycling as well as expanding the combined framework itself. Further research is suggested to:

- Investigate how designers can harness a knowledge of spiralling to design longevity of resources between textile industries, such as fashion, interiors and architecture.
- Exploring how blending can be harnessed as a design tool across the different mechanical and chemical recycling industries.
- Expanding knowledge of the sorting practices of all types of textile fibres.
- Explore how this framework might be relevant for different garment types beyond knitted input and production.
- Adapt the framework to include an understanding of how to design for the chemical recycling industry, both alone or in combination with mechanical recycling.

13 REFERENCES

Allwood, J. M., Laursen, S. E., Rodríguez, C. M. de and Bocken, N. M. P. (2006) Well dressed? the present and future sustainability of clothing and textiles in the United Kingdom. Cambridge: University of Cambridge, Institute for Manufacturing.

Amabile, T. M., Patterson, C., Mueller, J., Wojcik, T., Odomirok, P. W., Marsh, M. and Kramer, S. J. (2001) 'Academic-Practitioner Collaboration in Management Research: A Case of Cross-Profession Collaboration', Academy of Management Journal. Academy of Management Briarcliff Manor, NY 10510, 44(2), pp. 418–431. doi: 10.5465/3069464.

Arisa and Sympany (2020) Textile recycling unravelled: Exploring post- and pre-consumer textile recycling value chains in Panipat, India. Netherlands. Available at: https://arisa.nl/wp-content/uploads/TextileRecyclingUnravelled.pdf (Accessed: 18 September 2020).

Arnheim, R. (1969) Visual thinking. Berkeley ; London: University of California Press.

Ashby, M. F. and Johnson, K. (2010) Materials and design: the art and science of material selection in product design. Second edition. Amsterdam ; London: Butterworth-Heinemann.

Baden, S. and Barber, C. (2005) 'The impact of the second-hand clothing trade on developing countries', Oxfam Int. Available at: http://www.bcrglobal.com/assets/downloads/research_shc.pdf (Accessed: 21 March 2016).

Bakker, C. A., Wever, R., Teoh, Ch. and De Clercq, S. (2010) 'Designing cradle-to-cradle products: a reality check', International Journal of Sustainable Engineering, 3(1), pp. 2–8. doi: 10.1080/19397030903395166.

Barry, K. (2017) 'Diagramming: A creative methodology for tourist studies', Tourist Studies. SAGE Publications, 17(3), pp. 328–346. doi: 10.1177/1468797616680852.

Bell, N. C., Lee, P., Riley, K. and Slater, S. (2017) Tackling Problematic Textile Waste Streams. Aylesbury, UK: Oakdene Hollins Ltd. Available at: http://www.resyntex.eu/images/downloads/NiaCBell_TACKLING_PROBLEMATIC_TEXTILE_WASTE_STREAMS.pdf (Accessed: 4 December 2017).

van den Berg, M. R. and Bakker, C. A. (2015) 'A product design framework for a circular economy', in PLATE: Product Lifetimes and The Enviroment. PLATE, Nottingham Trent University. Available at: http://www.plateconference.org/pdf/plate_2015_proceedings.pdf (Accessed: 2 June 2019).

Beton, A., Dias, D., Farrant, L., Gibon, T., Le Guern, Y., Desaxce, M., Perwueltz, A., Boufateh, I., Wolf, O. and Kougoulis, J. (2014) 'Environmental improvement potential of textiles (IMPRO-Textiles)', European Commission. Available at: https://susproc.jrc.ec.europa.eu/textiles/docs/120423%20IMPRO%20Textiles_Publication%20draft%20v1.pdf (Accessed: 4 September 2019).

Beyond Green: Zero Waste (2016) Beyond Green: Zero Waste - Circle Economy - Pakhuis de Zwijger. Available at: https://vimeo.com/189638719 (Accessed: 30 October 2017).

Bhamra, T., Hernandez, R. and Mawle, R. (2017) 'Sustainability: Methods and Practices', in Walker, S., Giard, J., and Walker, H. L. (eds) The handbook of design for sustainability. London: Bloomsbury.

Bhamra, T. and Lofthouse, V. (2007) Design for sustainability: a practical approach. Aldershot: Gower (Design for social responsibility series).

Bogue, R. (2007) 'Design for disassembly: a critical twenty-first century discipline', Assembly Automation, 27(4), pp. 285–289. doi: 10.1108/01445150710827069.

Bonner, A. and Tolhurst, G. (2002) 'Insider-outsider perspectives of participant observation', Nurse researcher, 9(4), pp. 7–19.

Botticello, J. (2012) 'Between Classification, Objectification, and Perception: Processing Secondhand Clothing for Recycling and Reuse', TEXTILE, 10(2), pp. 164–183. doi: 10.2752/175183512X13315695424356.

Braungart, M. and McDonough, W. (2002) Cradle to Cradle. Remaking the Way We Make Things. 1st Edition. New York: North Point Press.

Brinkmann, S. (2014) 'Unstructured and Semi-Structured Interviewing', in Leavy, P. (ed.) The Oxford Handbook of Qualitative Research. Oxford University Press.

Brooks, Fletcher, Francis, Rigby, and Roberts (2018) 'Fashion, Sustainability, and the Anthropocene', Utopian Studies, 28(3), p. 482. doi: 10.5325/utopianstudies.28.3.0482.

Brown, T. (2008) 'Design Thinkning', Harvard Business Review. Available at: https://hbr.org/2008/06/design-thinking (Accessed: 28 July 2020).

Burgess, M. (2019) 'A new adidas shoe uses just one material – and is fully recyclable', Wired UK, 17 April. Available at: https://www.wired.co.uk/article/adidas-futurecraft-loop-running-shoe-recycle (Accessed: 6 April 2020).

Campbell-Johnston, K., Vermeulen, W. J. V., Reike, D. and Brullot, S. (2020) 'The Circular Economy and Cascading: Towards a Framework', Resources, Conservation & Recycling: X, 7, p. 100038. doi: 10.1016/j.rcrx.2020.100038.

Carlsson, J., Gwilt, A., Larsson, J., Mattila, H., Pal, R. and Torstensson, H. (2017) Feasibility of conditional design Organizing a circular textile value chain by design principles. Gothenberg Sweden: University of Borås,. Available at: http://hb.diva-portal.org/smash/record.jsf?dswid=9502&pid=diva2%3A1362431&c=29&searchType=RESEARCH&language=en&query=&af=%5B%5D&aq=%5B%5B%7B%22personId%22%3A%22rpa%22%7D%5D%5D&aq2=%5B%5B%5D%5D&aqe=%5B%5D&noOfRows=250&sortOrder=dateIssued_sort_desc&sortOrder2=title_sort_asc&onlyFullText=false&sf=all (Accessed: 6 January 2020).

Casey, C. (2020a) Knitwear: Core Item Updates A/W 21/22. Knitwear Trend Forecast. London, UK: WGSN. Available at: https://www-wgsn-com.arts.idm.oclc.org/content/board_viewer/#/87045/page/1 (Accessed: 31 August 2020).

Casey, C. (2020b) Women's Knit & Jersey Trend Concepts A/W 21/22: Conscious Clarity. Knitwear Trend Concept. London, UK: WGSN. Available at: https://www-wgsn-com.arts.idm.oclc.org/content/board_viewer/#/85666/page/1 (Accessed: 31 August 2020).

Cassidy, T. (2011) 'The Mood Board Process Modeled and Understood as a Qualitative Design Research Tool', Fashion Practice, 3(2), pp. 225–251. doi: 10.2752/175693811X13080607764854.

Centre for Circular Design (2020) Now, Near and Far Stamps (and the Now Wall). 10 April. Available at: https://www.youtube.com/watch?v=qcoZy_9nu2w (Accessed: 24 April 2020).

Child, E. (2016) 'Developing Models for Successful Upscaled Upcycling of Fashion', in Circular Transitions Proceedings. Circular Transitions, London, UK: Centre for Circular Design, pp. 20–31. Available at: http://circulartransitions.org/media/downloads/Circular-Transitions-Proceedings.pdf (Accessed: 27 February 2020).

Circle Economy (2019) Fibersort Fact Sheet. Amsterdam, The Netherlands: Interreg North-West Europe. Available at: https://www.circle-economy.com/wp-content/uploads/2019/07/Fibersort-Fact-Sheet-20190711-1.pdf (Accessed: 16 October 2019).

Circle Economy (2020) Clothing Labels: Accurate or not? Amsterdam, Netherlands: Ministerie van Infrastructuur en Waterstaat. Available at: https://www.circle-economy.com/insights/clothing-labels-accurate-or-not?utm_source=0.+Master+list&utm_campaign=0a20b8a1ff-EMAIL_CAMPAIGN_2019_09_10_10_16_COPY_01&utm_medium=email&utm_term=0_d023026741-0a20b8a1ff-&mc_cid=0a20b8a1ff&mc_eid=%5BUNIQID%5D (Accessed: 12 June 2020).

Circular Design Speeds (2019) Prototyping the Future of Circular Fashion, Circular Design Speeds. Available at: https://circulardesignspeeds.com/ (Accessed: 30 April 2020).

Cleveland, D. (2018) Weaving the Undervalued Threads of Textile Waste into a Value Added Change Model. PhD Thesis. Auckland University of Technology.

Collier, J. and Collier, M. (1986) Visual anthropology: photography as a research method. Rev. and expanded ed. Albuquerque: University of New Mexico Press.

Collopy, F. (2009) Thinking about "Design Thinking", Fast Company. Available at: https://www.fastcompany.com/1306636/thinking-about-design-thinking (Accessed: 31 July 2020).

Crang, M., Hughes, A., Gregson, N., Norris, L. and Ahamed, F. (2013) 'Rethinking governance and value in commodity chains through global recycling networks: Rethinking governance and value in commodity chains', Transactions of the Institute of British Geographers, 38(1), pp. 12–24. doi: 10.1111/j.1475-5661.2012.00515.x.

Creative Clusters (2019) 'Creative Industries Clusters Programme', Business of Fashion, Textiles and Technology (BFTT). Available at: https://bftt.org.uk/creative-clusters/ (Accessed: 12 August 2020).

Cross, N. (2011) Design Thinking: Understanding How Designers Think and Work. 1 edition. Berg Publishers.

Cruickshank, L., Whitham, R. and Morris, L. (2012) 'Innovation through the Design Of Knowledge Exchange and the Design ff Knowledge Exchange Design', in Proceedings of the DMI 2012 International Research Conference. Leading Innovation through Design - Design Managment Research Conference, Boston, USA: Design Management Institute. Available at: http://www.dmi.org/dmi/html/conference/academic12/AC12Proceedings.pdf (Accessed: 18 January 2021).

Cupit, M. J. (1996) Opportunities and barriers to textile recycling. Abingdon: AEA Technology, Recycling Advisory Unit.

Dahlbo, H., Aalto, K., Eskelinen, H. and Salmenperä, H. (2016) 'Increasing textile circulation—Consequences and requirements', Sustainable Production and Consumption. doi: 10.1016/j.spc.2016.06.005.

Dammer, L., Bowyer, C., Breitmayer, E., Eder, A., Nanni, S., Allen, B., Carus, M. and Essel, R. (2016) Cascading Use of Wood Products. Technical Report. WWF. Available at: http://bio-based.eu/policy/ (Accessed: 7 August 2019).

Day, C. (2016a) 'The Processes used in the Shoddy and Mungo Industry'. Henry Day & Sons Ltd. Available at: http://www.henryday.co.uk/documents/The-Processes-used-in-the-Shoddy-Industry.pdf (Accessed: 3 January 2018).

Day, C. (2016b) 'The Rise and Fall of Henry Day & Sons Ltd Shoddy Buisness'. Henry Day & Sons Ltd. Available at: http://www.henryday.co.uk/documents/Rise-and-fall-of-Henry-Day-and-Sons-Ltd..pdf (Accessed: 9 May 2019).

Day, C. (2016c) 'Waste Textiles Terms and Definitions'. Henry Day & Sons Ltd. Available at: http://www.henryday.co.uk/documents/Rise-and-fall-of-Henry-Day-and-Sons-Ltd..pdf (Accessed: 9 May 2019).

Design Council (2019) What is the framework for innovation? Design Council's evolved Double Diamond, Design Council. Available at: https://www.designcouncil.org.uk/news-opinion/what-framework-innovation-design-councils-evolved-double-diamond (Accessed: 6 July 2020).

Dutch Clothing Mountain (2017) Measuring the Dutch clothing mountain: Data for sustainability-oriented studies and actions in the apparel sector. Amsterdam: Hogeschool van Amsterdam. Available at: http://www.hva.nl/create-it/gedeelde-content/projecten/projecten-fashion/measuring-the-dutch-clothing-mountain.html (Accessed: 13 February 2018).

Earley, R. (2010) Worn Again: Rethinking Recycled Textiles (2005 – 2009). London, UK: Textile Enviromental Design. Available at: https://www.academia.edu/38311773/PROJECT_REPORT._Worn_Again_Rethinking_Recycled_Textiles_2005_2009_ (Accessed: 17 September 2019).

Earley, R. and Goldsworthy, K. (2019a) Circular design researchers in residence - a workshops report for the circular design speeds project with Filippa K (2016-2018). Centre for Circular Design: University of the Arts London. Available at: http://mistrafuturefashion.com/wp-content/uploads/2019/10/R-Earley.-circular-design-researchers-in-residence.-Mistra-future-fashion-report.pdf (Accessed: 6 January 2020).

Earley, R. and Goldsworthy, K. (2019b) 'Circular Textile design: Old myths and new models', in Charter, M. (ed.) Designing for the circular economy. London: Routledge, pp. 175–185.

Earley, R., Vuletich, C., Hadridge, P. and Reitan Andersen, K. (2016) 'A New "T" for Textiles: Training Design Researchers to Inspire Buying Office Staff Towards Sustainability at Hennes and Mauritz (H&M)', The Design Journal, 19(2), pp. 301–321. doi: 10.1080/14606925.2016.1130380.

ECAP (2019a) Circular Textiles Ready to Market. Amsterdam, Netherlands: Rijkswaterstaat: Ministry of Infrastructure and the Enviroment. Available at: http://www.ecap.eu.com/take-action/fibre-to-fibre/ (Accessed: 10 April 2020).

ECAP (2019b) Design Factsheet. Amsterdam, Netherlands: Rijkswaterstaat: Ministry of Infrastructure and the Enviroment. Available at: http://www.ecap.eu.com/take-action/fibre-to-fibre/ (Accessed: 10 April 2020).

ECAP (2019c) Internal Support Factsheet. Amsterdam, Netherlands: Rijkswaterstaat: Ministry of Infrastructure and the Enviroment. Available at: http://www.ecap.eu.com/take-action/fibre-to-fibre/ (Accessed: 10 April 2020).

ECAP (2019d) Quality of Fabric Factsheet. Amsterdam, Netherlands: Rijkswaterstaat: Ministry of Infrastructure and the Enviroment. Available at: http://www.ecap.eu.com/take-action/fibre-to-fibre/ (Accessed: 10 April 2020).

ECAP (2019e) WE Fashion Case Study. Amsterdam, Netherlands: Rijkswaterstaat: Ministry of Infrastructure and the Enviroment. Available at: http://www.ecap.eu.com/take-action/fibre-to-fibre/ (Accessed: 10 April 2020).

EcoTLC (2019) Circular Economy: Let's change of an Era! #8. France: L'eco-organisme du textile - du linge - de la chaussure. Available at: https://www.ecotlc.fr/ressources/Documents_site/8_Chemins-Innovation_2019_GB_BD.pdf (Accessed: 2 July 2019).

Elander, M. and Ljungkvist, H. (2016) Critical aspects in design for fibre-to-fibre recycling of textiles. IVL Swedish Environmental Research Institute. Available at: http://mistrafuturefashion.com/wp-content/uploads/2016/06/MFF-report-2016-1-Critical-aspects.pdf (Accessed: 10 March 2017).

EMF (2013) Towards the circular economy: Economic and business rationale for an accelerated transition. 1. London: Ellen Macarthur Foundation, pp. 23–44. Available at: https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf (Accessed: 1 June 2019).

EMF (2017) A New Textiles Economy: Redesigning Fashion’s Future. London: Ellen Macarthur Foundation and Circular Fibres Initiative. Available at: https://www.ellenmacarthurfoundation.org/assets/downloads/publications/A-New-Textiles-Economy_Full-Report.pdf (Accessed: 3 January 2018).

Essel, R., Breitmayer, E., Carus, M., Fehrenbach, H., von Geibler, J., Bienge, K. and Baur, F. (2014) Defining cascading use of biomass. Disscussion paper: R&D Project ‘Increasing resource efficiency by cascading use of biomass - from theory to practice’ FKZ 3713 44 100. Germany: nova-Institut GmbH. Available at: https://biomassekaskaden.de/wp-content/uploads/2014/04/14-03-14_Cascading_use_Discussionpaper.pdf (Accessed: 7 August 2019).

EU Commission (2012) ‘Innovating for Sustainable Growth: A Bioeconomy for Europe’, Industrial Biotechnology, 8(2), pp. 57–61. doi: 10.1089/ind.2012.1508.

European Commission (2003) Integrated Pollution Prevention and Control (IPPC) - Reference Document on Best Available Techniques for the Textiles Industry. European Commission, p. 626. Available at: https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/txt_bref_0703.pdf (Accessed: 17 March 2020).

Fakhredin, F., Bakker, C., Geraedts, J. and Huisman, J. (2013) ‘Five Perspectives on Design for End of Life: Highlights of a Literature Review’, p. 8.

Fallman, D. (2008) ‘The Interaction Design Research Triangle of Design Practice, Design Studies, and Design Exploration’, Design Issues, 24(3), pp. 4–18. doi: 10.1162/desi.2008.24.3.4.

Farrer, J. (2000) Wool: from straw to gold: an ecological assessment of the lifecycle of wool from cradle to grave and beyond resulting in yarns composed of 100% post consumer waste. PhD Thesis. Royal College of Art. Available at: https://researchportal.port.ac.uk/portal/en/theses/wool(7e0cff0d-33df-4717-9172-24ef43f85720).html (Accessed: 2 October 2017).

Fellner, J., Lederer, J., Scharff, C. and Laner, D. (2017) ‘Present Potentials and Limitations of a Circular Economy with Respect to Primary Raw Material Demand’, Journal of Industrial Ecology, 21(3), pp. 494–496. doi: 10.1111/jiec.12582.

Fibersort (2018a) Fibersort Reference Sheet. Interreg North-West Europe. Amsterdam, The Netherlands: Circle Economy. Available at: https://www.circle-economy.com/fibersort-industry-reference-sheet (Accessed: 8 January 2020).

Fibersort (2018b) Manual Sort of Post-Consumer Textiles in North-West Europe. Interreg North-West Europe. Available at: file:///Users/student/Downloads/26455816-0-Fibersort-interim-re.pdf (Accessed: 13 February 2018).

Fibersort (2020a) Fibersort: Overcoming barriers for long-term implementation. Amsterdam, The Netherlands: Interreg North-West Europe and Circle Economy. Available at: https://guides.co/g/fibersort-overcoming-barriers-for-long-term-implementation-case-study/173054 (Accessed: 18 March 2020).

Fibersort (2020b) Recycled Post-consumer Textiles: an industry perspective. Interreg North-West Europe. Amsterdam, The Netherlands: Circle Economy. Available at: https://gallery.mailchimp.com/7d5098e1bd0fc-695690cc8cfb/files/6e8add3e-5e2e-4837-8421-6dbdbe8b3a16/20200128_Fibersort_3.2_report_297x210mm.pdf?utm_source=Fibersort&utm_campaign=88d669c6e7-EMAIL_CAMPAIGN_2019_03_20_03_38_COPY_01&utm_medium=email&utm_term=0_0a269b1348-88d669c6e7-128132997&mc_cid=88d669c6e7&mc_eid=4786ff2b3f (Accessed: 5 February 2020).

Field-Springer, K. (2017) ‘Interviewees’, in Allen, M. (ed.) The SAGE Encyclopedia of Communication Research Methods. 2455 Teller Road, Thousand Oaks California 91320: SAGE Publications, Inc. doi: 10.4135/9781483381411.n274.

Fischer, A. and Pascucci, S. (2017) ‘Institutional incentives in circular economy transition: The case of material use in the Dutch textile industry’, Journal of Cleaner Production, 155, pp. 17–32. doi: 10.1016/j.jclepro.2016.12.038.

Fletcher, K. (2008) Sustainable Fashion and Textiles: Design Journeys. 1 edition. London ; Sterling, VA: Routledge.

Fletcher, K. and Tham, M. (2004) lifetimes, Lifetimes. Available at: http://lifetimes.info/ (Accessed: 1 May 2020).

Follett, G. and Marra, M. (2012) ‘Design in Action - Building a model for knowledge exchange between industry and academia, using design as a strategy for business growth in scotland’, in Proceedings of the DMI 2012 International Research Conference. Leading Innovation through Design - Design Managment Research Conference, Boston, USA: Design Management Institute. Available at: http://www.dmi.org/dmi/html/conference/academic12/AC12Proceedings.pdf (Accessed: 9 January 2021).

Fontell, P. and Heikkilä, P. (2017) Model of circular business ecosystem for textiles. VTT Technology 313. Finland: VTT, p. 62. Available at: https://www.vttresearch.com/sites/default/files/pdf/technology/2017/T313.pdf (Accessed: 28 March 2021).

Forst, L. (2019) ‘Disassembly Discussed: Creative Textile Sampling as a Driver for Innovation in the Circular Economy’, Journal of Textile Design Research and Practice, 0(0), pp. 1–21. doi: 10.1080/20511787.2019.1667156.

Forst, L. (2020) Textile Design for Disassembly. PhD Thesis. University of the Arts London. Available at: https://ualresearchonline.arts.ac.uk/id/eprint/16332/ (Accessed: 14 January 2021).

Forst, L. and Hall, C. (2018) There and Back Again, There and Back Again. Available at: https://thereandbackagain.myblog.arts.ac.uk/ (Accessed: 11 September 2020).

Fraanje, P. J. (1997) ‘Cascading of renewable resources hemp and reed’, Industrial Crops and Products, 6(3–4), pp. 201–212. doi: 10.1016/S0926-6690(97)00009-5.

Franco, M. A. (2017) ‘Circular economy at the micro level: A dynamic view of incumbents’ struggles and challenges in the textile industry’, Journal of Cleaner Production, 168, pp. 833–845. doi: 10.1016/j.jclepro.2017.09.056.

Fritsche, U. and Iriarte, L. (2014) ‘Sustainability Criteria and Indicators for the Bio-Based Economy in Europe: State of Discussion and Way Forward’, Energies, 7(11), pp. 6825–6836. doi: 10.3390/en7116825.

Gaver, B. and Bowers, J. (2012) ‘Annotated portfolios’, interactions, 19(4), p. 40. doi: 10.1145/2212877.2212889.

Gaver, W. (2012) ‘What should we expect from research through design?’, in Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI ’12. the 2012 ACM annual conference, Austin, Texas, USA: ACM Press, p. 937. doi: 10.1145/2207676.2208538.

Gee, N. C. (1950) Shoddy and Mungo Manufacture: Its Development, Ancillary Processes Methods and Machinery. 1st edition. Manchester: Emmott & Co.

Geetanjali Woollens (2014) Geetanjali Woollens Pvt. Ltd., Yarns. Available at: http://www.geetanjaliwoollens.com/yarns.html (Accessed: 30 March 2021).

GFA (2019) 2020 Circular Fashion System Commitment. Copenhagen, Denmark: Global Fashion Agenda. Available at: https://www.globalfashionagenda.com/wp-content/uploads/2019/07/Status_report_2019.pdf (Accessed: 23 March 2020).

Girn, T., Livingstone, C. and Calliafas, P. (2019) Fibre to fibre recycling: An economic & financial sustainability assessment. UK: WRAP and Petros EcoSolutions. Available at: http://www.wrap.org.uk/sites/files/wrap/Fibre_to_Fibre_report.pdf (Accessed: 4 February 2019).

Goldsworthy, K. (2012) Laser-finishing: a new process for designing recyclability in synthetic textiles. PhD Thesis. University of the Arts London. Available at: http://ualresearchonline.arts.ac.uk/11638/ (Accessed: 31 January 2018).

Goldsworthy, K. (2014) 'Design for Cyclability: pro-active approaches for maximising material recovery', Making Futures, 3. Available at: http://ualresearchonline.arts.ac.uk/6871/2/Cyclability%20Diagram.pdf (Accessed: 3 October 2017).

Goldsworthy, K. (2017) 'The Speedcycle: a design-led framework for fast and slow circular fashion lifecycles', The Design Journal, 20(sup1), pp. S1960–S1970. doi: 10.1080/14606925.2017.1352714.

Goldsworthy, K., Earley, R. and Politowicz, K. (2019) Circular design speeds: prototyping fast and slow sustainable fashion concepts through interdisciplinary design research (2015-2018). 2019:20. London, UK: Centre for Circular Design, p. 84. Available at: http://mistrafuturefashion.com/wp-content/uploads/2019/10/K.-Goldsworthy-Circular-Design-Speeds-project.-mistra-future-fashion.pdf (Accessed: 6 January 2020).

Gottlieb, A. (2006) 'Ethnographic Methods: Ethnography: Theory and Methods', in Perecman, E. and Curran, S. R. (eds) A handbook for social science field research essays & bibliographic sources on research design and methods. Thousand Oaks, Calif; London: SAGE.

Graedel, T. E., Comrie, P. R. and Sekutowski, J. C. (1995) 'Green Product Design', AT&T Technical Journal, 74(6), pp. 17–25. doi: 10.1002/j.1538-7305.1995.tb00262.x.

GreenLab (2020) GreenDesign 8.0 Circular City: Mapping Berlin's Material Streams. 8.0. BerLin, Weißensee: Weißensee Kunsthochschule. Available at: http://greenlab.kunsthochschule-berlin.de/wp-content/uploads/2020/06/greenlab_8_circular_city_weissensee_kunsthochschule_berlin-1.pdf (Accessed: 11 September 2020).

Gregson, N., Crang, M., Botticello, J., Calestani, M. and Krzywoszynska, A. (2014) 'Doing the "dirty work" of the green economy: Resource recovery and migrant labour in the EU', European Urban and Regional Studies, p. 0969776414554489.

Gulich, B. (2006) 'Designing textile products that are easy to recycle', in Wang, Y. (ed.) Recycling in textiles. Cambridge : Boca Raton, Fla: Woodhead ; CRC Press (Woodhead publishing in textiles).

Gupta, M. (2014) POTENTIAL USE OF SHODDY YARN FOR DEVELOPMENT OF TEXTILE PRODUCTS. PhD Thesis. Punjab Agricultural University Ludhiana. Available at: http://krishikosh.egranth.ac.in/bitstream/1/5810015918/1/PAU-Mohini%20Gupta.pdf (Accessed: 12 March 2019).

Gupta, M. and Saggu, H. K. (2015) 'Physical properties of shoddy yarn.', Man-Made Textiles in India, 43(2).

Haberl, H. and Geissler, S. (2000) 'Cascade utilization of biomass: strategies for a more efficient use of a scarce resource', Ecological Engineering, 16, pp. 111–121. doi: 10.1016/S0925-8574(00)00059-8.

Hall, C. (2018) 'MIXING IT UP IN PRATO: identifying innovation hotspots within mechanical textile recycling', in Global Fashion Conference. What's Going On? A discourse on Fashion, Design and Sustainability, London: GFC 2018. Available at: https://docs.wixstatic.com/ugd/eb22a2_4a7b43538fbf45a7bc753a8a8bf-b6aad.pdf (Accessed: 31 May 2019).

Hall, C. (2020a) 'A New Way to Play: Textile recycling and the Circular Economy', in Earley, R. (ed.) Research Circles: A collection of essays and interviews by researchers at Centre for Circular Design, University of the Arts London. London, UK: Centre for Circular Design, pp. 52–55. Available at: https://circulardesign.org.uk/research/research-circles/ (Accessed: 9 November 2020).

Hall, C. (2020b) 'TAKING NOTE: Annotated Portfolio as a Method to Analyse the Experience of Design Research Practice', Journal of Textile Design Research and Practice, 8(2-Futurescan 4: Valuing Practice), pp. 1–23. doi: 10.1080/20511787.2020.1751960.

Hall, C. and Earley, R. (2019) 'Divide, Switch, Blend: exploring two hats for industry entrepreneurship and academic practice-based textile design research', The Design Journal, 22(sup1), pp. 19–35. doi: 10.1080/14606925.2019.1595848.

Han, S. L. C., Chan, P. Y. L., Venkatraman, P., Apeagyei, P., Cassidy, T. and Tyler, D. J. (2017) 'Standard vs. Upcycled Fashion Design and Production', Fashion Practice, 9(1), pp. 69–94. doi: 10.1080/17569370.2016.1227146.

Hatch, K. L. (1993) Textile science. Minneapolis/Saint Paul: West Publishing Company.

Hawley, J. (2015) 'Economic Impact of Textile Clothing Recycling', in Hethorn, J. and Ulasewicz, C. (eds) Sustainable fashion: what's next? a conversation about issues, practices and possibilities. Second edition. New York, New York ; London, England: Fairchild Books.

Hawley, J. M. (2006) 'Digging for Diamonds: A Conceptual Framework for Understanding Reclaimed Textile Products', Clothing and Textiles Research Journal, 24(3), pp. 262–275. doi: 10.1177/0887302X06294626.

Henkel, L. A. (2014) 'Point-and-Shoot Memories: The Influence of Taking Photos on Memory for a Museum Tour', Psychological Science, 25(2), pp. 396–402. doi: 10.1177/0956797613504438.

Hepworth, J. (1954) 'RAGS AND SHODDY', Journal of The Textile Institute (Proceedings), 45(2), pp. 62–64.

Hewitt-Taylor, J. (2002) 'Inside knowledge: issues in insider research', Nursing Standard (Royal College of Nursing (Great Britain): 1987), 16(46), pp. 33–35. doi: 10.7748/ns2002.07.16.46.33.c3239.

Hildebrandt, J., Bezama, A. and Thrän, D. (2017) 'Cascade use indicators for selected biopolymers: Are we aiming for the right solutions in the design for recycling of bio-based polymers?', Waste Management & Research, 35(4), pp. 367–378. doi: 10.1177/0734242X16683445.

Hornbuckle, R. (2013) 'Materials Translators: Observations from a Study of Sustainable Materials Information Provision and Design Behaviour in London, UK', in Sustainable Innovation 2013 18th International Conference Proceedings. Sustainable Innovation 2013 18th International Conference, Epsom, UK, p. 1. Available at: https://cfsd.org.uk/site-pdfs/si13/abstracts/design-strategies-methodologies-and-tools/Ref%2018%20-%2011.15.pdf (Accessed: 27 February 2020).

Hornbuckle, R. (2016) 'What Else Do We Know? Exploring the application of design knowledge and skills for the circular economy beyond materials selection and design for production', in Circular Transitions Proceedings. Circular Transitions, London, UK: Centre for Circular Design, pp. 20–31. Available at: http://circulartransitions.org/media/downloads/Circular-Transitions-Proceedings.pdf (Accessed: 27 February 2020).

Hornbuckle, R. (2018) 'Materials Liaisons: facilitating communication in Design-Driven Material Innovation (DDMI) projects', in. Design Research Society Conference 2018. doi: 10.21606/drs.2018.446.

Hornbuckle, R., Qualmann, C. and Sutton, T. (2009) 'Are we the tool?', in Nordic Design Research Conference Proceedings. Nordes 2009 - Engaging Artifacts, Oslo School of Architecture and Design, Norway. Available at: https://archive.nordes.org/index.php/n13/issue/view/9 (Accessed: 27 February 2020).

Hultgren, N. (2012) Guidelines and Design Strategies for Improved Product Recyclability - How to Increase the Recyclability of Consumer Electronics and Domestic Appliances through Product Design. Master of Science Thesis in Industrial Ecology. Chalmers University of Technology.

Humpston, G., Willis, P., Tyler, D. and Han, S. (2014) Technologies for sorting end of life textiles. WRAP and Oakdene Hollins. Available at: http://www.wrap.org.uk/sites/files/wrap/priv_download/MPD007-014%20Final_End%20of%20life%20sorting%20technologies.pdf (Accessed: 5 December 2017).

Igoe, E. (2013) In textasis : matrixial narratives of textile design. PhD Thesis. Royal College of Art.

IHS Markit (2016) Acrylic and Modacrylic Fibers - Chemical Economics Handbook (CEH), Acrylic and Modacrylic Fibers. Available at: https://ihsmarkit.com/products/acrylic-and-modacrylic-chemical-economics-handbook.html (Accessed: 16 March 2020).

Irwin, T. (2015) ‘Transition Design: A Proposal for a New Area of Design Practice, Study, and Research’, Design and Culture, 7(2), pp. 229–246. doi: 10.1080/17547075.2015.1051829.

Irwin, T., Kossoff, G. and Tonkinwise, C. (2015) ‘Transition Design Provocation’, Design Philosophy Papers, 13(1), pp. 3–11. doi: 10.1080/14487136.2015.1085688.

ISO (2016) ISO 14021:2016(en), Environmental labels and declarations — Self-declared environmental claims (Type II environmental labelling). Available at: https://www.iso.org/obp/ui/#iso:std:iso:14021:ed-2:v1:en (Accessed: 18 October 2017).

Jubb, S. (1860) The History of the Shoddy Trade: It’s Rise, Progress, and Present Position. Houlston and Wright.

Kane, F. E. and Philpott, R. (2013) ‘Textile Thinking for Sustainable Materials’, in Proceedings of the Making Futures Conference 2013. Making Futures, Plymouth: Plymouth College of Art, p. 12. Available at: https://repository.lboro.ac.uk/articles/conference_contribution/Textile_thinking_for_sustainable_materials/9335612 (Accessed: 28 March 2021).

Karana, E., Barati, B., Rognoli, V. and Zeeuw van der Laan, A. (2015) ‘Material Driven Design (MDD): A Method to Design for Material Experiences’, International Journal of Design, 9(2). Available at: http://128.199.168.50/index.php/IJDesign/article/view/1965 (Accessed: 22 January 2020).

Karell, E. and Niinimäki, K. (2019) ‘Addressing the Dialogue between Design, Sorting and Recycling in a Circular Economy’, The Design Journal, 22(sup1), pp. 997–1013. doi: 10.1080/14606925.2019.1595413.

Karell, E. and Niinimäki, K. (2020) ‘A Mixed-Method Study of Design Practices and Designers’ Roles in Sustainable-Minded Clothing Companies’, Sustainability. Multidisciplinary Digital Publishing Institute, 12(11), p. 4680. doi: 10.3390/su12114680.

Kay, T. (1994) ‘Reiner Pilz’, Salvo, pp. 11–14. Available at: https://www.salvoweb.com/files/sn99sm24y94tk181119.pdf [Accessed: 30 March 2021].

KEMI (2016) Hazardous chemical substances in textiles - proposals for risk management measures. Stokholm, Sweden: The Swedish Chemical Agency. Available at: https://www.kemi.se/download/18.6df1d3df171c243f-b23a98e7/1591454108832/report-8-16-hazardous-chemical-substances-in-textiles.pdf (Accessed: 5 January 2020).

Kimbell, L. (2011) ‘Rethinking Design Thinking: Part I’, Design and Culture, 3(3), pp. 285–306. doi: 10.2752/175470811X13071166525216.

Kimbell, L. (2012) ‘Rethinking Design Thinking: Part II’, Design and Culture, 4(2), pp. 129–148. doi: 10.2752/175470812X13281948975413.

Kirchherr, J., Reike, D. and Hekkert, M. (2017) ‘Conceptualizing the circular economy: An analysis of 114 definitions’, Resources, Conservation and Recycling, 127, pp. 221–232. doi: 10.1016/j.resconrec.2017.09.005.

Kitaguchi, S., Kumazawa, M., Morita, H., Endo, M., Sato, T. and Sukigara, S. (2017) ‘Quality and Aesthetic of Wool Fabrics through Sensory Evaluation’, Journal of Textile Engineering. Textile Machinery Society of Japan, 63(2), pp. 33–41. doi: 10.4188/jte.63.33.

Kolko, J. (2010) ‘Abductive Thinking and Sensemaking: The Drivers of Design Synthesis’, Design Issues. MIT Press, 26(1), pp. 15–28. doi: 10.1162/desi.2010.26.1.15.

Koppert, P., Leon, S., Luiken, A., Mulder, E. and Steen, N. (2016) Sustainable Material Guide. Digital. Zeist, The Netherlands: Modint. Available at: https://modint.nl/2017/01/09/modints-sustainable-material-guide-smg/ (Accessed: 8 January 2020).

Koskinen, I., Zimmerman, J., Binder, T., Redstrom, J. and Wensveen, S. (2011) Design research through practice: from the lab, field, and showroom. San Francisco, Calif: Elsevier Science & Technology.

Kriwet, A., Zussman, E. and Seliger, G. (1995) ‘Systematic integration of design-for-recycling into product design’, International Journal of Production Economics, 38(1), pp. 15–22. doi: 10.1016/0925-5273(95)99062-A.

Langley, K. D., Kim, Y. K. and Lewis, A. F. (2000) Recycling and Reuse of Mixed Fibre Fabric Remnants (Spandex, Cotton & Polyester). Chelsea Center for Recycling and Economic Development Technical Research Program. Available at: http://masslib-dspace.longsight.com/bitstream/handle/2452/113641/ocn777578375-17.pdf?sequence=1&isAllowed=y (Accessed: 14 June 2018).

Laybourn-Langton, L., Rankin, L. and Baxter, D. (2019) This is a Crisis: Facing up to the age of enviromental breakdown - Summary. Available at: https://www.ippr.org/files/2019-02/risk-and-environment-feb19-summary.pdf (Accessed: 18 February 2019).

Lerpiniere, C. (2020) ‘Value Definition in Sustainable (Textiles) Production and Consumption’, in Granger, R. (ed.) Value Construction in the Creative Economy. Cham: Springer International Publishing (Palgrave Studies in Business, Arts and Humanities), pp. 85–107. doi: 10.1007/978-3-030-37035-0_5.

Lévi-Strauss, C. (1962) The savage mind. Chicago, IL: University of Chicago Press.

Lilani, H. (2020a) Sorting Categories of Post-consumer Wool Textiles. Interview with Cathryn Hall, 6 January. See also Appendix 14.2, page 343

Lilani, H. (2020b) Value of the different Sorting Categories of Post-consumer Wool Textiles. Interview with Cathryn Hall, 20 November. See also Appendix 14.3, page 344.

Lindström, K., Kadi, N. and Persson, A. (2018) ‘Utility of conditioner for reduced inter-fibre friction as predictor of gentler shredding’, in. Aachen-Dresden-Denkendorf International Textile Conference, Aachen, November 29-30, 2018, Denkendorf, Germany: Aachen Dresden Denkendorf. Available at: http://urn.kb.se/resolve?urn=urn:nbn:se:hb:diva-15740 (Accessed: 27 April 2021)..

Lindström, K., Sjöblom, T., Persson, A. and Kadi, N. (2019) ‘Decreasing inter-fiber friction with lubricants for efficient mechanical recycling of textiles’, in AUTEX2019 proceedings. AUTEX2019 – 19th World Textile Conference on Textiles at the Crossroads, 11-15 June 2019, Ghent, Belgium, p. 6.

Ljungkvist, H., Watson, D. and Elander, M. (2018) Developments in global markets for used textiles and implications for reuse and recycling. 2018:4. Stokholm, Sweden: IVL Swedish Enviromental Research Insistute. Available at: http://mistrafuturefashion.com/wp-content/uploads/2018/09/Mistra-Future-Fashion-2018.04-M-Elander-D.3.3.4.1.pdf (Accessed: 6 January 2020).

Löwgren, J. (2013) ‘Annotated Portfolios and Other Forms of Intermediate-level Knowledge’, Interactions, 20(1), pp. 30–34. doi: 10.1145/2405716.2405725.

Luttropp, C. and Lagerstedt, J. (2006) ‘EcoDesign and The Ten Golden Rules: generic advice for merging environmental aspects into product development’, Journal of Cleaner Production, 14(15–16), pp. 1396–1408. doi: 10.1016/j.jclepro.2005.11.022.

Mair, C. and Stern, T. (2017) ‘Cascading Utilization of Wood: a Matter of Circular Economy?’, Current Forestry Reports, 3(4), pp. 281–295. doi: 10.1007/s40725-017-0067-y.

Malin, J. C. (1979) The West Riding Recovered Wool Industry, ca. 1813-1939. PhD Thesis. University of York. Available at: http://etheses.whiterose.ac.uk/14148/1/532979.pdf (Accessed: 3 January 2019).

Marchant, D. (2016) ‘The design brief: requirements and compliance’, Journal of Information Technology in Construction (ITcon), 21(22), pp. 337–353.

Maris, E., Froelich, D., Aoussat, A. and Naffrechoux, E. (2014) ‘From Recycling to Eco-design’, in Worrell, E. and Reuter, M. A. (eds) Handbook of recycling: state-of-the-art for practitioners, analysts, and scientists. Amsterdam ; Boston: Elsevier.

Marshall, P. (2020) ‘How the UK’s fast fashion habits are polluting a country halfway around the world’, ITV News Online, 18 February. Available at: https://www.itv.com/news/2020-02-18/how-the-uk-s-fast-fashion-habits-are-polluting-a-country-halfway-around-the-world/ (Accessed: 1 May 2020).

Marx, K. (1990) Capital: a critique of political economy. Vol.1. Harmondsworth: Penguin, in association with New Left Review (Penguin classics).

McDonough, W. and Braungart, M. (2013) The upcycle: beyond sustainability - designing for abundance. New York: North Point Press.

Mcquillan, H. (2019) ZERO WASTE DESIGN THINKING. University of Boras. Available at: https://www.researchgate.net/publication/333210492_Zero_Waste_Design_Thinking (Accessed: 21 May 2019).

Merati, A. A. and Okamura, M. (2004) ‘Producing Medium Count Yarns from Recycled Fibers with Friction Spinning’, Textile Research Journal, 74(7), pp. 640–645. doi: 10.1177/004051750407400715.

Moeran, B. (2009) ‘Notes for a Theory of Values’, Creativity at Work, Creative Encounters Working Papers Series. Available at: https://odoko.cbs.dk/bitstream/handle/10398/7971/37_BM_Notes_for_a_Theory_of_Values_FINAL.pdf?sequence=1 (Accessed: 16 April 2020).

Mønsted, M. and Hansson, F. (2010) ‘Creating Space for Research: The Charismatic Entrepreneur as Research Director’, Creativity and Innovation Management, 19(1), pp. 47–56. doi: 10.1111/j.1467-8691.2009.00539.x.

Moon, J. A. (2004) A Handbook of Reflective and Experiential Learning: Theory and Practice. London, UNITED KINGDOM: Routledge. Available at: http://ebookcentral.proquest.com/lib/ual/detail.action?docID=181972 (Accessed: 16 January 2019).

Morley, N. J., Bartlett, C. and McGill, I. (2009) Maximising Reuse and Recycling of UK Clothing and Textiles: A report to the Department for Environment, Food and Rural Affairs. EV0421. Aylesbury, UK: Oakdene Hollins Ltd. Available at: http://www.oakdenehollins.com/media/173/defra_173_summary_issue_4.pdf (Accessed: 11 September 2017).

Morley, N., Slater, S., Russell, S., Tipper, M. and Ward, G. D. (2006) Recycling of low grade clothing waste. DEFR01 058 Low Grade Clothing WRT152. UK: Oakdene Hollins Ltd, Salvation Army Trading Company Ltd Nonwovens Innovation & Research Institute Ltd. Available at: http://www.inno-therm.com/wp-content/uploads/2013/10/Recycle-Low-Grade-Clothing.pdf (Accessed: 23 June 2020).

Moxey (2000) ‘The representation of concepts in textile design’, Point : art & design research journal., 9, pp. 50–58.

Murray, R. (2002) ‘Zero Waste’, Greenpeace Environmental Trust. Available at: https://www.yumpu.com/en/document/read/26286692/zero-waste-by-robin-murray-greenpeace-environmental-trust-2002 (Accessed: 23 April 2020).

Muthu, S. S. (2014) ‘End-of-life management of textile products’, in Assessing the Environmental Impact of Textiles and the Clothing Supply Chain. Cambridge: Elsevier Science (Woodhead Publishing Series in Textiles). Available at: https://ebookcentral.proquest.com/lib/ual/reader.action?docID=1651799&ppg=175 (Accessed: 2 October 2017).

Naudé, M. (2011) ‘Sustainable development in companies: theoretical dream or implementable reality?’, Corporate Ownership and Control, 8(4). doi: 10.22495/cocv8i4c3art4.

Niinimäki, K. and Karell, E. (2020) ‘Closing the Loop: Intentional Fashion Design Defined by Recycling Technologies’, in Vignali, G., Reid, L. F., Ryding, D., and Henninger, C. E. (eds) Technology-Driven Sustainability: Innovation in the Fashion Supply Chain. Cham: Springer International Publishing, pp. 7–25. doi: 10.1007/978-3-030-15483-7_2.

Norman, D. A. and Verganti, R. (2013) ‘Incremental and Radical Innovation: Design Research vs. Technology and Meaning Change’, Design Issues, 30(1), pp. 78–96. doi: 10.1162/DESI_a_00250.

Norris, L. (2005) ‘Cloth that lies: the secrets of recycling’, in Küchler, S. and Miller, D. (eds) Clothing as material culture. Oxford: Berg.

Norris, L. (2012a) ‘Economies of moral fibre? Recycling charity clothing into emergency aid blankets’, Journal of Material Culture, 17(4), pp. 389–404.

Norris, L. (2012b) Recycling imported secondhand textiles in the shoddy mills in Panipat, India: an overview of the industry, its local impact and implications for the UK trade. Available at: http://www.wornclothing.co.uk/wp-content/uploads/2011/01/SummaryShoddy.pdf (Accessed: 24 July 2018).

Norris, L. (2012c) ‘Shoddy rags and relief blankets: perceptions of textile recycling in north India’, in Alexander, C. and Reno, J. (eds) Economies of recycling: the global transformation of materials, values and social relations. London ; New York : New York: Zed Books ; Distributed in the USA by Palgrave Macmillan.

Norris, L. (2012d) ‘Trade and Transformations of Secondhand Clothing: Introduction’, TEXTILE, 10(2), pp. 128–143. doi: 10.2752/175183512X13315695424473.

Norris, L. (2019) ‘Waste, dirt and desire: Fashioning narratives of material regeneration’, The Sociological Review, 67(4), pp. 886–907. doi: 10.1177/0038026119854273.

Norris, L. and Mitchell, T. (2012) ‘Everything must go’, in The sustainable fashion handbook. London, England: Thames & Hudson.

Nørup, N., Pihl, K., Damgaard, A. and Scheutz, C. (2019) ‘Evaluation of a European textile sorting centre: Material flow analysis and life cycle inventory’, Resources, Conservation and Recycling, 143, pp. 310–319. doi: 10.1016/j.resconrec.2019.01.010.

Odegard, I., Croezen, H. and Bergsma, G. (2012) Cascading of Biomass. 13 Solutions for a Sustainable Bio-Based Economy. Delft, The Netherlands: CE Delft. Available at: https://www.cedelft.eu/publicatie/cascading_of_biomass%3Cbr%3E13_solutions_for_a_sustainable_bio-based_economy/1277 (Accessed: 5 August 2019).

Olsson, O., Bruce, L., Roos, A., Hektor, B., Guisson, R., Lamers, P., Hartley, D., Ponitka, J., Hildebrandt, J. and Thrän, D. (2016) Cascading of Woody Biomass: definitions, policies and effects on international trade.

Ørngreen, R. and Levinsen, K. (2017) ‘Workshops as a Research Methodology’, The Electronic Journal of eLearning, 15(1), p. 12.

Padovani, C. (2017) ‘MADE IN ITALY: Reclaiming social heritage and artisan know-how’, in Whittaker, P. and Padovani, C., Sustainability and the Social Fabric: Europe’s new Textile Industries. Bloomsbury Publishing PLC.

Pailthorpe, M. and Wood, E. (2012) ‘Notes- Topic 15 - Principles of Wool Fabric Finishing’. Woolwise - Australian Wool Education Trust. Available at: https://www.woolwise.com/wp-content/uploads/2017/07/WOOL-482-582-12-T-15.pdf (Accessed: 28 May 2020).

Paine, H. (2015) Laser Shaping: A method for controlling the elastic behaviour of stretch fabrics for a targeted and graduated compressive effect on the body. PhD Thesis. Royal College of Art.

Papanek, V. (2019) Design for the Real World. 3 edition. London: Thames and Hudson Ltd.

Park, S. H. and Kim, S. H. (2014) ‘Poly (ethylene terephthalate) recycling for high value added textiles', Fashion and Textiles, 1(1). doi: 10.1186/s40691-014-0001-x.

Payne, A. (2015) 'Open- and closed-loop recycling of textiles and apparel products', in Muthu, S. S. (ed.) Handbook of life cycle assessment (LCA) of textiles and clothing. Cambridge, England: Woodhouse Publishing (Woodhead publishing series in textiles, number 172).

Pedersen, E. R. G., Earley, R. and Andersen, K. R. (2019) 'From singular to plural: exploring organisational complexities and circular business model design', Journal of Fashion Marketing and Management: An International Journal, 23(3), pp. 308–326. doi: 10.1108/JFMM-04-2018-0062.

Peters, H. A. R., Toxopeus, M. E., Jauregui-Becker, J. M. and Dirksen, M.-O. (2012) 'Prioritizing "Design for Recyclability" Guidelines, Bridging the Gap between Recyclers and Product Developers', in Dornfeld, D. A. and Linke, B. S. (eds) Leveraging Technology for a Sustainable World. Berlin, Heidelberg: Springer, pp. 203–208.

Philpott, R. (2011) Structural Textiles: Adaptable Form and Surface in Three Dimensions. Doctoral thesis. Royal College of Art.

Pokkyarath, B. and Biddie, D. (2014) Evaluation of the end markets for textile rag and fibre within the UK. WRAP and Oakdene Hollins. Available at: http://www.wrap.org.uk/sites/files/wrap/priv_download/MPD007-015_Evaluation%20of%20End%20Markets_Final.pdf (Accessed: 7 December 2017).

Polanyi, M. (2009) The tacit dimension. Chicago, Ill: University of Chicago Press.

Pöllänen, S. (2013) 'The meaning of craft: Craft makers' descriptions of craft as an occupation', Scandinavian Journal of Occupational Therapy. Taylor & Francis, 20(3), pp. 217–227. doi: 10.3109/11038128.2012.725182.

Press, M. and Cooper, R. (2003) The design experience: the role of design and designers in the twenty-first century. Aldershot: Ashgate.

Quartinello, F., Vecchiato, S., Weinberger, S., Kremenser, K., Skopek, L., Pellis, A. and Guebitz, G. (2018) 'Highly Selective Enzymatic Recovery of Building Blocks from Wool-Cotton-Polyester Textile Waste Blends', Polymers, 10(10), p. 1107. doi: 10.3390/polym10101107.

Ralph, P. and Wand, Y. (2009) 'A Proposal for a Formal Definition of the Design Concept', in Lyytinen, K., Loucopoulos, P., Mylopoulos, J., and Robinson, B. (eds) Design Requirements Engineering: A Ten-Year Perspective. Design Requirments Workshop, Springer Berlin Heidelberg (Lecture Notes in Business Information Processing), pp. 103–136.

REACT (2019) Recycling of Waste Acrylic Textiles, REACT Project. Available at: https://www.react-project.net/ (Accessed: 16 March 2020).

Reay, S. D., McCool, J. P. and Withell, A. (2011) 'Exploring the Feasibility of Cradle to Cradle (Product) Design: Perspectives from New Zealand Scientists', Journal of Sustainable Development, 4(1), p. 9.

Reike, D., Vermeulen, W. J. V. and Witjes, S. (2018) 'The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options', Resources, Conservation and Recycling. (Sustainable Resource Management and the Circular Economy), 135, pp. 246–264. doi: 10.1016/j.resconrec.2017.08.027.

Renecell (2020) Re:newcell, re:newcell - We make fashion sustainable. Available at: https://renewcell.com/ (Accessed: 20 March 2020).

Rex, D., Okcabol, S. and Roos, S. (2019) Possible sustainable fibers on the market and their technical properties. Mistra Future Fashion 2019:02 part 1. Sweden: RISE Reserach Insitute of Sweden.

Ricketts, L. and Skinner, B. (2016) Dead White Man's Clothes, Dead White Man's Clothes. Available at: https://deadwhitemansclothes.org/intro (Accessed: 5 June 2020).

Rieple, A., Haberberg, A. and Gander, J. (2010) 'Hybrid Organizations as a Strategy for Supporting New Product Development', Design Management Review, 16(1), pp. 48–55. doi: 10.1111/j.1948-7169.2005.tb00007.x.

Rodgers, P. A., Innella, G. and Bremner, C. (2017) 'Paradoxes in Design Thinking', The Design Journal, 20(sup1), pp. S4444–S4458. doi: 10.1080/14606925.2017.1352941.

Rogers, M. (2012) 'Contextualizing Theories and Practices of Bricolage Research', The Qualitative Report, 17(48), pp. 1–17.

Roos, S., Sandin, G., Peters, G., Spak, B., Bour, L. S., Perzon, E. and Jönsson, C. (2019a) 'guidance for fashion companies on design for recycling', Mistra Future Fashion, p. 27.

Roos, S., Sandin, G., Peters, G., Spak, B., Bour, L. S., Perzon, E. and Jönsson, C. (2019b) white paper on textile recycling. 2019:09. RISE IVF AB: Mölndal, Sweden, p. 58. Available at: http://mistrafuturefashion.com/wp-content/uploads/2019/10/S.-Roos.-White-paper-on-textile-recycling.-Mistra-Future-Fashion.pdf (Accessed: 6 January 2020).

Rose, C. M. and Ishii, K. (1999) 'Product End-of-Life Strategy Categorization Design Tool', Journal of Electronics Manufacturing, 9(1), pp. 41–51. doi: https://doi.org/10.1142/S0960313199000271.

Rose, G. (2013) Visual Methodologies. Third edition. London ; Thousand Oaks, Calif: Sage Publications Ltd.

Rowe, P. G. (1987) Design thinking. Cambridge, Mass. ; London: MIT Press.

RSA (2016) LESSONS FROM THE GREAT RECOVERY 2012-2016. Available at: http://www.greatrecovery.org.uk/resources/new-report-lessons-from-the-great-recovery-2012-2016/ (Accessed: 14 November 2017).

Runnel, A., Raihan, K., Castle, N., Oja, D. and Bhuiya, H. (2017) The Undiscovered Business Potential of Production Leftovers within Global Fashion Supply Chains: Creating a Digitally Enhanced Circular Economy - Insight from research among fabric and garment factories of China and Bangladesh. Reverse Resources. Available at: https://reverseresources.net/about/white-paper (Accessed: 28 March 2021).

Sajn, N. (2019) Environmental impact of textile and clothes industry. PE 633.143. EPRS European Parlimentary Research Service, p. 10. Available at: http://www.europarl.europa.eu/RegData/etudes/BRIE/2019/633143/EPRS_BRI(2019)633143_EN.pdf (Accessed: 23 March 2020).

Sakthivel, S., Ramachandran, T., Chandhanu, R., Gowthami, R., Priya, J. P. and Vadivel, P. (2010) 'Development of products using reclaimed fibres', Indian Textile Journal, 121(1), pp. 24–33.

Sakthivel, S., Ramachandran, T., Chandhanu, R., Vignesh, R., Padma Priya, J. and Vadivel, P. (2012) 'Source & Effective utilisation of textile waste in Tirupur', Indian Textile Journal, 122(4), pp. 22–26.

Sandin, G. and Peters, G. M. (2018) 'Environmental impact of textile reuse and recycling - A review', Journal of Cleaner Production, 184, pp. 353–365. doi: https://doi.org/10.1016/j.jclepro.2018.02.266.

Sarioğlu, E. and Kaynak, H. K. (2018) 'PET Bottle Recycling for Sustainable Textiles', in Camlibel, N. O. (ed.) Polyester - Production, Characterization and Innovative Applications. InTech. doi: 10.5772/intechopen.72589.

Sauerwein, M., Bakker, C. and Balkenende, R. (2018) 'Annotated Portfolios as a Method to Analyse Interviews', in DRS Conference 2018. Catalyst for Change, University of Limerick: Scribd, pp. 1148–1158. Available at: https://www.scribd.com/document/382349704/DRS2018-Vol-3#download (Accessed: 24 July 2018).

Schön, D. A. (1983) The reflective practitioner: how professionals think in action. London: Temple Smith.

Sevaldson, B. (2009) Systems Oriented Design, Systems Oriented Design. Available at: https://www.systemsorienteddesign.net/index.php/sod/nutshell (Accessed: 4 August 2020).

Sevaldson, B. (2011) 'GIGA-MAPPING:Visualisation for complexity and systems thinking in design.', in Nordic Design Research Conference. Nordic Design Research Conference Proceedings, Helsinki, Finland: Nordes. Available at: https://archive.nordes.org/index.php/n13/article/view/104 (Accessed: 4 August 2020).

Sevaldson, B. (2013) 'Systems Oriented Design: The emergence and development of a designerly approach to address complexity', in DRS CUMULUS Oslo 2013. 2nd International Conference for Design Education Researchers, Olso, Norway: DRS, p. 23. Available at: https://www.researchgate.net/profile/Birger_Sevaldson/publication/319931083_Systems_Oriented_Design_The_emergence_and_development_of_a_designerly_approach_to_address_complexity/links/59c2231caca272295a0d9dd2/Systems-Oriented-Design-The-emergence-and-development-of-a-designerly-approach-to-address-complexity.pdf (Accessed: 3 August 2020).

Shell, H. R. (2014) 'Shoddy heap: a material history between waste and manufacture', History and Technology, 30(4), pp. 374–394. doi: 10.1080/07341512.2014.1003165.

Sherbourne, A. (2009) 'Acheiving sustainble textiles: a designer's perspective', in Blackburn, R. S. (ed.) Sustainable textiles: life cycle and environmental impact. Boca Raton, Fla. : Oxford: CRC Press ; Woodhead (Woodhead publishing in textiles, no. 98), pp. 3–32.

Simon, H. A. (1996) The sciences of the artificial. Third edition. Cambridge, Mass: MIT Press.

Sinclair, R. (2014) Textiles and fashion: materials, design and technology. Boston, MA: Elsevier.

Sirkin, T. and ten Houten, M. (1994) 'The cascade chain: A theory and tool for achieving resource sustainability with applications for product design', Resources, Conservation and Recycling. (The Cascade Chain), 10(3), pp. 213–276. doi: 10.1016/0921-3449(94)90016-7.

Smirnova, E. (2017) Colours in a circular economy - Värit kiertotaloudessa. Masters Thesis. Aalto University. Available at: https://aaltodoc.aalto.fi/handle/123456789/24669 (Accessed: 28 March 2021).

Stahel, W. R. (2019) 'Circular Industrial Economy', in Charter, M. (ed.) Designing for the circular economy. London: Routledge.

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., Vries, W. de, Wit, C. A. de, Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B. and Sörlin, S. (2015) 'Planetary boundaries: Guiding human development on a changing planet', Science, 347(6223). doi: 10.1126/science.1259855.

Sung, K. (2015) 'A review on upcycling: Current body of literature, knowledge gaps and a way forward', in International Conference on Environmental, Cultural, Economic and Social Proceedings. International Conference on Environmental, Cultural, Economic and Social, Venice, Italy, pp. 28–40. Available at: https://www.researchgate.net/publication/299559229_A_Review_on_Upcycling_Current_Body_of_Literature_Knowledge_Gaps_and_a_Way_Forward (Accessed: 27 February 2020).

Sung, K. (2017) Sustainable production and consumption by upcycling : understanding and scaling-up niche environmentally significant behaviour. Ph.D. Nottingham Trent University. Available at: http://irep.ntu.ac.uk/id/eprint/31125/ (Accessed: 22 February 2019).

Sung, K., Cooper, T. and Kettley, S. (2019) 'Developing Interventions for Scaling Up UK Upcycling', Energies, 12(14), p. 2778. doi: 10.3390/en12142778.

Tanttu, M., Kohtala, C. and Niinimäki, K. (2016) 'Can Design-Driven Material Innovation Also Drive Circularity?', in Circular Transitions Proceedings. Circular Transitions, London, UK: Centre for Circular Design, pp. 20–31. Available at: http://circulartransitions.org/media/downloads/Circular-Transitions-Proceedings.pdf (Accessed: 27 February 2020).

Testa, F., Nucci, B., Iraldo, F., Appolloni, A. and Daddi, T. (2017) 'Removing obstacles to the implementation of LCA among SMEs: A collective strategy for exploiting recycled wool', Journal of Cleaner Production, 156, pp. 923–931. doi: 10.1016/j.jclepro.2017.04.101.

Thackara, J. (2006) In the Bubble: Designing in a Complex World. Cambridge, UNITED STATES: MIT Press. Available at: http://ebookcentral.proquest.com/lib/ual/detail.action?docID=3339780 (Accessed: 6 April 2020).

Thompson, M. and Reno, J. O. (2017) Rubbish Theory: The Creation and Destruction of Value - New Edition. London: Pluto Press. Available at: https://ebookcentral.proquest.com/lib/ual/detail.action?docID=4898204 (Accessed: 20 May 2019).

Thompson, P., Willis, P. and Morley, N. (2012) A review of commercial textile fibre recycling technologies. WRAP and Oakdene Hollins. Available at: http://www.wrap.org.uk/system/files/private/Commercial%20textile%20fibre%20recycling%20technoloogies%20report.pdf (Accessed: 7 December 2017).

Tonkinwise, C. (2014) 'Design Away', in Yelavich, S. and Adams, B., Design as Future-Making. First edition. London: Bloomsbury Publishing. Available at: https://ebookcentral.proquest.com/lib/ual/detail.action?docID=1742610 (Accessed: 31 July 2020).

Toomey, A. and Kapsali, V. (2014) 'D-STEM: a Design led approach to STEM innovation', in 5th STS Italia Conference Proccedings. A Matter of Design: Making Society through Science and Technology, Milan, Italy: STS Italia. Available at: https://www.researchgate.net/publication/276076145_DSTEM''a'Design'led'approach'to'STEM'_innovation' (Accessed: 11 May 2020).

Trafford, V. and Leshem, S. (2008) Stepping stones to achieving your doctorate: focusing on your viva from the start. Maidenhead: Open University Press (Open UP study skills).

Trash-2-Cash (2018) Trash2Cash EU funded project, taking waste & making new fibres, Trash-2-Cash. Available at: https://www.trash2cashproject.eu/ (Accessed: 21 November 2018).

Tubito, C., Earley, R., Ellams, D., Goldsworthy, K., Hornbuckle, R., Niinimäki, K., Östmark, E., Sarbach, V. and Tanttu, M. (eds) (2019) 'APPLIED DDMI: A White Paper on How Design-Driven Material Innovation Methodology was Applied in the Trash-2-Cash Project'. Trash2Cash. Available at: https://www.trash2cashproject.eu/#/design-driven/ (Accessed: 29 May 2019).

Tufte, E. R. (1990) Envisioning information. Cheshire, Connecticut: Graphics Press.

Twigger-Holroyd, A. (2013) Folk fashion : amateur re-knitting as a strategy for sustainability. Ph.D. Birmingham City University.

Uchimaru, M., Kimura, T. and Sato, T. (2013) 'Study on Recycling System of Waste Textiles based on Colour', Journal of Textile Engineering, 59(6), pp. 159–164.

Vadicherla, T. and Saravanan, D. (2017) 'Effect of Blend Ratio on the Quality Characteristics of Recycled Polyester/Cotton Blended Ring Spun Yarn', FIBRES & TEXTILES in Eastern Europe, 25(122), pp. 48–52. doi: 10.5604/12303666.1227875.

Veelaert, L., Du Bois, E., Hubo, S., Van Kets, K. and Ragaert, K. (2017) 'Design From Recycling', in EKSIG 2017 Conference Proceedings. EKSIG 2017: Alive. Active. Adaptive, Delft University of Technology, The Netherlands: Design Research Society. Available at: https://www.researchgate.net/publication/320323527 (Accessed: 21 January 2020).

Veelaert, L., Ragaert, K., Hubo, S. and Kets, K. V. (2016) 'Bridging design and engineering in terms of materials selection', in Procceedings for International Polymers & Moulds Innovations Conference 2016. International Polymers & Moulds Innovations Conference 2016, Ghent, Belgium. Available at: https://

www.researchgate.net/publication/308873749_Bridging_design_and_engineering_in_terms_of_materials_selection (Accessed: 23 May 2020).

Venkatachalam, A. R., Mellichamp, J. M. and Miller, D. M. (1993) 'A knowledge-based approach to design for manufacturability', Journal of Intelligent Manufacturing, 4(5), pp. 355–366. doi: 10.1007/BF00123780.

Vettese, D. S. (2017) '3D printable recycled textiles : material innovation and a resurrection of the forgotten "shoddy" industry', in Intersections. on in textile design research, Loughborough University London.: Loughborogh University, p. 16. Available at: http://www.lboro.ac.uk/media/wwwlboroacuk/external/content/schoolsanddepartments/aed/downloads/Vettese_INTERSECTIONS2017.pdf (Accessed: 12 March 2019).

Vis, M., Mantau, U., Allen, B., Essel, R., Reichenbach, J., European Commission, Directorate-General for Internal Market, I., Entrepreneurship and SMEs, BTG, INFRO, Institute for European Environmental Policy, NOVA, and INTECUS (2016) CASCADES: study on the optimised cascading use of wood. Luxembourg: Publications Office. Available at: http://bookshop.europa.eu/uri?target=EUB:NOTICE:ET0416305:EN:HTML (Accessed: 5 August 2019).

Vis, M. W., Reumerman, P. and Gärtner, S. (2014) Cascading in the Wood Sector. 1741. Netherlands: BTG Biomass Technology Group B.V. Available at: http://www.btgworld.com/nl/nieuws/cascading-wood-sector-final-report-btg.pdf (Accessed: 5 August 2019).

Vuletich, C. (2015) Transitionary Textiles: a crafts-based journey of Textile Design Practice towards new values and roles for a Sustainable Fashion Industry. PhD Thesis. University of the Arts London.

Ward, G. D., Hewitt, A. D. and Russell, S. J. (2013) 'Fibre composition of donated post-consumer clothing in the UK', Proceedings of the Institution of Civil Engineers - Waste and Resource Management, 166(1), pp. 29–37. doi: 10.1680/warm.12.00014.

Watson, D., Elander, M., Gylling, A., Andersson, T. and Heikkilä, P. (2017) Stimulating textile-to-textile recycling. TemaNord. Denmark: Nordic Council of Ministers.

Webster, C. (2013) 'Engineering the circular economy: a field manual for re-designing a regenerative economy - The art of design for disassembly'. Ellen Macarthur Foundation. Available at: https://www.ellenmacarthurfoundation.org/assets/downloads/news/EMF_Engineering-the-Circular-Economy_300913.pdf (Accessed: 8 April 2020).

Wedin, H., Gupta, C., Mzikian, P., Englung, F., Hornbuckle, R., Troppenz, V., Kobal, L., Krecic, M., Costi, M., Ellams, D. and Olsson, S. (2017) Can automated NIR technology be a way to improve the sorting quality of textile waste? RISE: Trash2Cash. Available at: https://issuu.com/trash2cash/docs/report4/1?ff=true &e=30581983/55544808 (Accessed: 11 December 2017).

Weetman, C. (2019) 'Circular Economy Podcast - Episode 5 Katie Beverley - Ecodesign'. Available at: https://podcasts.google.com?feed=aHR0cHM6Ly9mZWVkcy5wb2RjYXN0bWlycm9yLmNvbS9jaXJjdWxhci1lY29ub215LXBvZGNhc3Q&episode=aHR0cHM6Ly93d3cucmV0aGluazdsb2JhbC5pbmZvLz9wPTQ5ODE (Accessed: 17 April 2020).

Wennberg, M. V. and Östlund, Å. (2019) The Outlook report 2011-2019 - Mistra Future fashion final program report. Stokholm, Sweden: Mistra Future Fashion. Available at: http://mistrafuturefashion.com/wp-content/uploads/2019/10/the-Outlook-Report_Mistra-Future-Fashion-Final-Program-Report_31-okt-2019.pdf (Accessed: 23 March 2020).

Worn Again (2020) Worn Again Technologie. Available at: http://wornagain.co.uk/ (Accessed: 20 March 2020).

Xing, K., Abhary, K. and Luong, L. (2003) 'IREDA: An Integrated Methodology for Product Recyclability and End-of-life Design', The Journal of Sustainable Product Design, 3(3–4), pp. 149–171. doi: 10.1007/s10970-005-3925-9.

Yee, J. S. R. and Bremner, C. (2011) 'Methodological Bricolage – What does it tell us about Design', in Proceedings of the Doctoral Design Education Conference. Doctoral Design Education Conference, Hong Kong.: Hong Kong Polytechnic, p. 11. Available at: http://nrl.northumbria.ac.uk/id/eprint/8822/ (Accessed: 11 September 2020).

Yelavich, S. and Adams, B. (2014) Design as Future-Making. First edition. London: Bloomsbury Publishing.

Yuksekkaya, M. E., Celep, G., Dogan, G., Tercan, M. and Urhan, B. (2016) 'A Comparative Study of Physical Properties of Yarns and Fabrics Produced From Virgin and Recycled Fibers', Journal of Engineered Fabrics & Fibers (JEFF), 11(2), pp. 68–76.

Zink, T. and Geyer, R. (2017) 'Circular Economy Rebound', Journal of Industrial Ecology, 21(3), pp. 593–602. doi: 10.1111/jiec.12545.

Ziout, A. (2014) Design for active disassembly and sustainable product recovery. Saarbrücken, Deutschland: LAP LAMBERT Academic Publishing.

Zitting, J. (2017) Optical sorting technology for textile waste: Development of an identification method with NIR spectroscopy. Masters Thesis. Lahti University of Applied Sciences. Available at: https://www.theseus.fi/bitstream/handle/10024/136518/Zitting_Jaakko.pdf?sequence=1&isAllowed= (Accessed: 28 June 2020).

14 APPENDICES

14.1 INTERVIEW ONE

RECYCLER X

Textile recycler in Prato, Italy

Questions and answers extracted and summarised from a whatsapp interview.
January 2020

When I visited your company, you showed me the yarn that the business produces. This uses recycled acrylic blended with polyester. What is the composition?
50% Acrylic
20% Wool
25% Polyester
5% Other Fibres

What are your yarns used for and where?
The yarn we produce are used for lots of things. Mostly for weaving. You can produce chenille, blankets, many things. We sell to companies that specialise in many types of end products. We mainly sell our materials in Prato and these are sold across the world. We have clients elsewhere in Europe and have even sold to South America.

When you collect the waste jumpers or buy recycled fibres, I would like to know what categories are available to buy? For example, 100% wool or 100% acrylic.
What categories are in between these?
What is the composition along with the wool, acrylic, nylon or polyester?
We buy recycled material from India but also in Italy - 50% wool and the rest is 'mostly acrylic' but this could also be 'other fibres'. This is because when you buy a jumper you will find a lot of different fibres inside. Mostly they are 50% wool / 50% acrylic.

The other kind is 80% wool. But when we speak about 80% it doesn't mean that all the jumpers are 80% wool - it is a medium. You can find 100% wool and 70% wool, and they are mixed. The result is 80 or 85% wool.

The same happens for 50% wool – these are the waste from the first-choice jumpers (80%). These might have 69% wool - 30% wool so the medium is more of less 50%. It actually usually is 40% but they call it 50%. After analysis we normally find 40% wool.

There is another category this is the acrylic. This is not 'all acrylic'. Again, we call it 'acrylic' but in the jumpers there might be some wool or another kind of fibre. You will usually find 95%, 90% or 85% acrylic and 5% or 10% or 15% wool - it depends. It is difficult to select the jumpers by the exact amount of Wool, but they are sorted to make a 'family'.

Can I buy 100% recycled acrylic fibre from you?
Yes, but It can be difficult to find 100% Acrylic in a specific colour. I have blue or black at the moment. I have more colours in 30% wool, 65% Acrylic, 5% other Fibres.

Is this 30% wool a different category and is it all recycled?
The reason I gave you the option to buy 30% wool fibre, as I explained before, is that I buy the 50% which is more or less 40%. I also buy acrylic which is more or less 15% wool. When we open the bale and select all the colours usually, we blend the 40% and the 15% together. Sometimes in the blend we can find 40%, 35%, 30%. I said 30% as this is the average that you might get. I have some colours with 35% wool, some colours with 40% wool, some colour with 25% wool.

Everything I am talking about is recycled fibre - post or pre consumer recycled. This can be waste yarn or waste from jumpers. I don't use new fibre. I don't separate the types of waste I create a blend. I buy 50% wool and acrylic and sort by colour and make my blend. Later when I have colour categories, white, black, light grey etc…
I can make an analysis. I then mix these with other fibres to make yarns. For your yarns, let me know the colour and I can tell you what I have.

If you can buy 100% Acrylic (mostly acrylic but with wool) does the same apply to other fibres such as polyamide? For example, can you buy 100% polyamide that is mostly polyamide but included other fibres in it too?

I don't use polyamide and if I do (for a special blend) it would be virgin. It works in a similar way to polyester. You can the buy recycled polyester fibres, but It is not the same as buying waste wool from jumpers. It usually comes from plastic bottles.

Does more wool equal higher value?
Yes.

14.2 INTERVIEW TWO

HASNAIN LILANI

Founder of the RECYCLE WOOL company.

Hasnain Lilani has worked in the denim industry for around 10 years as head of research and design Innovation. Currently trying to clean the global post-consumer clothing waste.

Questions and answers extracted and summarised from the interview.
January 2020

What categories of wool do you collect?
Even if a garment has 1% wool, we collect it. We collect every percentage of wool, synthetic included. Then we process the materials, as per the requirement of the customer. We clean, we sort by colour and then deliver to the client.

Are there generic categories that you sort into?
The generic categories in the market at the moment for recycling:
100% acrylic, 50% wool / 50% acrylic, 80% wool 20% acrylic, nylon, polyester -whatever the material is, or 100% wool.

100% acrylic might not be 100% I have heard this is the generic name for it, is this true?
It depends. Usually it is 100% acrylic but in the stitching process for example there might be polyester or cotton. The international law around fibres allows for the possibility of +/- 1% or 2% other fibres. You might call this 100% but if you tested in a lab you might find 1% or 2% other fibres. Recycled fibre has its own limitations. To get 100% pure materials - you can only find this in the new virgin material.

Do you sperate the knit material from the woven?
Yes, we have two categories one is knit, and the other is woven. We have to keep these separate. Knit material has limitations and strengths as a recycled material and these are different from the strengths and weakness of woven materials. The woven is very strong material because of the way it needs to be processed. Knit has a soft hand feel compared to woven. The biggest problem for the market is people not wanting to use the woven materials. People prefer the knits. They are using knit material and turning it into woven and therefore we are not closing the loop.

Do you collect 100% Acrylic?
We don't work with acrylic. We are focused on wool. Acrylic has a demand from a low category market. But often you can buy new acrylic at a low price, so people don't want to use the recycled fibre. We don't mind what the other fibres in the blend are we are only focused on collecting wool and cashmere.

Do you give your customers an indication of what is in the recycled batch other than the wool percentage?
We say 'other fibres' because we don't know the exact composition.

14.3 INTERVIEW THREE

HASNAIN LILANI

Founder of the RECYCLE WOOL company.
Bio - Hasnain Lilani has worked in the denim industry for around 10 years as head of research and design Innovation. Currently trying to clean the global post-consumer clothing waste.

Questions and answers extracted and summarised from a Whatsapp Interview
05 November 2020 & 15 March 2021

Cathryn Hall:
Can you let me know what category of wool waste my swatches would be sorted into based on Sorter A's predictions?

Hasnain Lilani:
Lowest category. Mostly in our grading system we treat them as mix blends garbage. Normally our lowest category composition starts from 50% wool minimum.

Cathryn Hall:
Ok thank you.

Hasnain Lilani:
But honestly after seeing swatches it's doesn't looks like lowest quality. I foresee a lot of potential.

Cathryn Hall:
Thanks

Hasnain Lilani:
The real challenge is using them on recycling machine. Our buyers usually complain about short fibre length. We need strong solutions for blended fibres.

Cathryn Hall:
Do you sell this type of waste to anyone?
I know your business is focused on the high wool content. But what do you do with anything your sorters decide is less than 50% wool? I'm just trying to get a really clear picture of how it works. 😊

Hasnain Lilani:
We do take low wool too. There is usage for it as filler in pillows and blankets.

Cathryn Hall:
So, you just sort for the 4 categories: low wool - 50% wool - 80 % wool and 100% wool

Hasnain Lilani:
Also 100% cashmere.
We also do wool coats and wool pants. Nobody is doing this these days, but we are doing it.

Cathryn Hall:
What percentage do they have? Similar to the knitwear?

Hasnain Lilani:
Yes

Cathryn Hall:
Do you ever collect and sort between, for example: 10% wool and 30% wool If a client asks you to?

Hasnain Lilani:
We do collect it and we keep to one side. Today we got 10 tons of low-quality wool. There is a lot of demands these days. Demand because of prices. We have to do the same job we do for high end composition. At rock bottom prices.

Cathryn Hall:
Not ideal

Hasnain Lilani:
We have to do to maintain the business in this current economy situation. Plus, we have to do as my vision is not to waste single sweater. Use it, mend it, use it again, reuse it, recycle it, but don't waste.

Cathryn Hall:
🙌

Hasnain Lilani:
Sometime clients ask to blend with high content to reduce the prices

Cathryn Hall:
So you sort the lower end (everything less than 50% wool) into colour etc... and resell or mix it in with higher wool content to reduce the price? Have I got that right?

Hasnain Lilani:
We don't blend. We sell to customers they do the blends. We only provide a service.

Cathryn Hall:
But you mix the jumpers of qualities together for the client?

Hasnain Lilani:
No, we have several stages and requirements. We ship separate bales for them, then they blend during the composition of yarn. We can't blend it will be big problem in our quality standards. But we don't leave anything with wool content. Sometimes we find very good quality high end wearable brands.

Cathryn Hall:
👍
So you don't deal with 100% synthetic at all?

Hasnain Lilani:
No. 100% Acrylic is completely wasted.

Cathryn Hall:
The colours of my yarns, can they be sorted easily?

Even Blend 2 (see picture of multicoloured fibres in the yarn)?

What about Blend 6?
Hasnain Lilani:
Yes we can sort Blend 2 but it will be melange.
Blend 6 is also a melange.

Cathryn Hall:
Is this worth less when you sell it?

Hasnain Lilani:
Yes
The solid and the melange colours, as for the price they are similar.

Cathryn Hall: (voice note)
Ok so there are three categories - solid colours which are sorted into family colours and shades. Then there is melange, like my Blend 2, this is navy and yellow and would turn green when it is recycled. Would you sort this into a green category? How do melange jumpers get sorted? Then you have garments with patterns on them, the fancy sweaters, how do you sort those?

Hasnain Lilani: (voice note)
Melange is not like yellow and blue combined together. It doesn't happen like this. They [recyclers] prefer to have the yellow with the yellow shades and the blue with the blue shades. Then once it is turned into fibre the recyclers can then use these colours to make their own blend recipes. But there are some sweaters that have

many shades inside like your Blend 2 that have many different fibre shades inside. If you look closely, they have different shades inside. These go into the melange colours and then these go into categories.

We sort melange usually for double tones - you can see there are two tones in the fabrics, so we try and sort for these tones separately. We try to make different categories for these things. Mostly it is difficult, we don't often get big enough volumes of this. It's the normal thing, if we find something we keep it separate. Not that much we find.

For the fancy sweaters - If jumpers are half solid and half fancy, we cut the half out and put this into the solid category and remaining half is kept separately in the fancy category. The mixed coloured and patterned jumpers can be used as yarns. They can used for 'Rosino yarn' fancy yarns. These yarns are mostly used for blankets. Sometimes they produce the yarns and make the fabrics and overdye on top of it.

We find a lot of fancy jumpers, but we do not do the separation by colour of fancy. We keep them all together in the one place. If we did separate by colour then it would be very hectic for us and would take time, space and energy, so we keep it separate. Once we have some orders we bring it out and try to use as much as we can. We put energy on that. There are people that prefer to use this fancy material in local market products. Sometimes they prefer to use them as inner filling of pillows and this type of thing. They can easily use these blended fancy materials. Most of the customers want to take these materials because they are less expensive. The quality is really good because most of the fancy sweaters come in heavy sweaters and mostly pure wool and the quality is super super nice. For recycling it is worth nothing, it has low value and no quality. But those fancy sweaters are the best ones. I cannot find this quality in the solids. But this is the market trend and the norm. We have to go with the market.

Cathryn Hall:
Thank you

14.4 INTERVIEW FOUR

RECYCLER X

Textile recycler in Prato, Italy

Questions and answers extracted and summarised from a whatsapp interview.
March 2021

I have some questions about colour.
This is the melange colour (it's a mix of blue, yellow and navy) I was asking about? Do you recycle this type of knit in its own category? Or Do you combine it with other wastes to recycle?

I can recycle with, for example colour 'avio' on my shade card which is a blue melange. For that colour I can recycled this type of jumper.

What about this one with navy and turquoise?

It is the same. I have some blue groups, for example, dark blue, navy blue, light blue but it is not possible to put this into these categories because these colour categories are not melange. But the melange colours such as 'avio' or 'dark avio', melange colours are suitable for creating these melange yarns so this could be used. It is possible to recycle it like this.

Fancy waste - can this only be downcycled? Can you use this for recycling for yarn?

Regarding these fancy fabrics, the recycling depends on the composition. Say the composition is wool/nylon or wool/acrylic or wool/polyester specifically or better pure composition like pure wool or pure acrylic then you can dye it. All the fancy material you can dye it the dark colours such as blue, black or dark brown. If the composition is easy to dye otherwise you can put it in the waste. One of the solutions to recycle this waste is you can create felt for insulation or insulation for car interiors. There is a lot of applications but not in textiles for clothing.

The recycled navy acrylic fibre you sold me, might this have been overdyed?
Yes it could be.

This one has two contrasting colours how would you deal with this type of colour? Downcycle it or can it be used?

This is the same for the fancy fabrics but because it is a melange made up of black and white. We can use it for a fancy yarn called 'Filato bottonato'. You can use this fibe and put it inside with a grey colour and when you produce the yarn it is not a solid colour or a melange colour and there are 'buttons' of other colours for example, medium grey yarn with buttons in white, button grey/dark grey and button in black. You could recycle this kind like this. But also, in this case, it all depends on the composition. Either Wool/acrylic or pure wool is better to recycle. If the jumper is made from a lot of compositions, then it is better to put it in waste and it becomes felt, insulation and applications not in textiles and clothing.

Is Filato bottonato yarn used to make this type of fabric?

[Recycler X Sent an image of filato bottonato yarn from the range]

Could you recycle this material?
(sent image again of multi coloured filato bottonato [neps])

This you cannot recycle because the colours are different from grey and white and it is difficult to know what colour to sort it in to so it is not possible.

What about a jumper with a double pattern? Can it be used for melange shade? Would this be recycled with dark navy jumpers?

No cathryn, this is not melange, this is fancy for us. It is two different colours. From my view it is brown and grey, so it is not melange. This is fancy. We can only dye if we recycle it. We dye it if has a good composition or it becomes felt etc...

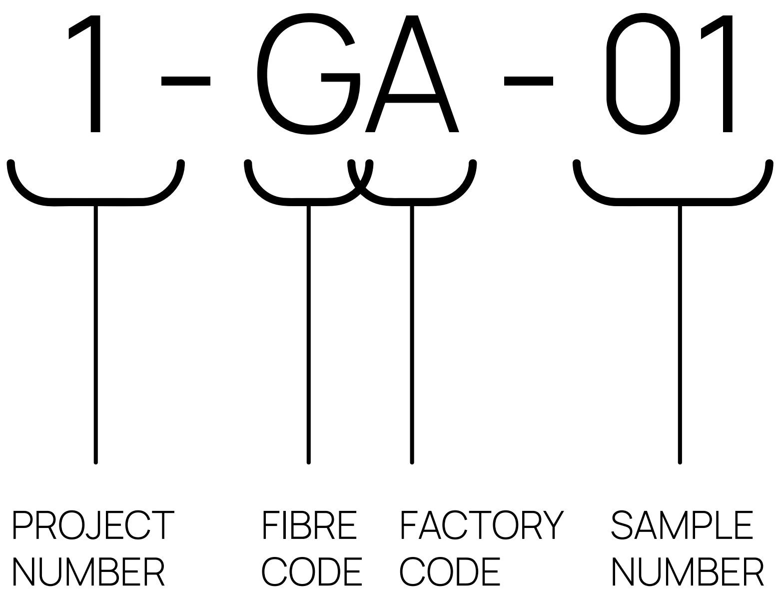
The picture is not good. The colours are black and navy. Does this make a difference?

In this case it depends about the material. If it is woven it cannot be recycled. If it is knitted you can recycle it. If the textile is knitted the quality is higher, but from the picture it looks like it is woven, so for me it is not good to recycle. But if it is a knitted jumper with dark blue and black you can put it in either the blue or the black sorting category. A little navy in the black is not a problem.

Thank you so much.

14.5 DEVELOPMENT SAMPLES

SAMPLE CARD CODE



PRACTICE 0

1PRACTICE 0 - Fibre
100% acrylic-mix fibre - garnetted as wool

PRACTICE 0 - Fibre
100% acrylic-mix fibre - Garnetted as cashmere

PRACTICE 0 - Yarn
70% acrylic-mix fibre / 30% Nylon - 2/10 YSW

PRACTICE 0 - Yarn
50% acrylic-mix fibre / 50% wool - 2/19 YWS

PRACTICE 0 - Woven
Weft: 1-GB-04
Warp: Availbale yarn (67% wool, 33% viscose 2/10 YWS)

PRACTICE 0 - Woven
Weft: 1-GB-04
Warp: Availbale yarn (67% wool, 33% viscose 2/10 YWS)

PRACTICE 0 - Knit
Yarn: 1-GB-04

PRACTICE 0 - Knit
Yarn: 1-NB-03

PRACTICE 0 - Non-woven needle punch (polyester scrim backing)
Fibre: 1-GA-01

PRACTICE 0 - Non-woven needle punched with a woven polypropylene backing.
Fibre: as 1-GA-01 - Navy

PRACTICE 2 - Woven - unfinished
Yarn: 1-GB-04

PRACTICE 2 - Woven - unfinished
Yarn: 1-GB-04 and 1-NB-03

PRACTICE 2 - Woven - finished - milled as wool
Yarn: 1-GB-04 and 1-NB-03

PRACTICE 2 - Woven - finished - milled as synthetic
Yarn: 1-GB-04 and 1-NB-03

PRACTICE 2 - Woven - selvage waste
Yarn: 1-GB-04 and 1-NB-03

PRACTICE 2 - Waste from milling process
100% wool - collected wet

PRACTICE 5 - Fibre pad and mock spun yarn
70% acrylic-mix fibre (1-GA-02) / 25% white wool / 5% summer yellow flax

PRACTICE 5 - Fibre pad and mock spun yarn
50% acrylic-mix fibre (1-GA-02) / 45% white wool / 5% white polypropylene

PRACTICE 5 - Fibre pad and mock spun yarn 1ply and 2ply
70% acrylic-mix fibre (1-GA-02) / 30% summer yellow flax

PRACTICE 5 - Waste collected from under the machine
(3-GB-17 and 3-GB-19)

PRACTICE 7 - carded fibre
50% acrylic-mix fibre (1-GA-01) / 30% white wool / 20% white nylon

PRACTICE 7 - Spun yarn (from 4-GD-21)
50% acrylic-mix fibre (1-GA-01) / 30% white wool / 20% white nylon

PRACTICE 7 - carded fibre
50% acrylic-mix fibre (1-GA-01) / 30% purple wool /20% white nylon

PRACTICE 7 - Spun yarn (from 4-GD-22)
50% acrylic-mix fibre (1-GA-01) / 30% white wool / 20% white nylon

PRACTICE 7 - carded fibre
50% acrylic-mix fibre (1-GA-01) / 30% mixed colour pre-consumer waste wool / 20% white nylon

PRACTICE 7 - Spun yarn (from 4-GD-25)
50% acrylic-mix fibre (1-GA-01) / 30% white wool / 20% white nylon

PRACTICE 7 - carded fibre Blend 1
50% acrylic-mix fibre (1-GA-01) / 30% blue wool / 20% white nylon

PRACTICE 7 - carded fibre Blend 2
25% acrylic-mix fibre (1-GA-01) / 45% blue wool / 20% white nylon

PRACTICE 7 - carded fibre Blend 3
12.5% acrylic-mix fibre (1-GA-01) / 52.5% blue wool / 35% white nylon

PRACTICE 7 - Spun yarn (from 4-GD-29)
12.5% acrylic-mix fibre (1-GA-01) / 52.5% blue wool / 35% white nylon

PRACTICE 7 - Waste collected from carding teeth (4-GD-23)

PRACTICE 3 - Pulled fibre
100% acrylic-mix fibre

PRACTICE 3 - Pulled and single carded
100% acrylic-mix fibre

PRACTICE 3 - Pulled and double carded
100% acrylic-mix fibre

PRACTICE 3 - Double carded on sample machine for spinning
Fibre:5-WC-32

PRACTICE 3 - needle punched
Fibre: 5-WC-33

PRACTICE 3 - needle punched
Fibre: 5-WC-34

PRACTICE 3 - Fibre pad and spun yarn 1ply
50% acrylic-mix fibre (5-WC-35) / 50% white polyester

PRACTICE 3 - Fibre pad and spun yarn 2ply
50% acrylic-mix fibre (5-WC-35) / 50% white polyester

PRACTICE 3 - Fibre pad and spun yarn 1ply
50% acrylic-mix fibre (5-WC-34) / 50% white polyester

PRACTICE 3 - Fibre pad and spun yarn 1ply
50% acrylic-mix fibre (5-WC-34) / 50% white polyester

PRACTICE 3 - Waste from under the carding machine
(6-WB-38 - 41)

PRACTICE 9 - Yarn 2ply and sample of each component
50% acrylic-mix fibre (5-WC-33) / 20% white pre-consumer recycled wool / 30% black virgin wool

PRACTICE 9 - Yarn 2ply and sample of each component
50% acrylic-mix fibre (5-WC-33) / 40% deep green polypropylene / 10% teal viscose

PRACTICE 9 - Yarn 2ply and sample of each component
30% acrylic-mix fibre (5-WC-33) / 60% bright blue polypropylene / 10% teal viscose

PRACTICE 10 - Pulled fibre - worked for carded
50% acrylic-mix fibre / 50% wool

PRACTICE 10 - Pulled fibre - open ended
100% acrylic-mix fibre

PRACTICE 10 - Blend 1 components
Navy recycled acrylic / turq & blue virgin wool / black wool
(substitute for rPET)

PRACTICE 10 - Blend 1 - fibre pad and mock yarn
Fibre: 7-PD-48
50% acrylic-mix / 30% wool / 20% wool (substitute for rPET)

PRACTICE 10 - Blend 2 components
Navy recycled acrylic / blue & yellow mohair-wool-cashmere blend / white mohair / black wool

PRACTICE 10 - Blend 1 - fibre pad and mock yarn
Fibre: 7-PD-50
50% acrylic-mix fibre / 26% mohair / 23% wool / 2% cashmere

PRACTICE 10 - Blend 3 components
Navy recycled acrylic / brown waste cashmere / slate blue wool / black wool (substitute for rPET)

PRACTICE 10 - Blend 3 - fibre pad
Fibre: 7-PD-52
50% acrylic-mix fibre / 30% pre-consumer cashmere / 10% wool / 10% wool (substitute for rPET)

PRACTICE 10 - Silk blend trial 1
Compontants, fibre pad and mock yarn
acrylic-mix / pink waste cashmere / red-green-blue silk / black wool

PRACTICE 10 - Silk blend trial 2
Fibre pad and mock yarn
acrylic-mix / brown waste cashmere /blue and white silk / black wool

PRACTICE 10 - Yarn 1 - 2/8Nm
50% acrylic-mix fibre / 30% wool / 10% rPET

PRACTICE 10 - Yarn 2 - 2/8Nm
50% acrylic-mix fibre / 26% mohair / 23% wool / 2% cashmere

PRACTICE 10 - Yarn 3 - 2/8Nm
50% acrylic-mix fibre / 20% pre-consumer cashmere waste / 10% wool / 10% rPET

PRACTICE 10 - Yarn 4 - 2/8Nm
50% acrylic-mix fibre / 30% wool / 10% rPET

PRACTICE 10 - Yarn 5 - 2/8Nm
50% acrylic-mix fibre / 50% rPET

PRACTICE 10 - Yarn 6 - 2/4Nm
50% acrylic-mix fibre / 30% wool / 20% rPET

PRACTICE 10 - Swatch Yarn 1 - 2/8Nm- 5gg
50% acrylic-mix fibre / 30% wool / 10% rPET

PRACTICE 10 - Swatch Yarn 2 - 2/8Nm- 5gg
50% acrylic-mix fibre / 26% mohair / 23% wool / 2% cashmere

PRACTICE 10 - Swatch Yarn 3 - 2/8Nm- 5gg
50% acrylic-mix fibre / 20% pre-consumer cashmere waste / 10% wool / 10% rPET

PRACTICE 10 - Swatch Yarn 4 - 2/8Nm- 5gg
50% acrylic-mix fibre / 30% wool / 10% rPET

PRACTICE 10 - Swatch Yarn 5 - 2/8Nm- 5gg
50% acrylic-mix fibre / 50% rPET

PRACTICE 10 - Swatch Yarn 6 - 2/4Nm- 5gg
50% acrylic-mix fibre / 30% wool / 20% rPET

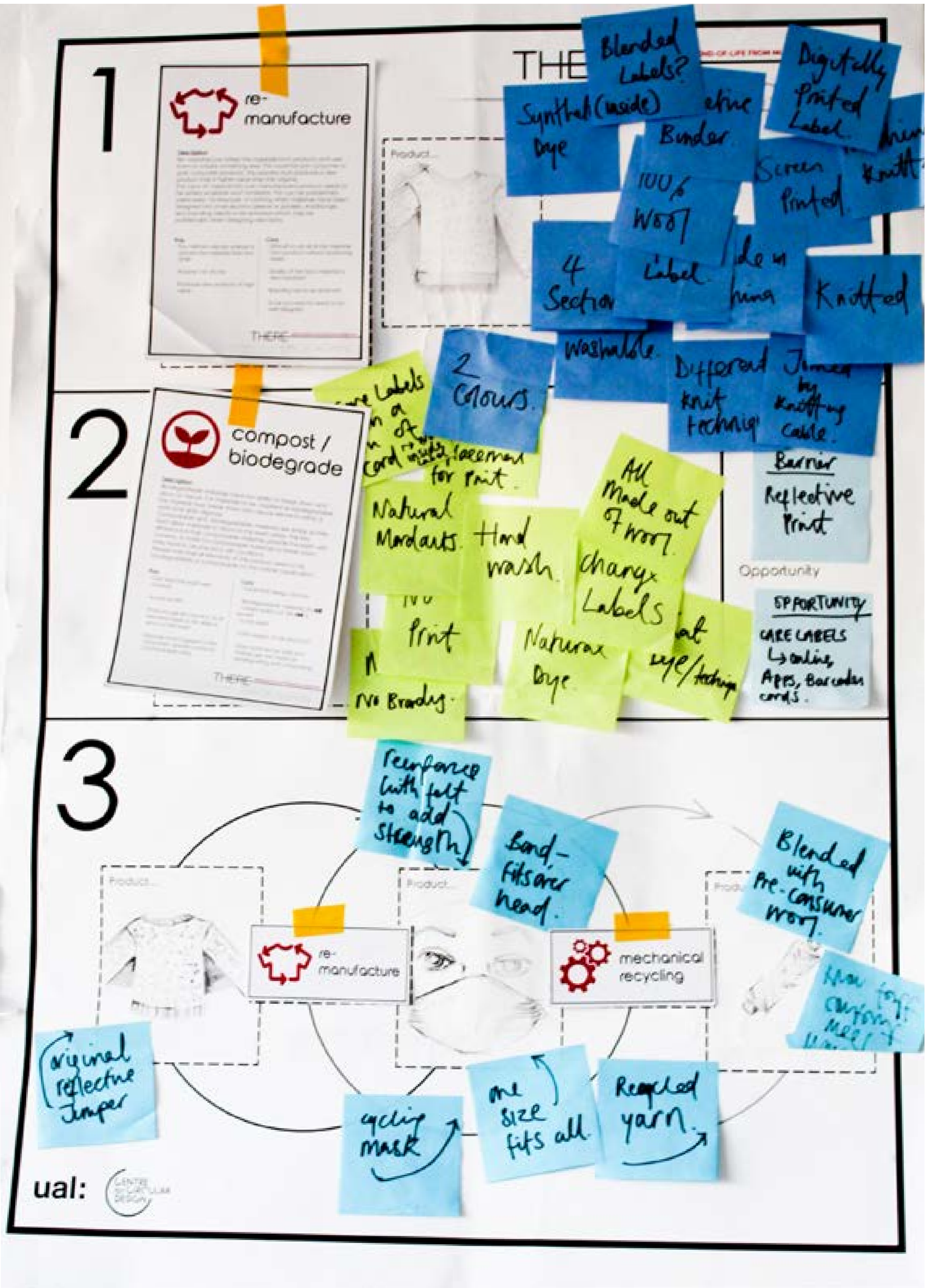
PRACTICE 10 - Swatch Yarn 4 - 2/8Nm - 2ply - 5gg
50% acrylic-mix fibre / 30% wool / 10% rPET

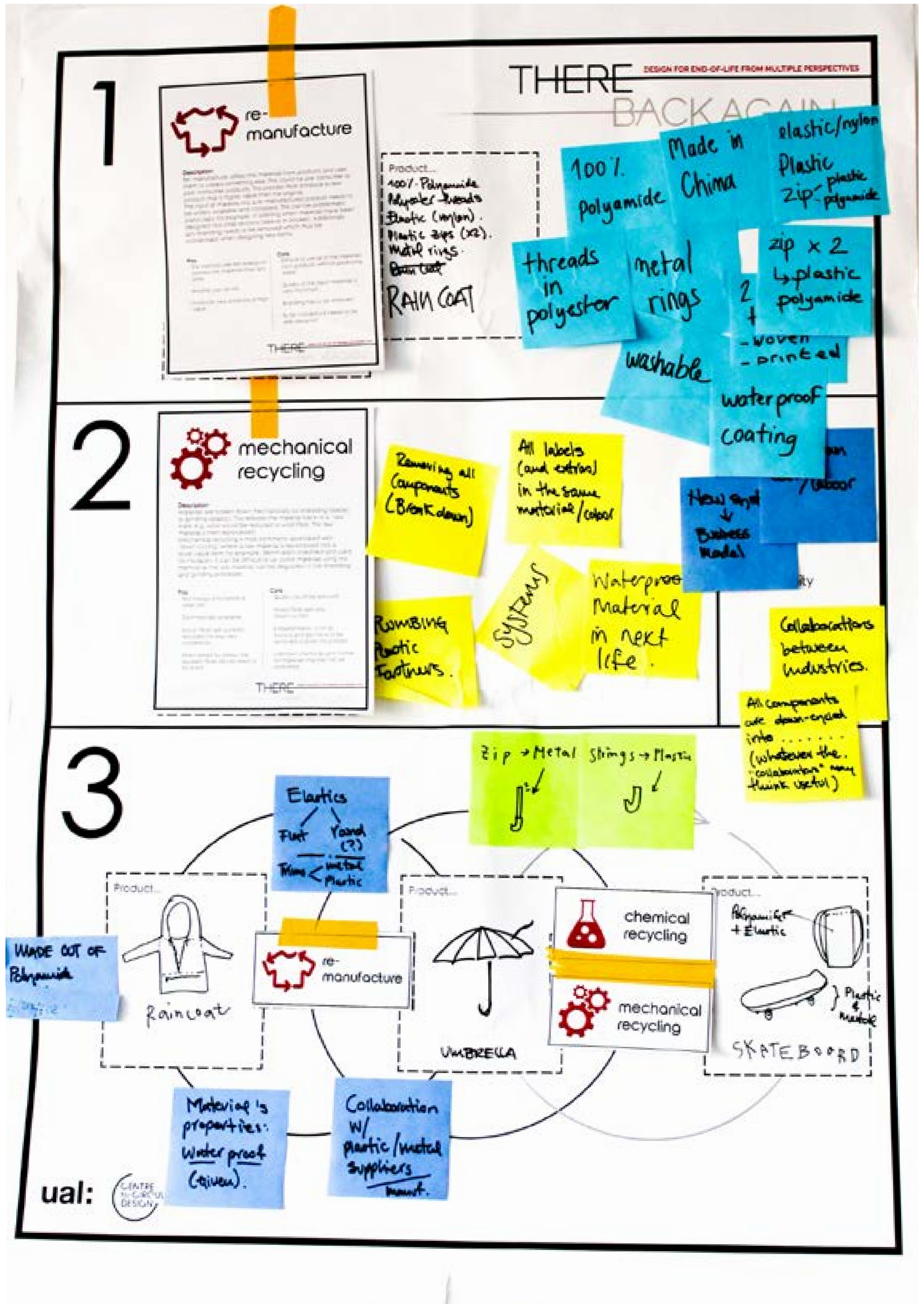
PRACTICE 10 - Swatch Yarn 4 - 2/8Nm- 5gg
Tighter tension and finished with added softner
50% acrylic-mix fibre / 30% wool / 10% rPET

PRACTICE 10 - Five prototype jumpers
Yarn 2 - Yarn 3 - Yarn 1 - Yarn 5 - Yarn 4

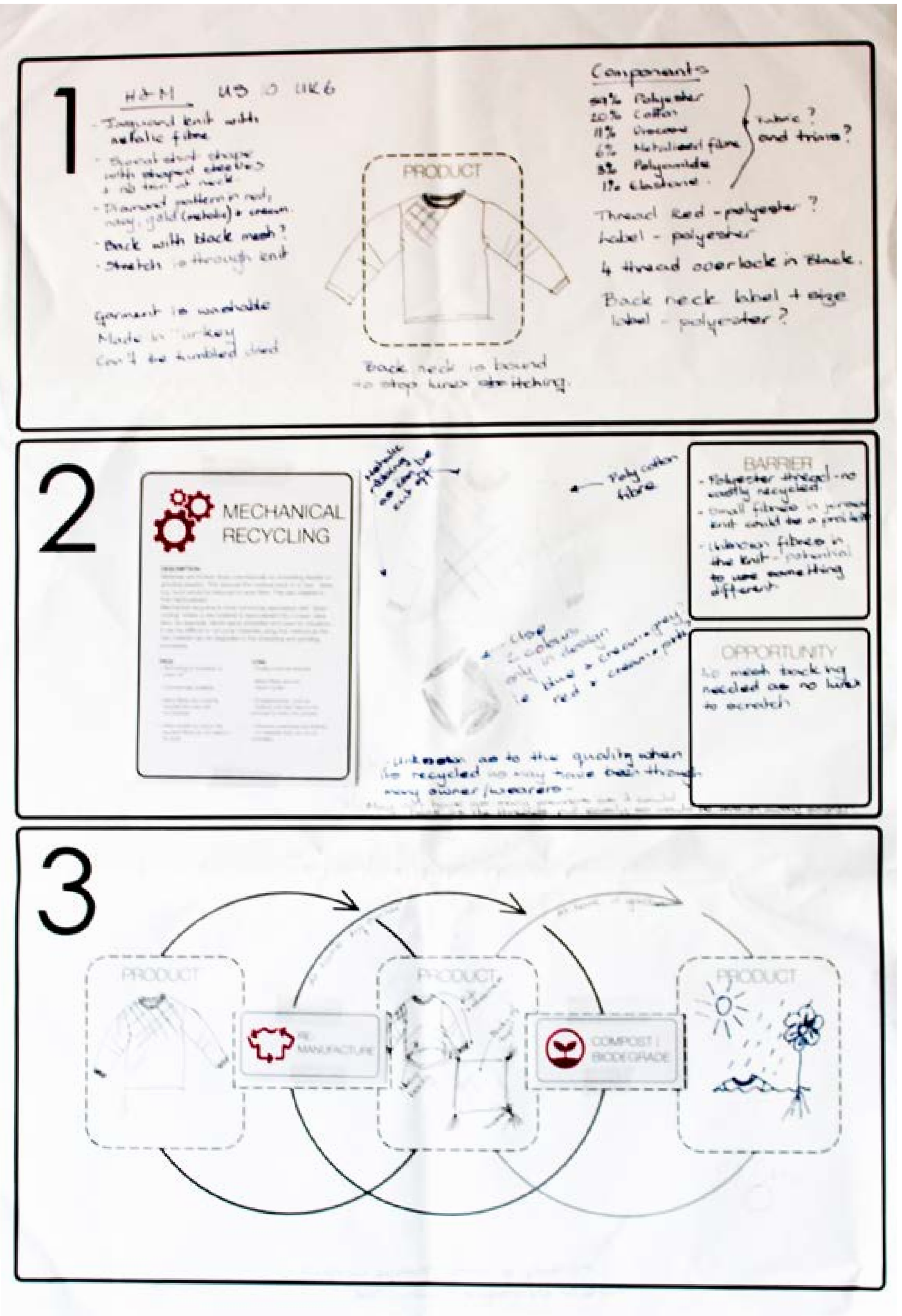
14.6 WORKSHOP WORKSHEETS

14.6.1 WORKSHOP 1





14.6.2 WORKSHOP 2



1

H&M US 10 UK6

- Jacquard knit with metallic fibre
- Sweatshirt shape with shaped sleeves + rib hem at neck
- Diamond pattern in red, navy, gold (metallic) + cream.
- Back with black mesh?
- Stretch is through knit

Garment is washable
Made in Turkey
Can't be tumbled dried

PRODUCT

Back neck is bound to stop lines stretching.

Components
59% Polyester
20% Cotton
11% Viscose
6% Metallised fibre
3% Polyamide
1% Elastane.
fabric? and trims?

Thread Red - polyester?
Label - polyester
4 thread overlock in black.
Back neck label + edge label - polyester?

2

MECHANICAL RECYCLING

Metallic ribbing as can be cut off

Poly cotton fibre

- Close 2 colours only in design
- blue + cream/grey
- red + cream/pink

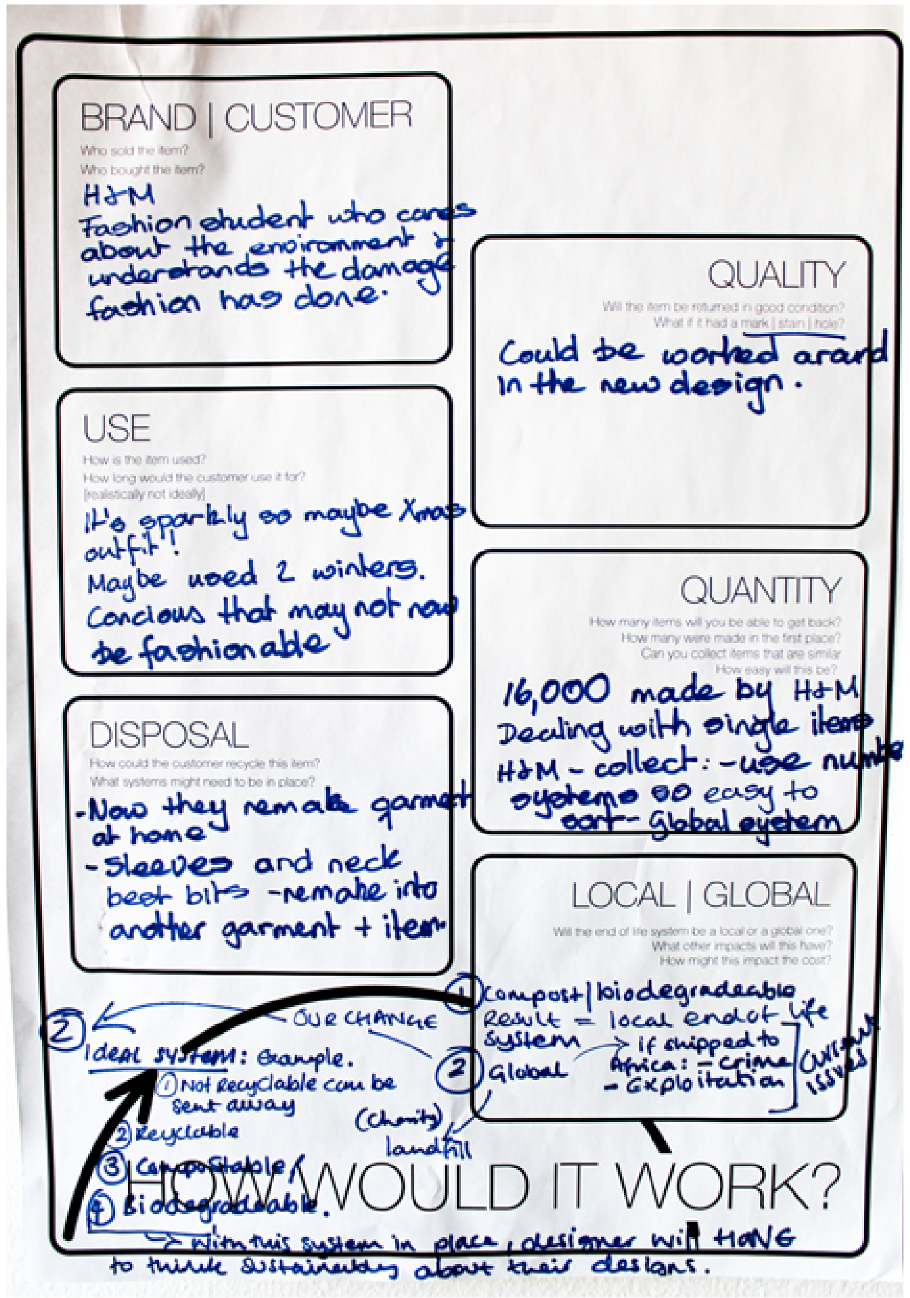
Unknown as to the quality when recycled as may have been through many owner/wearers.

BARRIER
- Polyester thread - no easily recycled
- Small fibres in jersey knit could be a problem
- Unknown fibres in the knit - potential to use something different

OPPORTUNITY
No mesh backing needed as no holes to scratch

3

PRODUCT
RE-MANUFACTURE
PRODUCT
COMPOST | BIODEGRADE
PRODUCT



BRAND | CUSTOMER
Who sold the item?
Who bought the item?
H&M
Fashion student who cares about the environment & understands the damage fashion has done.

QUALITY
Will the item be returned in good condition?
What if it had a mark | stain | hole?
Could be worked around in the new design.

USE
How is the item used?
How long would the customer use it for?
[realistically not ideally]
It's sparkly so maybe Xmas outfit!
Maybe used 2 winters.
Concious that may not now be fashionable

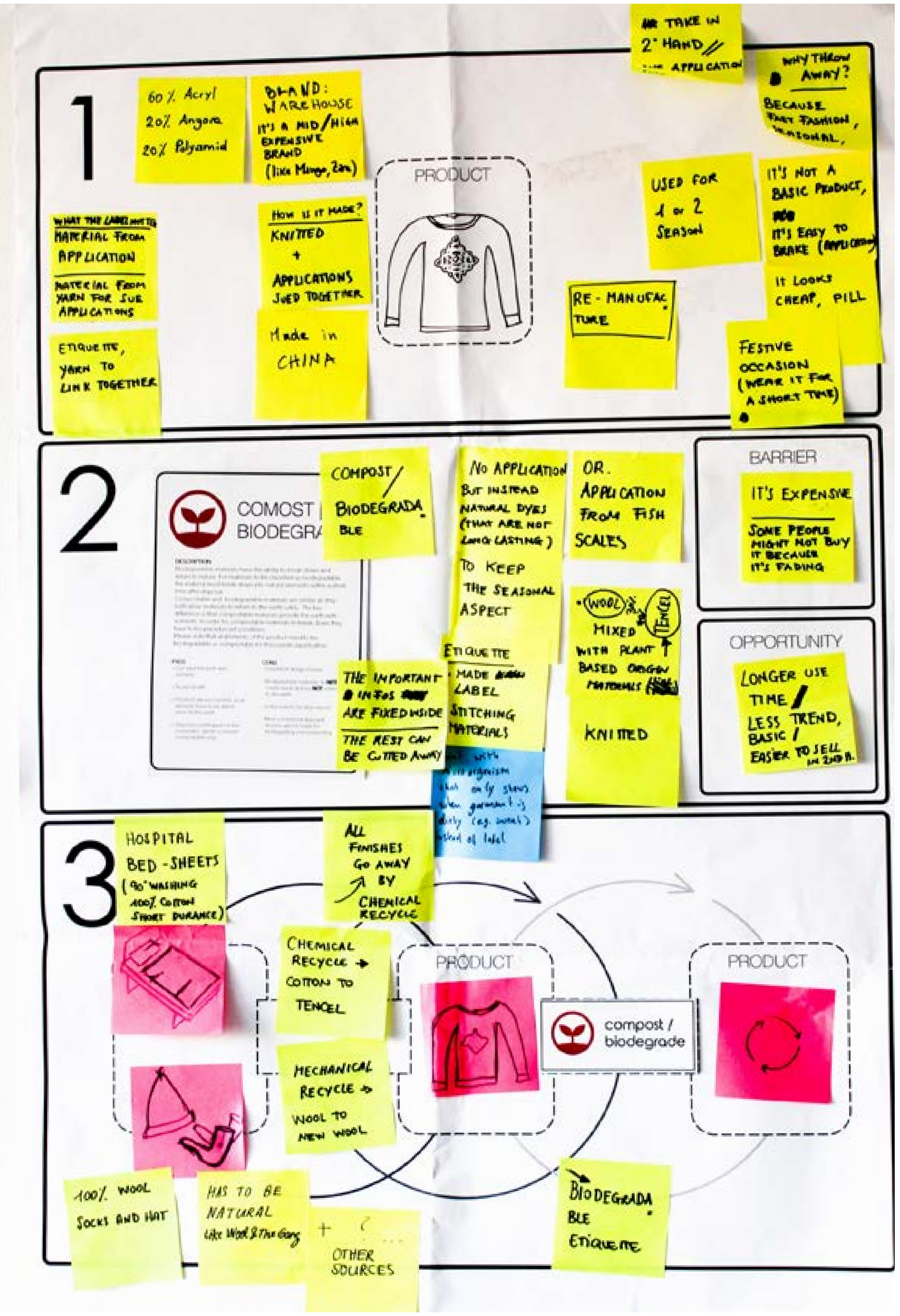
QUANTITY
How many items will you be able to get back?
How many were made in the first place?
Can you collect items that are similar
How easy will this be?
16,000 made by H&M
Dealing with single items
H&M - collect: - use number systems so easy to sort - Global system

DISPOSAL
How could the customer recycle this item?
What systems might need to be in place?
- Now they remake garment at home
- Sleeves and neck best bits - remake into another garment + item

LOCAL | GLOBAL
Will the end of life system be a local or a global one?
What other impacts will this have?
How might this impact the cost?
① Compost | biodegradeable
Result = local end of life system
② Global → if shipped to Africa: - crime - Exploitation
Current issues

② ← OUR CHANGE
Ideal system: Example.
① Not Recyclable can be sent away
(Charity)
landfill
② Recyclable
③ Compostable /
④ Biodegradeable.
→ With this system in place, designer will HAVE to think sustainably about their designs.

HOW WOULD IT WORK?



1

60 % Acryl
20% Angora
20% Polyamid

BRAND: WAREHOUSE
IT'S A MID/HIGH EXPENSIVE BRAND
(like Mango, Zara)

TAKE IN 2° HAND// APPLICATION

WHY THROW AWAY?
BECAUSE FAST FASHION, SEASONAL,

WHAT THE LABEL NOTED
MATERIAL FROM APPLICATION
MATERIAL FROM YARN FOR SUE APPLICATIONS

HOW IS IT MADE?
KNITTED
+
APPLICATIONS SUED TOGETHER

PRODUCT

USED FOR 1 or 2 SEASON

IT'S NOT A BASIC PRODUCT,
IT'S EASY TO BRAKE (APPLICATION)

IT LOOKS CHEAP, PILL

RE-MANUFAC-TURE

ETIQUETTE, YARN TO LINK TOGETHER

Made in CHINA

FESTIVE OCCASION (WEAR IT FOR A SHORT TIME)

2

COMOST | BIODEGRA

COMPOST/BIODEGRADABLE

NO APPLICATION BUT INSTEAD NATURAL DYES (THAT ARE NOT LONG LASTING)
TO KEEP THE SEASONAL ASPECT

OR. APPLICATION FROM FISH SCALES

BARRIER
IT'S EXPENSIVE
SOME PEOPLE MIGHT NOT BUY IT BECAUSE IT'S FADING

WOOL
TENCEL
MIXED WITH PLANT BASED ORIGIN MATERIALS

KNITTED

THE IMPORTANT INFOS ARE FIXED INSIDE
THE REST CAN BE CUTTED AWAY

ETIQUETTE
- MADE LABEL
STITCHING MATERIALS

with microorganism that only shows when garment is dirty (eg. wool) instead of label

OPPORTUNITY
LONGER USE TIME /
LESS TREND, BASIC /
EASIER TO SELL IN 2ND H.

3

HOSPITAL BED-SHEETS (90° WASHING 100% COTTON SHORT DURANCE)

ALL FINISHES GO AWAY BY CHEMICAL RECYCLE

CHEMICAL RECYCLE → COTTON TO TENCEL

MECHANICAL RECYCLE → WOOL TO NEW WOOL

PRODUCT

compost / biodegrade

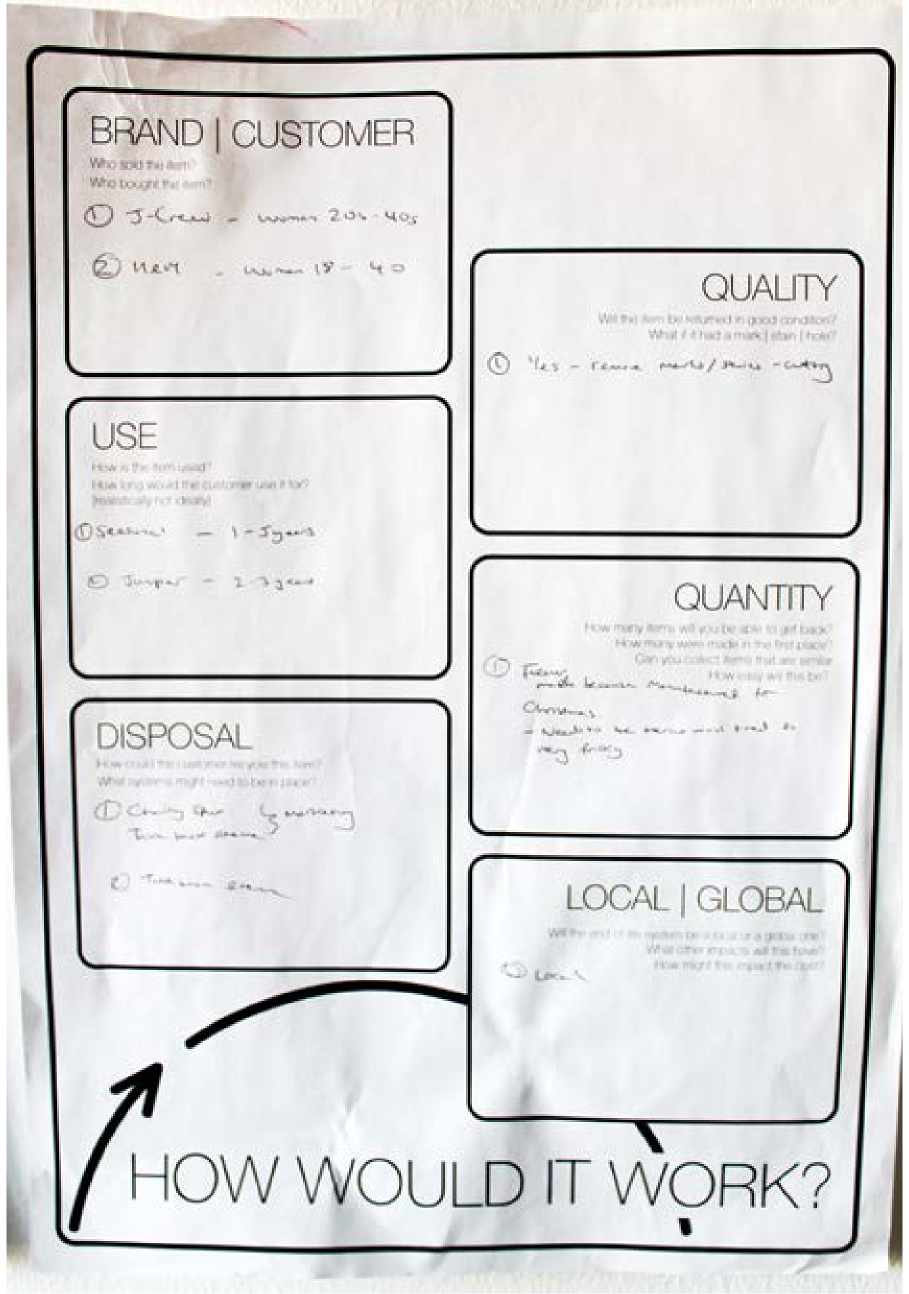
PRODUCT

100% WOOL SOCKS AND HAT

HAS TO BE NATURAL like Wool & The Gang

+ ? ... OTHER SOURCES

BIODEGRADABLE ETIQUETTE



BRAND | CUSTOMER
Who sold the item?
Who bought the item?
① J-Crew - Women 20s - 40s
② H&M - Women 18 - 40

QUALITY
Will the item be returned in good condition?
What if it had a mark | stain | hole?
① Yes - remove marks / stains - cutting

USE
How is the item used?
How long would the customer use it for?
(realistically not ideally)
① Seasonal - 1-3 years
② Jumper - 2-3 years

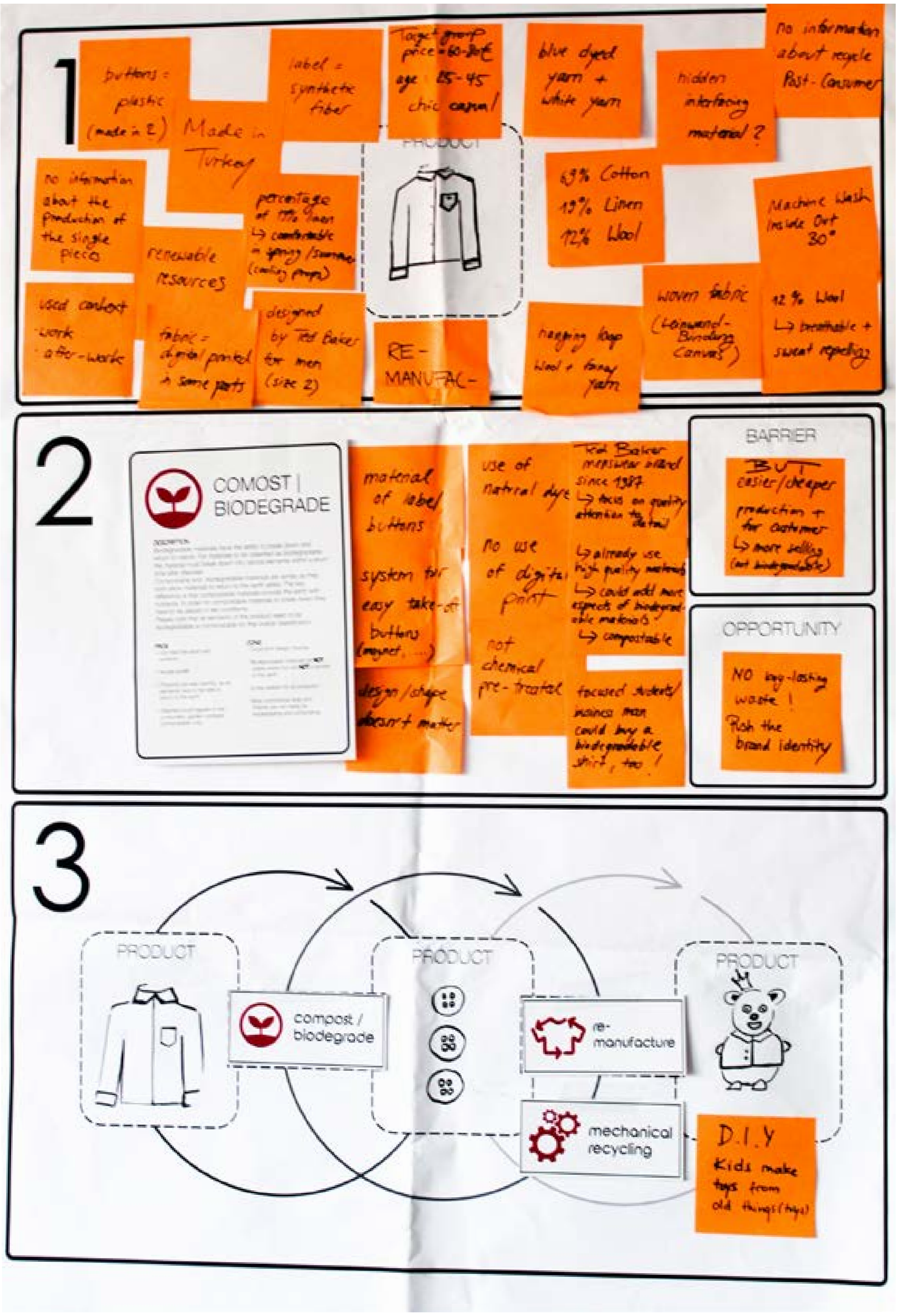
QUANTITY
How many items will you be able to get back?
How many were made in the first place?
Can you collect items that are similar
How easy will this be?
① Festive made between November to Christmas
- Needs to be [illegible] to very [illegible]

DISPOSAL
How could the customer recycle this item?
What systems might need to be in place?
① Charity shop [illegible] Take back scheme
② Take back scheme

LOCAL | GLOBAL
Will the end of life system be a local or a global one?
What other impacts will this have?
How might this impact the cycle?
① Local

HOW WOULD IT WORK?

14.6.3 WORKSHOP 3



1

buttons = plastic (made in 2)

Made in Turkey

label = synthetic fiber

Target group price = 60-80€ age 25-45 chic casual

blue dyed yarn + white yarn

hidden interfacing material ?

no information about recycle Post-Consumer

no information about the production of the single pieces

renewable resources

percentage of 17% linen ↳ comfortable in spring / summer (cooling props)

PRODUCT

69% Cotton 19% Linen 12% Wool

Machine wash inside out 30°

used context · work · after-work

fabric = digital printed in some parts

designed by Ted Baker for men (size 2)

RE-MANUFAC-

hanging loop wool + fancy yarn

woven fabric (Leinwand-Bindung Canvas)

12 % Wool ↳ breathable + sweat repelling

2

COMOST | BIODEGRADE

material of label buttons

system for easy take-off buttons (magnet, ...)

design / shape doesn't matter

use of natural dye

no use of digital print

not chemical pre-treated

Ted Baker menswear brand since 1987 ↳ focus on quality attention to detail

↳ already use high quality materials ↳ could add more aspects of biodegradable materials ↳ compostable

focused students / business man could buy a biodegradable shirt, too !

BARRIER

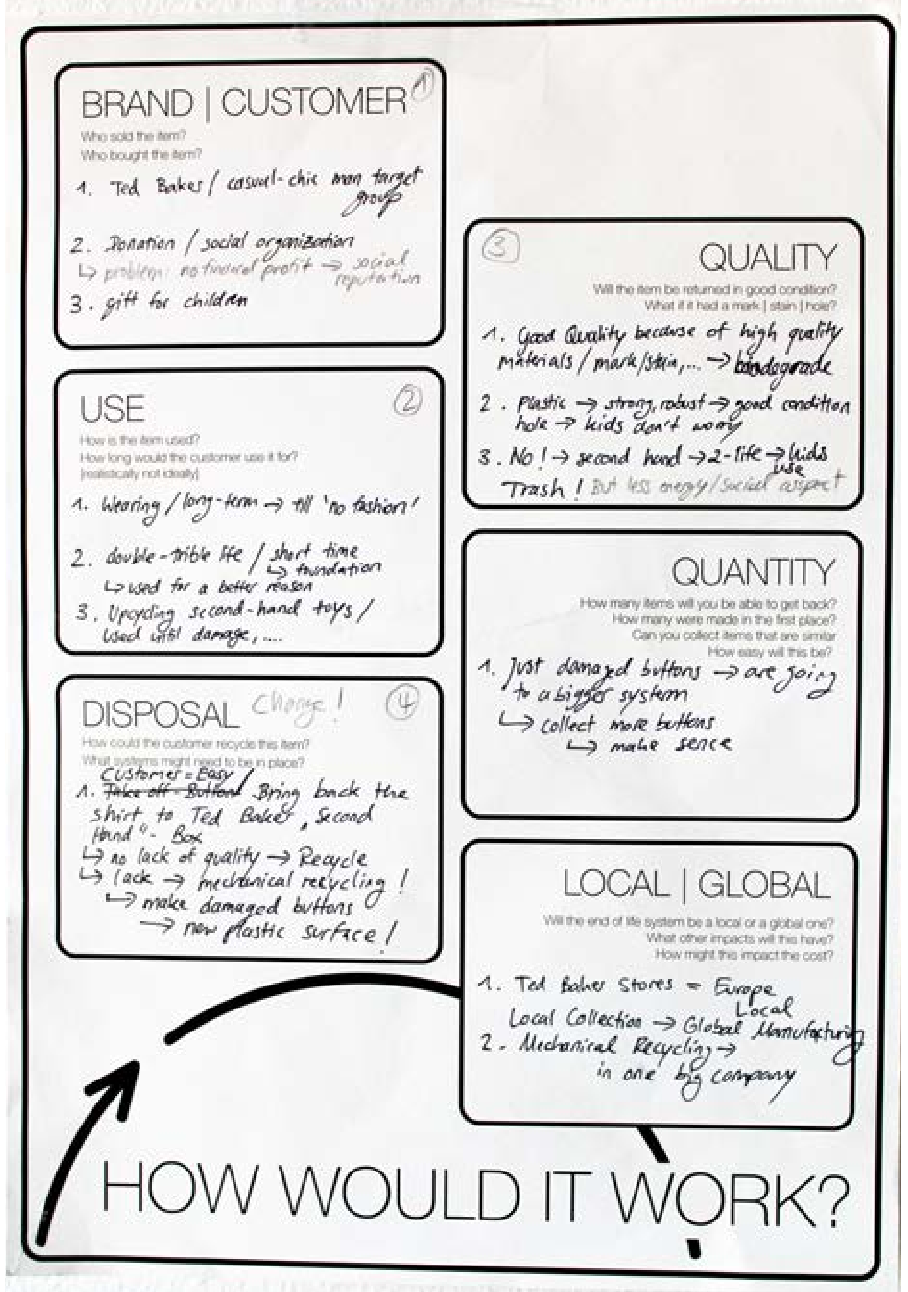
BUT easier/cheaper production + for customer ↳ more selling (not biodegradable)

OPPORTUNITY

NO long-lasting waste ! Push the brand identity

3

D.I.Y Kids make toys from old things (toys)



BRAND | CUSTOMER ①

Who sold the item?
Who bought the item?

1. Ted Baker / casual-chic man target group
2. Donation / social organization
↳ problem: no financial profit → social reputation
3. gift for children

USE ②

How is the item used?
How long would the customer use it for?
(realistically not ideally)

1. Wearing / long-term → till 'no fashion'
2. double-trible life / short time ↳ foundation
↳ used for a better reason
3. Upcycling second-hand toys / used until damage, ...

DISPOSAL Change ! ④

How could the customer recycle this item?
What systems might need to be in place?

1. ~~Take off Button~~ Customer = Easy / Bring back the shirt to Ted Baker, Second Hand "- Box
↳ no lack of quality → Recycle
↳ lack → mechanical recycling !
↳ make damaged buttons
→ new plastic surface !

③ QUALITY

Will the item be returned in good condition?
What if it had a mark | stain | hole?

1. Good Quality because of high quality materials / mark/stain, ... → biodegrade
2. Plastic → strong, robust → good condition
hole → kids don't worry
3. No ! → second hand → 2-life → kids use
Trash ! But less energy / social aspect

QUANTITY

How many items will you be able to get back?
How many were made in the first place?
Can you collect items that are similar
How easy will this be?

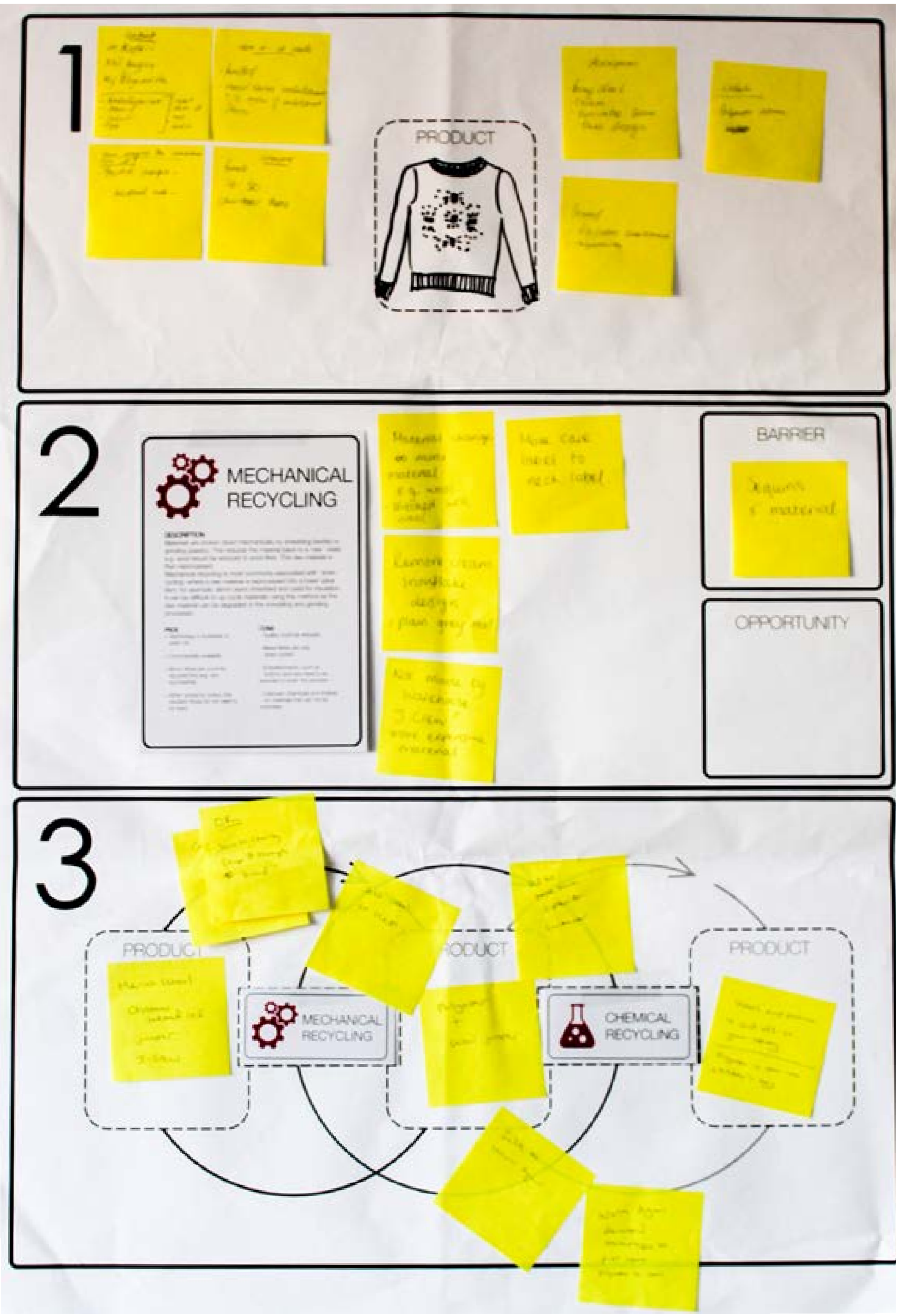
1. Just damaged buttons → are going to a bigger system
↳ collect more buttons
↳ make sence

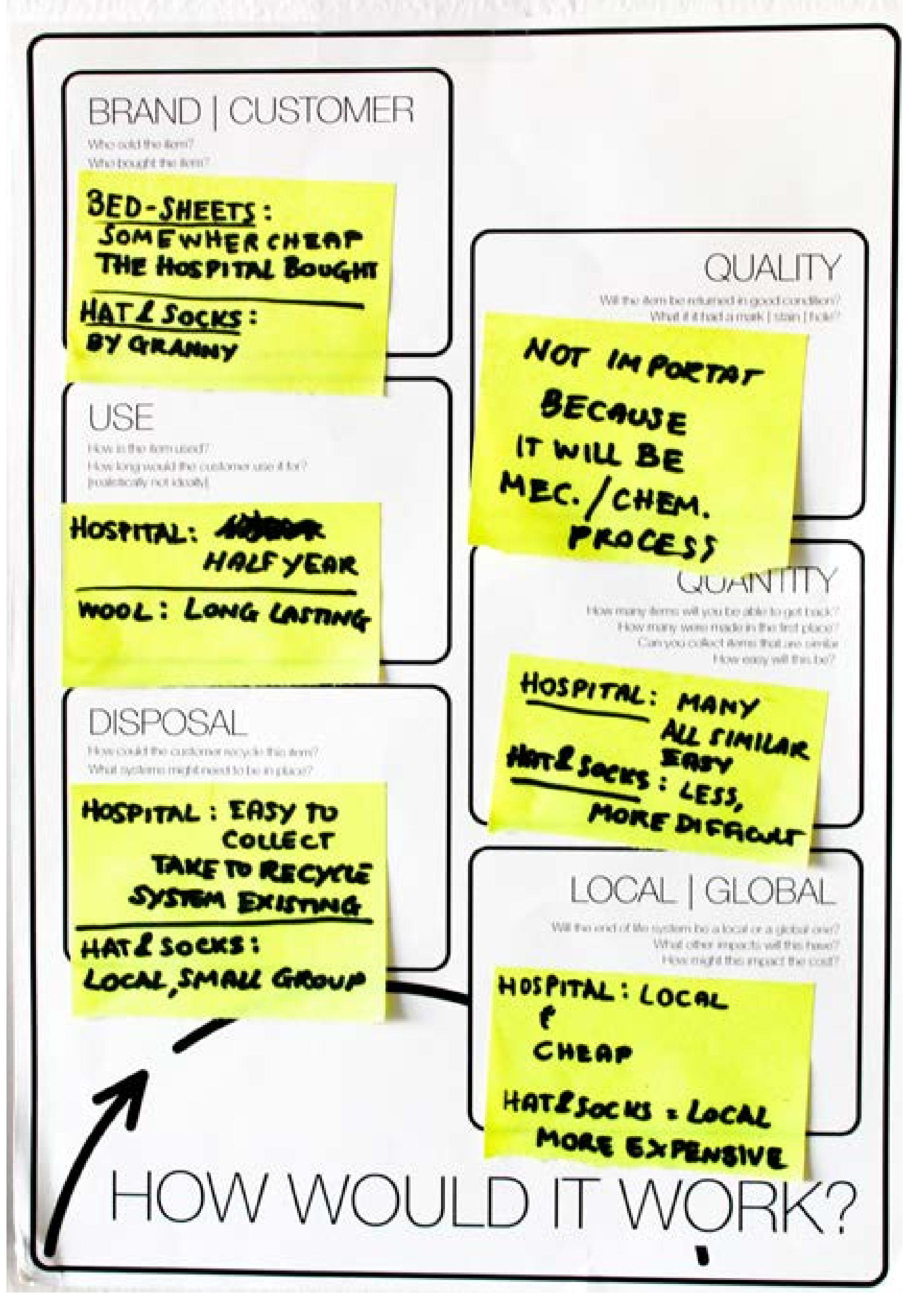
LOCAL | GLOBAL

Will the end of life system be a local or a global one?
What other impacts will this have?
How might this impact the cost?

1. Ted Baker Stores = Europe
Local Collection → Global Local Manufacturing
2. Mechanical Recycling → in one big company

HOW WOULD IT WORK?


1
PRODUCT
2
MECHANICAL RECYCLING
BARRIER
OPPORTUNITY
3
PRODUCT
MECHANICAL RECYCLING
PRODUCT
CHEMICAL RECYCLING
PRODUCT


BRAND | CUSTOMER
Who sold the item?
Who bought the item?
BED-SHEETS: SOMEWHER CHEAP THE HOSPITAL BOUGHT
HAT & SOCKS: BY GRANNY
USE
How is the item used?
How long would the customer use it for?
(realistically not ideally)
HOSPITAL: HALF YEAR
WOOL: LONG LASTING
DISPOSAL
How could the customer recycle this item?
What systems might need to be in place?
HOSPITAL: EASY TO COLLECT TAKE TO RECYCLE SYSTEM EXISTING
HAT & SOCKS: LOCAL, SMALL GROUP
QUALITY
Will the item be returned in good condition?
What if it had a mark | stain | hole?
NOT IMPORTAT BECAUSE IT WILL BE MEC./CHEM. PROCESS
QUANTITY
How many items will you be able to get back?
How many were made in the first place?
Can you collect items that are similar
How easy will this be?
HOSPITAL: MANY ALL SIMILAR EASY
HAT & SOCKS: LESS, MORE DIFFICULT
LOCAL | GLOBAL
Will the end of life system be a local or a global one?
What other impacts will this have?
How might this impact the cost?
HOSPITAL: LOCAL & CHEAP
HAT & SOCKS = LOCAL MORE EXPENSIVE
HOW WOULD IT WORK?

14.7 ANNOTATED PORTFOLIO

10 DESIGN AND TESTING IN PRACTICE

Designer

Researcher

Engineer

10.1 PRACTICE CONTEXT

The practice described at the intersessions in this document (Practice 0-9) explore the research ideas which led to the Design for Cascading Recycled Textiles framework (Chapter 9). In order to test this framework a larger-scale experiment was conducted in collaboration with industry partners. The experiment itself would involve sourcing acrylic-mix recycled fibres to be blended and spun into yarns suitable for a knitted garment application. This would be followed by designing and industrial production of proof-of-concept prototype jumpers. Finally, knitted swatches of the yarns would be sent to both hand and automated sorters to establish if the design of the materials had successfully increased in value at the recycling stage.

First, recycled acrylic fibre needed to be obtained. Unlike Practice 0 where sorting, cleaning and pulling were conducted by the researcher, the recycled fibre here was sourced directly from the recycling industry to ensure an accurate representation of the fibres available. Second, a yarn spinner was required to advise on and conduct the blending, carding and spinning of the fibres Third, a knitting manufacturer produced swatches and sample prototypes. These three stages followed the recycling system as highlighted in Figure X.

Designer directed by available materials

Collaboration

Figure X. A simplified Recycling system diagram highlighting the elements covered by the practice experiment.

Once the active experimentation had taken place, the knitted materials were sent to a hand and automated sorter for testing. The experiment aimed to move the resulting knitted materials from the lowest (100% acrylic) sorting category into a higher value category, such as 30% or 50% wool. The two sorters would process the swatches and the resulting sorting categories would indicate if the material had increased in recycling value. Because Hasnain Lilinai's interview (Appendix X) and the Fibersort testing results (Circle Economy, 2019) contributed to the generic sorting grades within the framework both these companies were asked to test the final materials.

Figure X. Women's Knit & Jersey Trend Concepts A/W 21/22: Conscious Clarity- Action points, (Casey, 2020b)

Figure X. Market research comparing wool and acrylic blended knitwear from a range of brands.

As highlighted in WGSN's report, 'Knitwear: Core Item Updates A/W 21/22', the scoping also identified the 'roll neck' silhouette as a key core shape in the A/W 20/21 collections of most brands. WGSN's update suggestions for this shape directly informed the creative design brief in which over-sized silhouettes, deep rib cuffs and split-seam details were included (see circled key words in Figure X).

Design Brief

Figure X. The Roll Neck - WGSN Knitwear: Core Item Updates A/W 21/22, (Casey, 2020a)

Beyond the shape and update features, the yarn blend also has to be designed. Returning to WGSN's 'Conscious Clarity' trend report, in combination with the researcher's own scoping also highlighted a trend for soft tactile yarns with a 'blurred' aesthetic. In particular, wool content in a mid-gauge yarn was a key focus of the WGSN trend (See Figure X).

Figure X. WGSN Women's Knit & Jersey Trend Concepts A/W 21/22: Conscious Clarity – Soft Blurred, (Casey, 2020b)

To summarise this trend/market research, a mood board was created bringing together inspirational images as a focus for the creative design (see Figure X). From this, the final design and specification was created ready for the yarns to be developed (see Figure X).

Figure X. Inspirational mood board created to summarise the design research for the direction of the project.

Figure X. Final Design specification

10.3 DESIGNING & MAKING THE YARNS

Once a design brief had been created, the yarns could then be designed and developed. Prior to sourcing recycled fibre, a collaboration needed to be agreed with a spinner to spin yarns using both recycled content and from synthetic materials. A range of spinning companies were approached that were willing but ultimately unable to help with the research. Barriers that were cited included: size, time, cost and contamination. For example, one company explained that the size of the project was too small; another wasn't able to spare the time to work on the project outside of its current production; a third costed the project and at the scale required the costs exceeded the researchers funding and finally many companies considered the potential contamination of synthetic fibre to their primarily wool production too great a risk.

Collaboration

Barriers to collaboration

10.2 THE CREATIVE DESIGN BRIEF

To test the Design for Cascading Recycled Textiles framework a specific brief needed to be created. Unlike the previous practice experiments which were purposely left open-ended, this final experiment needed to have a specific design direction. The criteria of the framework provided a basis for the brief. These were as follows:

- The use of recycled acrylic fibre as the base material
- A minim of 30% wool should form the final blend
- A yarn is to be produced suitable for a knitted garment

Research brief

In addition to the framework's recycling and cascading conditions, a creative design brief was formed to provide direction for the performance, aesthetics and cost aspects. Using the researcher's own tacit knowledge of the industry design process, market, trend and inspirational research was undertaken followed by a concept design (Sinclair, 2014).

Creative design brief

TREND, MARKET AND INSPIRATION RESEARCH

Trend and market research were conducted both online and by visiting a number of different types of fashion retailers. To start the process, trend forecasting website, WGSN, was visited and the AW21/22 trend concept 'conscious clarity' was chosen as the start of the inspiration (See Figure X). This highlighted the priority of sustainability into the design process alongside simplified silhouettes and timeless design. This also fitted the research ambition to produce a proof-of-concept garment that focused on the textile material rather than on creating a bold fashion shape or pattern. This type of design, therefore, could be categorised as a 'core' product type; a classic garment found every year in a brand's collection alongside the faster-changing trend-led pieces.

Industry methods

Research methods

A scoping exercise to assess the acrylic-wool market was undertaken across a range of retailers to complement the more trend-focused inspiration. A combination of online and physical research placed particular focus on the composition of yarns used in knitwear. Knitwear containing acrylic was found across a range of brands and sold at a variety of price points. Where blended with wool, the wool content varied, and in general, it was found that the higher the wool content, the higher the price. It was also noted that the high wool-content garments tended to be classic design shapes. However, wool content did not necessarily dictate the price level, since there are other factors at play such as manufacturing quality and the design or lifestyle attributes of individual brands. A cross section of the scoping exercise can be seen in Figure X.

Industry methods

However, an agreement was finally settled with a small commission spinner using a woollen system to produce ring-spun yarns. Previously, multiple visits to this facility had taken place, and at one of these visits the researcher's test experiment, Practice 7, had been conducted. The research was only able to take place if certain conditions were met, namely complying with the MOQs of 50Kg per yarn (significantly smaller than others that had been approached) and obtaining seam-cleaned acrylic fibre to reduce the contamination during production. The spinner explained that cleaning was a vital step for them in the recycling system because the strong synthetics threads often used in the construction of knitwear causes breakages in the spinning process. Thus, fibres are released into the air which in turn could contaminate other production. Therefore, the next step was to source cleaned recycled acrylic fibre.

Manufacturing methods

Engineers conditions

Cleaning step is vital

10.3.1 SOURCING THE RECYCLED ACRYLIC FIBRE

It had been assumed by the researcher that recycled acrylic, seam cleaned, sorted by colour and pulled back to fibre, would be easy to obtain While waste acrylic knitwear is an abundant resource in Europe, finding this waste source that was both colour-sorted and recycled back to fibre proved difficult. This was because acrylic knits in Europe usually flow into mixed colour recycling streams for non-woven materials. Furthermore, many of the European companies able to supply the required fibre could only do so with MOQs of a scale beyond the budget of this research.

Research Challenges

A working relationship with an Italian recycling company had been established during Practice 1. As a favour, this company agreed to sell and ship a small quantity of recycled acrylic fibre to the spinner in Yorkshire. The conversation and interview with the Italian recycling company regarding the sourcing of this material led to insights about the sorting system (see Appendix X). As they primarily recycled wool/acrylic blends rather than the desired 100% acrylic, the fibre was only available in navy and black. As with all mechanically recycled fibre and in line with the interviews conducted with the Italian recycler (see also Section X, page X and Appendix X, page X) and the composition of the '100% acrylic' purchased could in fact contain a small percentages of other fibres.

Design Relationships

Research Relationships

10.3.2 DESIGNING THE YARNS

Once the challenges of obtaining seam-cleaned acrylic fibre had been overcome a formal meeting was set up to discuss the yarn design. As the company was small all the research was conducted with the owner who has a vast experience of working in the industry and on the factory floor. This not only gave him the experience to problem-solve but as the owner, he also

Opportunities for Collaboration

had the power to make quick decisions. For the remainder of the discussion he will be referred to as the engineer.

The Italian company providing the acrylic, had sent samples of two different qualities of fibre and these were brought to the spinner to assess. The first fibre sample fibre had been pulled to create a better-quality fibre however as this has been pulled more thoroughly the fibre length was reduced. The second had been 'worked/pulled less' and therefore was expected to be of lower quality but had longer fibre length. The first sample was singled out as most effective for the woollen spinning method the company employed, and this sample fibre was then used to create mini test blend pads. Rather than create these pads using a test machine (as in Practice 7), a quicker method using hand combining brushes was used to explore many ideas in a short time frame.

Two physical meetings were conducted. For the sake of clarity, the meetings have been described by breaking down the activities into four stages: discussion, exploration, blend testing and design confirmation. While the practice is presented in an obvious chronological order, many of the stages overlapped or happened in parallel to one another. Conversations, for example, were often half finished and returned to at another stage in the same session.

STAGE ONE – DISCUSSION

The meeting started with the company owner in his office and the conditions of the research project were established, namely, to use the recycled acrylic as a base fibre, blending with a minimum of 30% wool and spinning for a knitted application. In response, the engineer laid out his own conditions. For example, based on previous experience he was only prepared to produce a yarn with up to 50% recycled acrylic content. This was to ensure ease of manufacture of and avoid problems that could lead to a lower yield and higher costs. A further condition relating to the use of shorter recycled fibres meant than there was a limit to how fine the yarns could be. Clearly, a significant amount of co-operation and communication to balance the interests of both parties was needed.

Research brief

Manufacturing requirements

Communication

These conditions led to some discussion. The designer-researcher explained that in a previous test (Practice 0) 70% recycled content had been used but in this case the yield had been reduced with more wastage from the process. The engineer was surprised but insisted, based on his knowledge, that a 50% recycled acrylic maximum would be beneficial for the manufacture and final product. This was then agreed.

Manufacturing requirements

Further discussion also ensued around the minimum thickness of the yarns. An example yarn was brought into the room to illustrate the engineer's technical explanations. He suggested processing the recycled fibres for a knitted applicated to 2/8Nm yarn count (Figure X), adding that creating a finer yarn could cause complications in the manufacture. This in turn could affect the cost. If a finer yarn was required, the engineer explained, the blend would have to be adapted reducing the recycled content. In the end, the minimum yarn count (2/8Nm) met the creative brief for a mid-gauge yarn. These initial conversations about the brief and manufacturability were vital to lay the groundwork for the next three stages.

Designer Priority
Yarn count

Collaboration

Figure X. Example yarn brought into the room for context

STAGE TWO – EXPLORATION

Figure X. The fibres available for blending.

The next stage was to decide on a blend for the yarn. The 50% recycled acrylic had already been confirmed and the content of the other 50% was yet to be decided. One of the conditions of the research was to include 30% wool in the yarn, but this still left a range of wool options to consider. Wool is available in many different forms, for example, lamb's wool, merino wool and cashmere, and all of these could be used within the experiment. With the overarching aim of the research being to design for recycling value, the recycling system would equally accommodate other protein-based fibres such as yak, mohair or angora. The 30% wool content, therefore, could be comprised of a variety of combinations. However, given the constraint of large MOQs for purchasing most fibre types and colour ways, an experiment of this size was limited to those held in stock by the spinning company.

Designer/Researcher
Wool blend

Challenges

The remaining 20% of the blend could be made up of any material as long as the design did not negatively impact onward recyclability. During this decision-making process the merits of including man-made fibres were debated. The engineer was very knowledgeable about the origins of the different fibres, their performance/function and cost. For example, nylon was described as very strong and soft but could only be added in small quantities to this particular spinning process (woollens) because, as the engineer advised, it would cause problems during manufacturing. Polyester again was strong but had a harsher "squeaky" hand feel and, as the engineer explained, polyester is more prone to pilling in the final material. He also highlighted that unlike yarns for the warp in woven applications where synthetic content would be added for strength, for a knitted application this was not an issue. However, synthetic content is often added to yarns for knitwear because of their cost benefits, with polyester being the cheapest fibre available.

Designer Priority
Research Priority

Engineer Expertise

A further consideration made when selecting materials for blending was the impact they would have on the texture and hand-feel of the yarns. While the recycled acrylic fibres felt very soft in fibre form, as discovered in Practice 0 and 7, this softness disappears when spun into yarn. The engineer explained, however, that during the spinning process finer fibres (such as acrylic) are forced to the middle of the yarn and coarser fibres (such as wool) would be brought to the outside. The condition of blending 30% or more wool, therefore, would overcome some of these issues but any remaining part of the blend needed to be considered carefully. This level of expertise and collaboration was significantly helping to narrow the designer-researcher's final choices.

Designer Priority
Hand feel / texture

Technical expertise

Colour was another aesthetic consideration. Choosing colours to blend together at fibre level was more complex and entirely different to the design-researcher's previous experience in selecting colour palettes for textiles or a garment collection. The process of blending colour at yarn level is more akin to the painter's experience of blending paint. In order to explore how this worked the engineer suggested the conversation moved upstairs to the factory floor. Here, he showed a blend of fibres waiting to be carded and spun: mainly beige with streaks of deep brown, white, bright yellow and orange (Figure X) that would be used to create a uniform beige shade (Figure Y). This illustrated what the engineer had been trying to explain downstairs.

Aesthetics

Figure X. Fibre blend - beige, brown yellow and white - waiting to be processed

Figure X. Carding process combing the fibres ready for spinning.

It was during this time on the factory floor that the possibilities for blending expanded. Discussion ensued amongst the rattles of the machines about the priority of sustainability within the project Keen to know whether other recycled content would meet the research conditions, the engineer suggested some pre-consumer cashmere waste could be used. In earlier visits to this and other companies, the designer-researcher had been advised that using pre-consumer waste was not a viable option due to limited quantities of any single colour. This engineer's suggestion therefore pleasantly contradicted his previous reluctance to use anything but virgin materials. This meant that with the relatively small-scale (in industry terms) of the research project, using the pre-consumer waste would be possible.

Researcher priority
Recyclability

Engineer Collaboration

From his back-storage room the engineer produced a box of pink and brown 'roving' cashmere waste. This type of waste is the product of the roving stage that occurs after carding and before spinning. Although previously considered to be too costly, the engineer suggested this might be used in a small quantity in a blend to improve the hand feel. Using the waste cashmere was thus a mutually beneficial proposition. While using a waste product cut the cost of cashmere content by a third for the designer-researcher, for the engineer, it was making good use of waste that was too small in quantity for a production run of its own. The engineer was quick to point out, however, that if it was to be used as a blend for this research, repeatability might be an issue. While the brown could be easily replicated by taking lighter coloured cashmere waste and overdying it, this would not be an option with the lighter shade of pink.

Designer priority
Hand feel

Engineer Collaboration

Engineer priority
Repeatability

Out of this exploration with the engineer and the variety of blending options discussed, the designer-researcher concluded that a small range of yarns should be produced and compared to establish best practice. At this stage it was thought that three different yarn blends would provide sufficient comparison. A final discussion regarding the cost of the resulting yarns verses the aims of the experiment was not easy to resolve. Given the designer-researcher's aim was to create a wool blend yarn suitable for the mass market the experiment's relatively small production size meant it would not be comparable. While the research would not be able to draw any formal conclusions on cost it was concluded that the range of yarns proposed for the research should be designed to represent the different market levels (standard to luxury). This would ensure that cost aspect of designing was not completely removed from the discussion.

Researcher Priority
comparison

STAGE THREE – BLEND TESTING

BLEND 1

The third stage of the experiment was conducted in the testing room. This held the small-scale carding machine which had been used as part of Practice 7. On this occasion hand carding brushes were used to simulate the process of combining fibres (Figure X). The exact amount of fibre to be blended was calculated on an old set of miniature scales (Figure X). The process created a small blended fibre pad which could be mock spun in order to visualise the yarn (Figure X).

Figure X. Scales used to weigh out the fibres for a small blend tes

Figure X. Hand carding brush used to comb the fibres and blend them together

The blend testing started simply and built up to the more complex blends. The first blend was comprised of the agreed 50% recycled acrylic and minimum 30% wool. The remaining 20% would consist of a cheaper man-made fibre. This represented the most standard blend type within the conditions of the test. When designing the colour of the yarn, the engineer recommended extremely bright and more contrasting colours to produce a more dramatic final yarn. From the available stock colours, the designer researcher selected two bright shades, a blue and a turquoise to complement the navy acrylic. Without any samples of synthetic fibre in stock, black wool was used as a substitute. The final synthetic content would be decided later in the process. The result of using brightly coloured wool yarns highlighted their coarser textured appearance against the finer acrylic. The result met the creative 'soft blurred' brief and the colour and composition was confirmed as the first yarn blend.

Engineer expertise

Design Priority
Colour / Texture

Figure X. Fibres selected for the first blending test

BLEND 2

The second blending test was conducted in response to the market research findings. During one of the retail visits it had been noted that many of the knits contained a percentage of luxury fibres. The luxury content of these jumpers were marketed with labels such as 'cashmere mix' or 'mohair blend'. The long fibre quality of mohair, in particular, was used by brands to create a more dramatic textured appearance. As the engineer explained, mohair would be difficult to obtain in small quantities, although in this instance he was able to offer a mohair blend (mohair, cashmere and wool) leftover from a larger order. This was formed of tropical colours (honey bird and lemon shades) to which some stock white mohair could be added to make up the total 'luxury' content required for the final yarn In combination, these colours were not dissimilar to the Blend 1 and would provide a good visual comparison

Designer Priority Texture

Engineer Priority Cost

To fulfil the aim of creating a small range of yarns to compare, the designer-researcher decided to increase the wool content of Blend 2 from 30% to 50%. Without the addition of any synthetic material, Blend 2, therefore, would represent a more luxury yarn in line with the market research.

Researcher Priority Comparison / Range

Figure X. Second blending test fibre combinations

BLEND 3

As the blending tests progressed it was clear the engineer had a preference for luxury fibres to make, what he described as, 'beautiful' or 'quality' yarns. It was partly for this reason that waste cashmere (as previously described, page X) was suggested to be used for the research. In addition to cashmere, silk was also advocated. The engineer explained that using silk would create a smooth feel to the fibres. And if a mix of three or four colours were incorporated some of silk would form multi-coloured neps in the final yarn. To demonstrate this, the engineer selected a range of colours (green, red and blue) and started blending these with the pink cashmere and navy acrylic. The designer-researcher was concerned about this suggestion for two reasons. First, silk was not strictly suitable for the wool recycling process she was designing for. Second, the colours were not harmonious and her tacit knowledge as designer meant she took an instant dislike to the combination. In addition, as a researcher she was concerned for the impact of the colour contamination for the future sorting and recycling processes. However, this form of quick experimentation was a useful tool for taking risks and so she stood back and waited for the result. Ironically, the resulting fibre had a distinct 'recycled' aesthetic. The combination of navy

Engineer Priority Luxury

Researcher Priority Recyclability

Designer Priority Design Brief

(also known as polyamide) was discussed. This was highlighted by the designer-researcher as a popular blending agent seen during the market research. Furthermore, in the recycling industry both nylon and polyester are known to be used when creating yarns in Prato. For onward recyclability, neither materials type was deemed problematic as both these types of fibres were most likely present in the recycled acrylic-mix fibre being used in the test.

Designer Priority Design Brief

Researcher Priority Recyclability

The engineer explained that the major differences between the two fibres were hand feel and cost. He brought out two examples of test yarns for comparison; one blended with a small amount of polyester and the other with a small amount of nylon. After studying the yarns, the designer-researcher established that there was only a small difference between the feel of yarns, the nylon being slightly softer. Yet, the cost was more dramatic; the nylon fibre was almost double that of the polyester.

Engineer expertise

Designer Priority Cost

Figure X. Commercial wool blends one with polyester and one with nylon

BLEND 4 & 5

During this discussion, the designer-researcher decided that it would be prudent to spin a 'control' yarn without any wool content for a direct comparison. In line with all the other blends this would contain the same 50% recycled acrylic but would be blended with 50% synthetic. At this point the engineer pointed out nylon could not be used in such high quantities in the woollen spinning process. Therefore, for the sake of consistency the use of nylon was discounted from the research Virgin acrylic was also put forward as an option. This was appealing as it would increase the acrylic content making the final yarns more mono material, but the researcher also had concerns from a sustainability standpoint and using this virgin material might encourage further a very harsh and chemical virgin production process. However, the MOQs for acrylic were significantly large to prohibit its use in the test. Thus, the decision was taken out of the designer-researcher's hands and polyester was confirmed for all blends requiring synthetic content. In the spirit of experimenting using recycled materials the engineer advised he was able to source a recycled polyester fibre produced from plastic bottles. The use of recycled polyester in this form is very commonplace within the mass market.

Researcher Priority Comparison

Engineer Expertise

Researcher Priority Recyclability / Sustainability

Barriers

Engineer Collaboration

Design Priority Market

The addition of the control yarn, which represented the most basic blend, lead the designer-researcher to reflect on how the yarns might be analysed. Solely from the perspective of composition the three blends and the control provided a good range to be compared. However, visual comparisons might be limited as the control yarn would only be comprised navy (recycled acrylic) and black (recycled polyester) rather than blending a number of shades (as in Blend 1, 2 and lesser extent 3) To overcome this barrier a repeat of Blend 1 was confirmed replacing the bright coloured wool with black to ensure a visually unbiased comparison could be made. This

Researcher Priority Comparisons

and pink created a sludgy purple base and mixed coloured neps looked like a more uniform colour contamination (Figure X).

Figure X. Third blend test with cashmere and silk

A second attempt was made to create a silk/cashmere blend. This time the brown cashmere waste was used and the designer-researcher requested permission to select a range of harmonious colours (grey and light blue) and the result was much more appealing. However, the researchers concern for onward recyclability was enough to drop this blend from the range. Additionally, she concluded that the inclusion of silk had not been seen during the market or trend research. In this specific instance, the blend was unsuitable.

Designer Priority colour

Researcher Priority Recyclability

Figure X. Blend test four with brown cashmere and blue/grey silk neps

A final version of Blend 3 was tested removing the silk content. The aims of the research were at the forefront of the designer-researchers mind during the selection process. She reflected on the composition of both Blend's 1 and 2 and how these represented standard (30% wool) and luxury (50% wool) approaches to blending. To produce a range of options, Blend 3 would therefore need to be designed halfway between the two. To achieve this Blend 3 used the composition structure of Blend 1 (50%, 30% 20%) but incorporated a small amount of luxury content more akin to Blend 2. The resulting composition was 50% recycled acrylic, 20% cashmere, 10% wool (forming the desired 30%) and 20% additional synthetic. Once again for the test black wool was used in lieu of the unavailable synthetic fibre.

Designer Priority markets

Researcher Priority Comparisons

The colours in this case were dictated mainly by the availability of fibres. For example, navy had been pre-chosen for the recycled acrylic; pre-consumer waste cashmere was provided in brown and small quantities of synthetic materials could only be obtained in black or white. Black had been selected for all the yarns to deepen rather than lighten the yarn shades. An exception was the 10% wool content, and this could be selected from range of stock colours. A 'slate' blue was chosen to compliment this dark colour range. This resulted in a deep but grungy blur of colour suitable for the brief.

Designer Priority Colour

Figure X. Fifth blend test and its components

STAGE FOUR – DESIGN CONFIRMATION

The final stage of the design process was to finalise all the blending decisions for production. This occurred both at the end of the first meeting and during a second meeting a few weeks later. The conversation focused on the type of synthetic that would be used in the blends. The discussion went back and forth between the different synthetic materials which could be used. Firstly, nylon

repeat of Blend 1 in an alternate colourway was confirmed as Blend 4 and the control yarn was confirmed as Blend 5. It was considered necessary by the designer than the original coloured blends remained in the range as this also might yield results in the comparisons of the materials.

Designer Priority Colour

BLEND 6

Finally, a sixth yarn was added to complete the range. This yarn was confirmed with a thicker yarn count (2/4.25Nm) which would be produced to establish if yarn count effected yarn quality, yield and manufacture. All the blends up until this point had been designed at the finest count the engineer was willing to manufacture when incorporating 50% recycled content (2/8Nm). Once again for a direct comparison a repeat of a previous blend was used (Blend1). Blend 6 was confirmed, and this finalised the six yarns to be produced.

Researcher Priority Comparisons

Engineer Priority Manufacturability

10.4 SIX BLENDS – SIX YARNS

Each of the six fibre blends were spun adhering to the spinning companies MOQ (50kg). The engineer advised that while 50kg of fibre would be used at the beginning of the process the yield (resulting amount of yarn) could be lower depending on the success of processing of each blend type. The total yarn produced for all six yarns was 286Kg. Table X summarises the designs of all six yarns. Once spun each yarn was sent to a knitting factory to be knitted into swatches and for prototype garments to be developed.

Engineer Expertise

Figures X-X, Snapshots of some of the spinning processes: Blended Fibre, Blended Fibre in the carding machine, Carding process, Laying the fibres, Roving, Winding

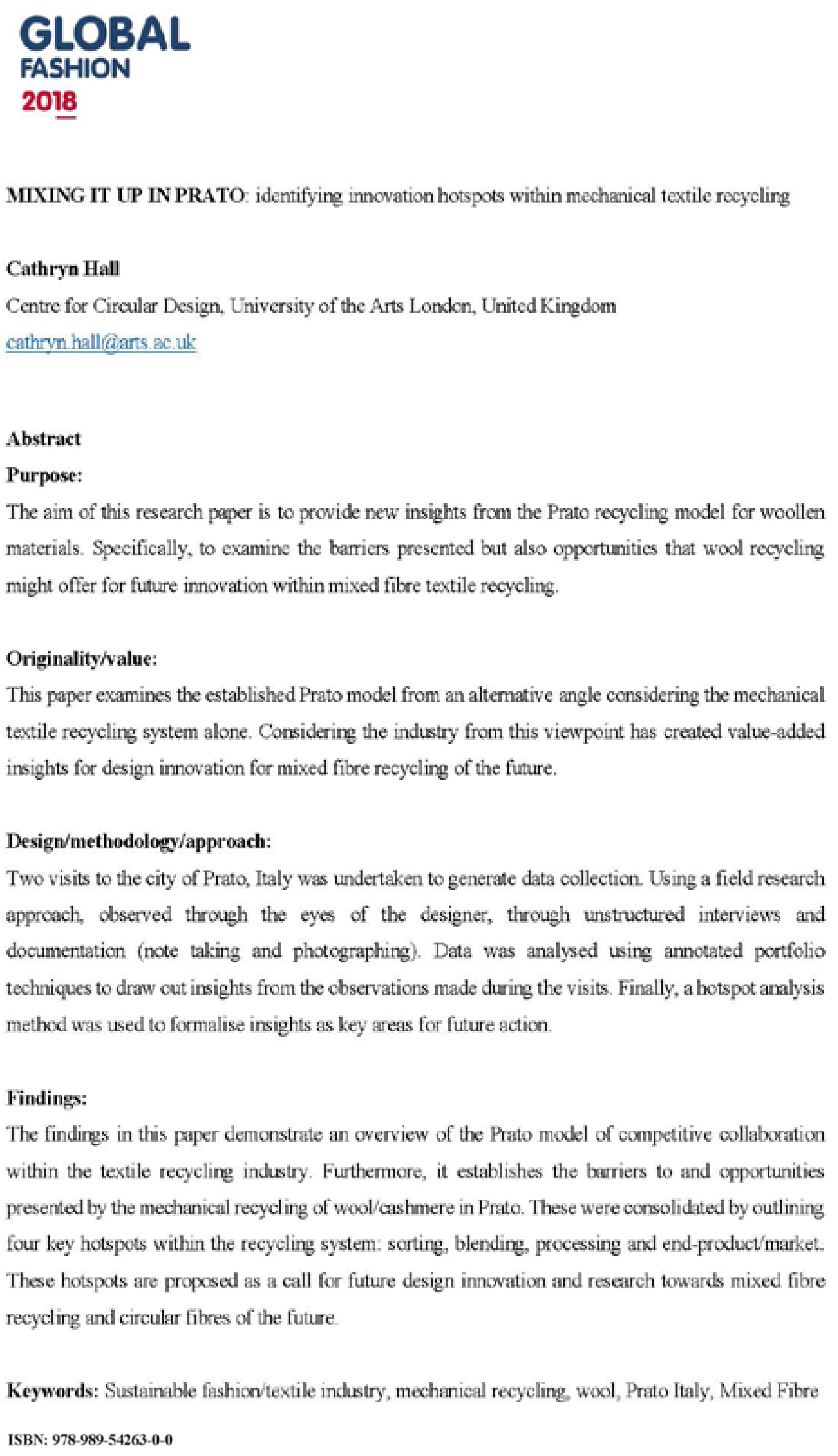
Figure X. Final six yarns

Figure X. Six Knitted swatches

Figure X. Prototype garment

14.8 PUBLISHED PAPERS

14.8.1 MIXING IT UP IN PRATO



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MIXING IT UP IN PRATO: identifying innovation hotspots within mechanical textile recycling

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Abstract

Purpose:

The aim of this research paper is to provide new insights from the Prato recycling model for woollen materials. Specifically, to examine the barriers presented but also opportunities that wool recycling might offer for future innovation within mixed fibre textile recycling.

Originality/value:

This paper examines the established Prato model from an alternative angle considering the mechanical textile recycling system alone. Considering the industry from this viewpoint has created value-added insights for design innovation for mixed fibre recycling of the future.

Design/methodology/approach:

Two visits to the city of Prato, Italy was undertaken to generate data collection. Using a field research approach, observed through the eyes of the designer, through unstructured interviews and documentation (note taking and photographing). Data was analysed using annotated portfolio techniques to draw out insights from the observations made during the visits. Finally, a hotspot analysis method was used to formalise insights as key areas for future action.

Findings:

The findings in this paper demonstrate an overview of the Prato model of competitive collaboration within the textile recycling industry. Furthermore, it establishes the barriers to and opportunities presented by the mechanical recycling of wool/cashmere in Prato. These were consolidated by outlining four key hotspots within the recycling system: sorting, blending, processing and end-product/market. These hotspots are proposed as a call for future design innovation and research towards mixed fibre recycling and circular fibres of the future.

Keywords: Sustainable fashion/textile industry, mechanical recycling, wool, Prato Italy, Mixed Fibre

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1 Introduction

The fashion/textile industry is causing catastrophic environmental impacts throughout all lifecycle stages (Fletcher and Grose, 2012), in particular at the end-of-life where less than 1% of our waste clothing is recycled back textile-to-textile (EMF, 2017). However, the industry's consistent use of blended yarns, increasingly desired for their function and price benefits (Turley *et al.*, 2009), and the resultant mixed fibres are problematic for developments in new technology, both chemical and traditional mechanical recycling (Mathews, 2015).

Over the last decade advancements in the field of textile recycling have evolved, yet mechanical recycling has been overlooked as calls for investment refer to chemical processes alone (Dahlbo *et al.*, 2016). The challenge now is how solutions to this growing issue can impact the industry at both a local and global level. Understanding the barriers to textile recycling can support the next generation in how we educate, train and employ this sector.

This paper explores the historic and current situation for mechanical textile recycling within the wool industry in Prato, Italy. Understanding the development, both positive and negative, of Prato's historic industrial model (Ottati, 2009) forms the backdrop for insights around innovation. Using a field research methodology (Burgess, 1982) the author visited a small selection of wool/cashmere recycling facilities with the aim of understanding their current and varying approaches. Through conversation, first-hand experience and designerly ways of exploring these industrial processes (Cross, 2007) data was generated for analysis.

The insights from this paper seek to demonstrate some of the principal opportunities and barriers faced by the textile recycling industry for wool, and in turn how this might affect the more challenging mixed fibre recycling. Furthermore, by creating an overview of the recycling system in Prato, this enabled the author to identify key 'hotspots' (Barthel *et al.*, 2015) for future potential innovation. This paper explores insights towards creating circular fibres (EMF, 2017) of the future within mechanical textile recycling.

2 Context

The continuing rise in global resource consumption has instigated a growing trend for increased fibre production. This gross over consumption of fibre and has caused a ripple effect of excessive textile waste in the global fashion industry (Mathews, 2015). This waste is increasingly low in quality, unable to be reused as clothing and holds little or depleted value as it filters into limited end markets (Dutch Clothing Mountain, 2017). Textile waste in this context is either 'post-consumer' or 'pre-consumer'. The former is defined here as any waste textiles including garments that have been used by the consumer, while the latter refers to the type of waste that does not reach the consumer such as factory waste clippings (Hawley, 2006).

The lack of textile to textile recycling globally can be attributed to a lack of technology and end market potential. However, it has been suggested with the right technologies and infrastructure recycling could increase to be in line with current rates of collection (Fibresort, 2017).

One of the biggest challenges for recycling technology today is the industry's consistent use of blended materials, used for their resultant functional properties and price benefits. Currently, there is limited research investigating the composition of our textile waste. Still, current available data gives us some understanding of the problem. A recent UK based exploration of clothing collected by The Salvation Army found that 36% of its sample was made up of two or more fibre components (Ward, Hewitt and Russell, 2013). This was supported by Dutch Clothing Mountain's 2017 report which generated similar data, finding 37% of their sample was blended textiles. Furthermore, this percentage could increase as 30% of the clothing were unidentifiable due to missing labels. Although both studies demonstrate mono-fibre textiles occupying the majority, blended textiles are still a growing issue that needs to be addressed. Finding a solution for waste mixed fibre textiles is prevalent as they continue to be problematic for both chemical and mechanical recycling technology.

2.1 Historical Context

Prato's historic textile industry dates back to the middle ages and today every stage of textile manufacture can be seen around the city (Mondadori, 2013, p. 14). The origins of wool recycling - or more specifically the invention of machinery to tear fibres from cloth – are attributed to Benjamin Law in Yorkshire, England in 1813 (Shell, 2014). These tearing machines, now known as pulling machines, appeared in Prato in 1850. Later carbonizing machines emerged, to separate wool from cotton fibres, meaning that Prato could be competitive with the northern Italian wool industries. By 1870 a centralised factory-based system had been introduced. This allowed for the development of mechanised wool carding and spinning, and enabled Prato to become an exclusive and specialised centre. Prato's carding method, allowing shorter wool fibres to be spun (virgin or reprocessed), is what distinguishes its famous woollen cloth (Museo del tessuto Edizioni, 2007).

During the first half of the twentieth century low-medium quality regenerated wools and carded fabrics were in high demand until the textiles industry was forced to adapt to post-war conditions. Larger factories struggled without the military textile demand and were dismantled to create smaller family-run enterprises and craft workshops, building a flexible industrial structure. At the same time, new synthetic materials were entering the market offering functional and cost-effective competition. Fast adaption saw Prato blending synthetics with regenerated wool to retain competitive business (Museo del tessuto Edizioni, 2007). Despite this, Prato remained famous for its carded woollen product, until the 'carded wool crisis' in the late eighties. This caused many factories to drop their traditional carded lines for higher quality worsted spinning, a technique which uses long virgin fibres for couture production. The trend for worsted fabrics has continued, fighting off competition from developing countries. Today, the mark of quality woollen product is synonymous with the 'made in Italy' label (Weibel-Orlando, 2012). Yet, as the success of worsted cloth has grown, the traditional carded manufacture has continued to fall into decline (Ottati, 2009).

2.2 Prato Model

The 'Prato Model', according to Magi and Ceccarelli (2002), is completely unique in that it is comprised of many small and medium enterprises. It is for this reason, Padovani (2017) asserts, that the model is based upon value added partnerships.

> The Prato system is based on the decentralization of production among a large number of small companies capable of adapting to specific design demands and able to produce short runs to tight delivery times. This model of collaborative competition provided the basis for the rise of luxury and bespoke manufacturing (Padovani, 2017, p. 144)

In addition, the industry's deep-rooted history over a changing landscape has produced an expert tacit knowledge. This has led to an 'innovation pipeline' between traditional processes and new products. It is the combination of the Prato model and the expertise of the industry that has allowed it to dominate the regenerated wool market (Padovani, 2017). However, as Ottati (2009) points out the Prato industry is in potential crisis with two contrasting views considered. Either Prato's successes lie in the past or it will be able to adapt to a future of globalisation.

More recently, the industry has joined forces, assisted by Prato Centre of Commerce, to promote the growing consumer interest in sustainability (Testa *et al.*, 2017). The creation of the 'Cardato Recycled' brand was created to boost the declining carded wool industry by creating a certification and unique selling point of the recycled cloth. There are strict requisites for any brands to display the 'Cardato Recycled' label. The materials must be made of at least 65% recycled content (clothing or factory waste), must be produced in the Prato district and brands must measure the environmental impacts of production (water, energy and CO^2 Levels) (Cardato, 2018).

3 Methods

The methodology undertaken for this research paper brings together a variety of data collection and analysis methods in its qualitative approach. Using traditional field research methods such as observation, unstructured interviews and documentary evidencing (Burgess, 1982) with 'designerly ways of knowing' (Cross, 2007) and tacit knowledge (Polanyi, 1958) has enabled data to be collected. Combined with a variety of analysis techniques such as annotated portfolio (Gaver and Bowers, 2012) and hotspot analysis (Barthel *et al.*, 2015) this facilitated the author to extract insights from Prato's wool recycling industry towards future increased mixed fibre textile recycling.

Across two field visits to the city of Prato four key factories, Companies A-D (see Table 1), were selected as a sample to provide a balanced framing of the developed wool recycling industry. This was supplemented by three additional companies E-G (see Table 2), affording a broader understanding of the opportunities and barriers within the field. While A-D were researched in far greater depth, Companies E-G provided additional insights that contributed significantly to the overall findings.

Observed through the eyes of the designer this method provided a foundation for future innovation in design (Suri, 2005). The author's tacit knowledge from working previously as a commercial knitwear designer ensured understanding of both the commercial and practical process. The importance of a second visit allowed the author to build relationships with experts, gain extended first-hand experience, and ensure thorough data collection meaning industrial processes, systems design, and recycling design practices could be fully explored. Consent for visits and was obtained from each participating company with the agreement that their details would be anonymised.

Analysis was primarily achieved using an annotated portfolio method (Gaver and Bowers, 2012, Sauerwein, Bakker and Balkenende, 2018) using photographs taken throughout the experience. This was accomplished by using the collected field notes, and memories of the experience to annotate the images. These annotations were organised into themes across all the factory visits and formalised into simplified tables (see below Table 1 and 2).

By building upon previously established recycling systems diagrams by WRAP (2012), meant visualising the specific processes for the wool recycling systems in Prato. Hotspot analysis was applied to bridge the gap between Prato insights and the wider textile recycling system. This method provided a more comprehensive understanding of impacts and therefore a prioritisation of future actions (Barthel *et al.*, 2015), which in this paper applies to complex mixed fibre recycling.

4 Discussion

The aim of this research paper was to establish key areas for innovation within mechanical recycling processes. The objectives included gaining an understanding of the Prato model and the industry's array of processes, then from this ascertain barriers and opportunities in wool recycling to offer innovations within mixed fibre textile recycling.

4.1 Diversities

As shown in Table 1, Companies A – D were selected for their individual approaches and to create a balanced framing. A variety of final products were seen to be produced: fibre, yarn, fabric or a combination, all of which ranged from high to lower market values. The balance of the sample range is further demonstrated by the assortment of 'input' or 'feedstock' and output materials across woven/knit, pre/post-consumer and mono/blended.

		COMPANY A	COMPANY B	COMPANY C	COMPANY D
END PRODUCT PERCEIVED QUALITY		HIGH	HIGH	HIGH/MEDIUM	MEDIUM/LOW
FIBRE TYPE INPUT		CASHMERE	WOOL	WOOL	WOOL / WOOL BLEND
FIBRE TYPE OUTPUT		CASHMERE / CASHMERE BLENDS	WOOL BLEND	WOOL	WOOL BLEND
END PRODUCT		YARN / FIBRE / KNITTED PRODUCT	WOVEN FABRIC	FIBRE ONLY	YARN
WASTE TYPE		KNIT	WOVEN	KNIT	KNIT / WOVEN
END MARKET		KNIT	WOVEN	WOVEN	WOVEN
WASTE: POST CONSUMER		X	X	X	X
WASTE: PRE CONSUMER			X (SMALL %)		X
OUTPUT YARN	MONO	X			
	BLEND	X	X	X (ONCE SOLD)	X

Table 1. *Simplified recycling system insights from companies A-D,* Source: Author

All stages in mechanical wool recycling (see Figure 1 below) were seen first-hand in the field. Through conducting this research not only the procedure, but the decisions and requirements at every stage, were clearly identified. This enabled the author to understand how these choices impacted future processes and final products. It was this overview which enabled insights for future design innovation.

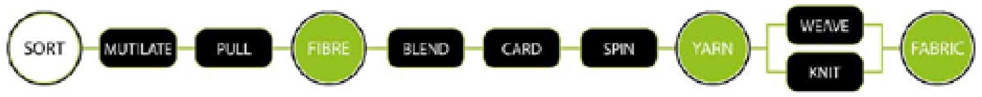

Figure 1. Simplified processes of recycling textiles, adapted from WRAP (2012), Source: Author

4.2 Collaboration

As previously described by Padovani (2017), the Prato model has been built from decentralisation and competitive collaboration. One of the main reasons the industry has been able to adapt. During the field visits the author witnessed how Companies D and E used the same processing facility to transform fibre to yarn by giving a tour of the same workshop. This partnership between the two businesses had developed between the owners which was later found to be based on a deeper friendship established over generations.

	COMPANY E	COMPANY F	COMPANY G
END PRODUCT	YARN/FABRIC	FABRIC	YARN
RECYCLED FIBRE	WOOL	WOOL	COTTON WOOL
PRODUCTION	ON SITE	OFF SITE	OFF SITE

Table 2. *Simplified recycling system insights from companies E-G*, Source: Author

Quickly, it was recognised that all companies in the sample had close relationships with the other businesses, although not always as deep rooted as the previous example. Much like a small village, everyone knew everybody else. Each company had their own segment of the recycled wool market. Company C, for example, specialised in sorting knitted post-consumer waste which was outsourced to be pulled into fibre and returned for quality control. The final product, the fibre, could then be sold for processing into yarn.

In contrast, Company A demonstrated collaboration in reverse, 'insourcing' rather than outsourcing. By allowing second hand traders access to the incoming bales of cashmere (before colour sorting) they were able to search for the 'diamonds'. Diamonds referred to here comes from Hawley's (2006) categorisation of textile waste sorting, considered to be rare finds, often designer items of high value to the vintage or second-hand market. It is this interconnected competitive collaboration amongst smaller specialist companies which has allowed the Prato model to flourish.

4.3 Sorting

The sorting process embedded within the recycling system stretches far beyond the selecting of 'diamonds'. Companies A-D all emphasised the importance of sorting on the quality of the end material. However, it was recognised that sometimes companies bought in pre-sorted clothing waste, processed in special economic zones such as India, connecting Prato to the global recycling industry. Nevertheless, others prided themselves on training specialist employees who sorted mixed bales by colour and shade. Company C took this one stage further separating shades into 'ordinary' (chunky guage knits) and 'fine' (fine guage knits) to produce, as they claimed, a higher quality resultant fibre.

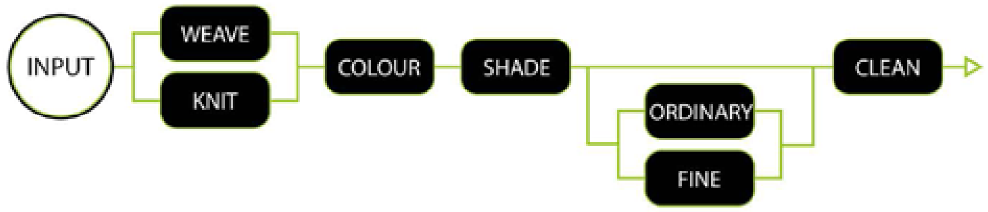

Figure 2. Simplified processes of sorting waste textiles, Source: Author

The sorting stage is one of the most costly processes within textile recycling. Although this hand process was a unique selling point for companies such as B, it was accepted that this labour-intensive method in a high wage country strained the industry economically. Nonetheless, one of the largest barriers to successful recycling is colour contamination, the result of inefficient sorting. Contamination itself presents in the form of 'neps'; contrasting coloured specs which stand out and, in some cases, protrude from the yarn or fabric surface. This could be exploited as a design feature, often requested by designers for fashion clothing. However, it is still problematic when a mono-colour is required. It was understood that mechanically recycled yarns can never be completely solid. Time and effort is often taken creating melange effects from virgin materials, which without any effort is a natural quality of recycled yarn that ought to be taken advantage of. However, stock colour cards exhibited a wide range of colours in melange as well as close to sold shades (Figure 3).

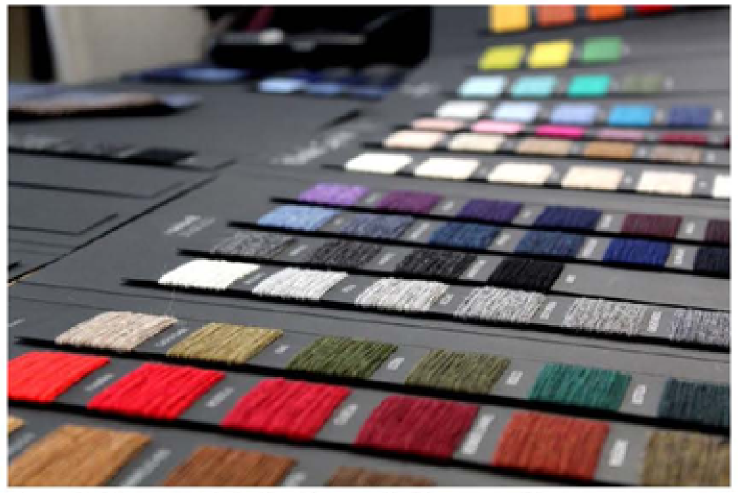

Figure 3. Company B stock colour cards, Source: Author

4.4 Overdyeing

Due to the nature of the process, single colour materials were valued over multi-colour items. While generally avoided, all companies used overdyeing as a solution for these multi-coloured materials. Company D did this to tonal patterned garments to create uniform shades, whereas true multi-colours could only be dyed black to ensure complete coverage. Another reason to overdye was to obtain a specific colour shade which otherwise could not be produced. The availability of feedstock was proved to be fundamental in producing a material's final colour. If a client required a specific shade, a combination of coloured fibre would be blended to produce its exact colour, as seen in Figure 4.

However, if one element of a colour blend is not readily available, overdyeing a similar shade provides a solution to deliver the overall blend.

Figure 4. Company B shade blending for client colour development, Source: Author

4.5 Input and Output

Across companies A-D perceived quality of feedstock materials was found to be reflected in the quality of output material. This follows that the purer the fibre to be recycled, the higher quality it is considered to have i.e. mono materiality. The Prato recycling system is therefore centred around sorting and finding the highest quality fibre for recycling, in this case wool. Even Company D, whose input material was lower value wool blended product, was sorted according to the quantity of wool content.

In contrast, as Table 1 demonstrates, across the four key companies, each used a different combination of input to output. A and C exclusively was found to use knitted waste, whereas B used woven waste. Contradicting information was supplied in terms of what feedstock produced the best quality result. This was attributed to the bias of each company to promote themselves. However, all companies agreed that knitted feedstocks were easier to pull, generating longer fibres. Yet this was not reflected in the authors analysis of the perceived quality of the end product. For example, Company B produced a quality product from a woven waste feedstock. The greatest insights in this area came from Company D who demonstrated that mixing a combination of woven, knitted, pre/post-consumer waste would balance out the qualities to create a mid-value end batch. The main attribute affecting the perceived quality of the material output was the percentage of the wool fibre.

A common misconception, one that was made by the author, is that Prato predominantly uses pre-consumer waste as a feedstock. It was found that pre-consumer wool recycling formed a small section of the overall industry. Although pre-consumer waste was utilised by other businesses, as clarified by C it was too expensive for them to warrant using. The only active example of pre-consumer waste recycling was company D. By mixing lower value post-consumer fibre with higher value pre-consumer meant the wool composition could be closely controlled for each batch.

4.6 Quality

The quality of fibres was a reoccurring theme throughout the visits. A concern presented by Company F were its customers complaints about the varying eveness and colour fastness of the recycled fabrics. Colour fastness was ascribed as a property passed forward from the previous garments, with little solutions available. However, the notion of garments passing on properties it not always attributed to the negative. Recycling in this way retains the colour from their previous lives utilised it in the new material.

One of the main processes that can promote quality is 'cleaning'. This refers to the removal of buttons, zips, seams, and contrasting coloured trims. Although these are established practises of raising quality of recycled fibre, the removal of seams was a debated exception. Seam removal was dependant on the quality of the resultant fabric required by a customer. It would only be completed if the companies felt it would add value to the end product. As a labour intensive and costly exercise, economically it had to present value for money.

4.7 Blending

The quality of mechanically recycled fibre has been criticised laboriously by researchers and brands alike. It is well documented that recycling yarns in this way damages the fibres and reduces length (Gupta and Saggu, 2015, Yuksekkaya *et al*., 2016). Blending offers a solution to this issue, one that has been used throughout history (Shell, 2014). This can be done for colour, composition, function and/or ascetics. For the new schools of thought centered around a circular economy blending has been rejected as the emphasis is placed on mono-materiality within a cradle to cradle model (Braungart and McDonough, 2002). That said, blending virgin fibres in the modern day is common place. It is widely established that for a circular economy; products, components, and materials must be maintained at their highest utility and value at all times (EMF, 2017). For mechanical recycling this means blending. Most prominently this was seen by virgin fibre being blended with recycled, although more innovative examples were revealed. Company A for example, would sell the 'cleaned' cashmere seam waste for blends. The seam waste would be approximately 95% cashmere composition therefore, it could be added into a virgin or recycled batch to achieve 10/20% cashmere blend. Whereas D's blended woollen feedstock was utilised to produce a blended wool product not inappropriate for today's blend heavy market.

Recycled stock yarns were a common service provided by companies B and D. Any other blends were specially developed for individual clients, and therefore heavily dependent on the requirements for the end product or market. The design decisions throughout the process were crucial when reaching this stage. All six companies maintained the materials produced could be recycled again, yet there was no evidence this had been planned for within the system. This wasn't due to a lack of enthusiasm for sustainability, but restricted by the global market for buying Italian wool and the lack of any formalised take-back system.

A further concern is the incompatibility of the feedstock and resultant material. Company B for example, brought in high percentage wool input, accepting no lower than 97%. In contrast the output was a wool blend, with the richest wool stock service yarn reaching 75%. Meaning the output materials would be unacceptable if recaptured and could only be down-cycled.

4.8 End Markets

The need for developing end markets for recycled fibres has been found by Elander and Ljungkvist (2016) supported by the 2014 WRAP report as a residing issue across many areas of the textile recycling industry. This was echoed in Prato, as businesses felt pressure to continually increase the value of materials. This was demonstrated most prominently by Company A who was not only selling fibres, but yarns and garments too, and was also seeking to develop new end markets by producing products using traditional recycling methods. This included producing a needle felt for inside luxury quilted outerwear and using blended cashmere fibre to replace feather down, as an alternative for active-wear apparel.

5 Insights

5.1 Prato Recycling Model

The unique Prato model that has established within its woollen textile industry can be segmented to focus on recycling in which little research has been conducted exclusively. As a form of analysis, a simplified diagram modelling the connections and flow of materials was created (Figure 5).

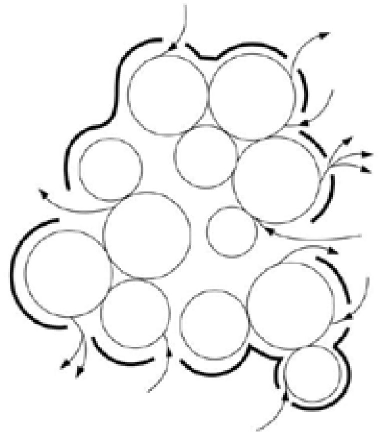

Figure 5. Simplified Model of Prato Wool Recycling Industry, Source: Author

The diagram uses circles representing single companies and signifying the life cycle of the materials or services they provide. The boundary of the Prato district is broken by incoming materials and outgoing products connecting this small segment to the global recycling industry. The circles meet as the small and medium sized facilities collaborate. In Figure 6 we can see in detail the example of companies D and E and how this worked in practice.

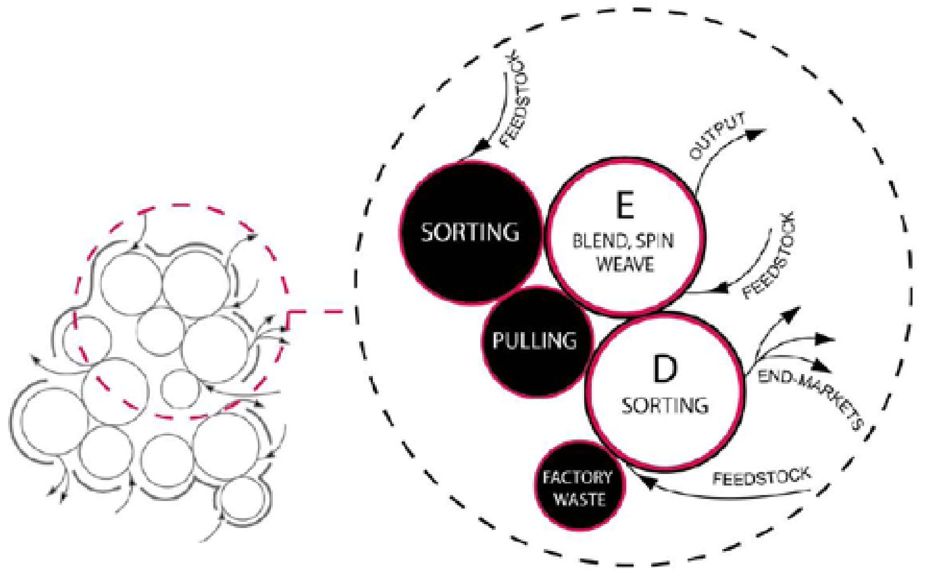

Figure 6. Detail of Prato wool recycling industry simplified model, Source: Author

This visualised system falls into the category of open loop recycling in which Payne (2015) points out materials are generally not reclaimed. The open loop system, which is fed from the global waste woollen apparel industry, is down-cycled often into blended woollen fabric that is not readily recycled again.

This model demonstrates how a small and specifically located industry is embedded and connected to global recycling as well as the virgin textile industry. The problem of material collection is one that spans these two industries, and is one of the biggest barriers that is faced. This is challenged in the most recent ECAP report suggesting collection can only be solved with a spectrum of methods collaboratively rather than competitively, much like the Prato model suggests but on a larger scale (Watson *et al.*, 2018).

5.2 *Barriers to the opportunities*

Understanding the barriers and in turn how these might be future opportunities for innovation witnessed in Prato was a first step. The Prato wool recycling model, visualised by the author in Figure 5 and 6 has enabled a simplified overview for a future systems approach which can be considered towards mixed fibre recycling. Understanding the underlying system in which the industry operates can aid design choices which are critical for innovation. Ripple effects could be seen from every decision along the process from the sorting to the end product, leading to the author plotting the key barriers and opportunities along the recycling process. This resulted in four areas being highlighted as impact hotspots (Barthel *et al.*, 2015) for future design intervention towards increased value of materials (see Figure 7).

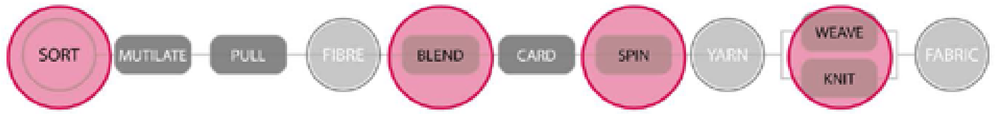

Figure 7. Hotspots for innovation within the processes of recycling textiles, Source: Author

5.2.1. Hotspot: Sort

The first hotspot area identified was the sorting stage. Current work on new technological innovation to replace manual sorting is being developed using NIR technology (Wedin *et al.*, 2017). This could provide a solution to the cost barriers prevalent in Prato, but as Wedin *et al.* (2017) points out does not solve the issue of sorting blends particularly with a low fibre content or multilayer garments. More specific to the issues in Prato was the inconsistent information regarding the quality of woven verses knitted materials to the process. These are therefore potential areas for the further design research.

A key opportunity within the sorting stage was the sorting by primary fibre. For Prato this was wool. Even when recycling blended fibres, the materials were categorised by the amount of wool content. Wool in this case was the most desirable, due to the fact it was being processed within a wool industry. From this we might infer that for mixed fibre sorting, categorising using a ‘primary fibre’ could aid the process. This insight demonstrates the need to understand the material composition, which currently is skilled and labour intensive, to aid sorting technology for new types of ‘primary fibre’ categories which should flow into specific end markets.

5.2.2. Hotspot: Blend

The feedstock of any recycling process is one of the most important factors, but is still heavily reliant on the types and colours of materials coming into the system. As previously discussed overdyeing is used when there is limited availability of coloured feedstock for shade blending. The challenge of varying feedstocks is a targeted area for innovation exploiting areas of opportunity such as melange effect of recycled yarns.

Blending is often associated with negative connotations when concerning the circular economy. However, for mechanical textile recycling, blending represents a positive by increasing quality and often creates a cost-effective end product. Notably there is a lack of research comparing woven verses knitted feedstocks and the effects of combining these different inputs of waste. It is a challenge to find new ways of increasing quality at the blending stage, as well as utilising different forms of blended materials to produce appropriate products for end markets.

5.2.3. Hotspot: Processing

Processing, or spinning most prominently used in Prato, is one of the more technical areas for innovation. Yet, this could provide a significant space for intervention. Spinning yarn for weaving or knitting is only one way of processing fibres. Looking to more traditional methods to produce alternative products is an opportunity. For this approach to work there needs to be full system understanding, connecting this hotspot to the other processes and developing new ideas towards circular and recyclable products of the future.

5.2.4. Hotspot: End Product/Market

Developing recycled alternatives for the needs of the textile manufacturers, currently using virgin and often blended materials, is a challenge across the industry. This reiterates the importance of understanding recycling feedstocks as a fundamental way to design and develop desirable materials. This knowledge can then be used to exploit advantages and seek solutions for properties that are passed on from feedstock to output and plan for this in the design process for suitable end markets.

5.3 Limitations

The scope of this research could be limiting due to using a small sample used as a form of analysis of an entire industry. Owing to the time scale available only two visits to Prato were undertaken, meaning the sample size was selected from the companies willing and available. Subsequently, this affected the number of observations that could be completed. However, to achieve the research aims the time allocated was accepted to enable thorough analysis and meaningful insights. When reflecting on the learnings from a single small area to seek solutions for mixed fibre recycling it is important to remember that textile recycling is a global industry. Therefore, further research into other textile recycling sectors might be considered to form more comprehensive deductions.

6 Conclusion

The field research undertaken was a means to develop designerly understanding of the wool recycling industry in Prato. The insights unearthed were a method to seek further solutions for the more problematic mixed fibre textile recycling urgently needed in today's wasteful fashion industry.

By completing this, a deeper understanding of the processes within the wool recycling industry have been yielded. Furthermore, by reflecting on the barriers and opportunities and translating these insights towards mixed fibre recycling, key hotspots for innovation have been uncovered. Understanding the value of the hotspots can signpost further research to create material and systemic interventions within mechanical textile recycling to create circular fibres of the future.

References

Barthel, M. *et al.* (2015) 'Hotspots Analysis: Providing the Focus for Action', in Sonnemann, G. and Margni, M. (eds) *Life Cycle Management*. Dordrecht: Springer Netherlands (LCA Compendium – The Complete World of Life Cycle Assessment), pp. 149–167. doi: 10.1007/978-94-017-7221-1_12.

Braungart, M. and McDonough, W. (2002) *Cradle to Cradle. Remaking the Way We Make Things*. 1st Edition. New York: North Point Press.

Burgess, R. G. (ed.) (1982) *Field research: a sourcebook and field manual*. London: Unwin Hyman (Contemporary social research series, 4).

Cardato (2018) *Cardato Recycled Brand*, *Cardato*. Available at: http://www.cardato.it/ (Accessed: 31 July 2018).

Cross, N. (2007) *Designerly ways of knowing*. Basel: Birkhäuser.

Dahlbo, H. *et al.* (2016) 'Increasing textile circulation—Consequences and requirements', *Sustainable Production and Consumption*. doi: 10.1016/j.spc.2016.06.005.

Dutch Clothing Mountain (2017) *Measuring the Dutch clothing mountain: Data for sustainability-oriented studies and actions in the apparel sector*. Amsterdam: Hogeschool van Amsterdam. Available at: http://www.hva.nl/create-it/gedeelde-content/projecten/projecten-fashion/measuring-the-dutch-clothing-mountain.html (Accessed: 13 February 2018).

Elander, M. and Ljungkvist, H. (2016) *Critical aspects in design for fibre-to-fibre recycling of textiles*. IVL Swedish Environmental Research Institute. Available at: http://mistrafuturefashion.com/wp-content/uploads/2016/06/MFF-report-2016-1-Critical-aspects.pdf (Accessed: 10 March 2017).

EMF (2017) *A New Textiles Economy: Redesigning Fashion's Future*. Ellen Macarthur Foundation and Circular Fibres Initiative.

Fletcher, K. and Grose, L. (2012) *Fashion & Sustainability : Design for Change*. Laurence King Publishing.

Gaver, B. and Bowers, J. (2012) 'Annotated portfolios', *interactions*, 19(4), p. 40. doi: 10.1145/2212877.2212889.

Gupta, M. and Saggu, H. K. (2015) 'Physical properties of shoddy yarn.', *Man-Made Textiles in India*, 43(2).

Hawley, J. M. (2006) 'Digging for Diamonds: A Conceptual Framework for Understanding Reclaimed Textile Products', *Clothing and Textiles Research Journal*, 24(3), pp. 262–275. doi: 10.1177/0887302X06294626.

Magi, F. and Ceccarelli, F. (2002) *Prato's Carded Fabrics: From a historical product to a new opportunity for development*.

Mathews, B. (2015) *Closing the loop: an essential guide for the global textile supply chain*. Normanton, England: MCL Global.

Mondadori (2013) *Prato: Guide to the City*. Milano: Mondadori Electa S.p.A.

Museo del tessuto Edizioni (2007) *Museo del tessuto di Prato. Trenta anni di donazioni. Prato Textile Museum. Thirty years of Donations*. Prato.

Ottati, G. D. (2009) 'An Industrial District Facing the Challenges of Globalization: Prato Today', *European Planning Studies*, 17(12), pp. 1817–1835. doi: 10.1080/09654310903322322.

Padovani, C. (2017) 'MADE IN ITALY: Reclaiming social heritage and artisan know-how', in Whittaker, P. and Padovani, C., *Sustainability and the Social Fabric: Europe's new Textile Industries*. Bloomsbury Publishing PLC, p. 28.

Payne, A. (2015) 'Open- and closed-loop recycling of textiles and apparel products', in Muthu, S. S. (ed.) *Handbook of life cycle assessment (LCA) of textiles and clothing*. Cambridge, England: Woodhouse Publishing (Woodhead publishing series in textiles, number 172).

Polanyi, M. (1958) *Personal knowledge: towards a post-critical philosophy*. London: Routledge.

Sauerwein, M., Bakker, C. and Balkenende, R. (2018) 'Annotated Portfolios as a Method to Analyse Interviews', in *DRS2018. Catalyst for Change*, University of Limerick: Scribd, pp. 1148–1158. Available at: https://www.scribd.com/document/382349704/DRS2018-Vol-3#download (Accessed: 24 July 2018).

Shell, H. R. (2014) 'Shoddy heap: a material history between waste and manufacture', *History and Technology*, 30(4), pp. 374–394. doi: 10.1080/07341512.2014.1003165.

Suri, J. F. (2005) *Thoughtless acts? observations on intuitive design*. San Francisco, Calif: Chronicle.

Testa, F. *et al.* (2017) 'Removing obstacles to the implementation of LCA among SMEs: A collective strategy for exploiting recycled wool', *Journal of Cleaner Production*, 156, pp. 923–931. doi: 10.1016/j.jclepro.2017.04.101.

Turley, D. B. *et al.* (2009) *The role and business case for existing and emerging fibres in sustainable clothing: final report to the Department for Environment, Food and Rural Affairs (Defra),*. London, UK. Available at: file:///Users/student/Downloads/EV0420_9092_FRP.pdf (Accessed: 30 January 2018).

Ward, G. D., Hewitt, A. D. and Russell, S. J. (2013) 'Fibre composition of donated post-consumer clothing in the UK', *Proceedings of the Institution of Civil Engineers - Waste and Resource Management*, 166(1), pp. 29–37. doi: 10.1680/warm.12.00014.

Watson, D. *et al.* (2018) *Used textile Collection in European Cities*. PlanMiljø, Denmark: Study commissioned by Rijkswaterstaat under the European Clothing Action Plan (ECAP).

Wedin, H. *et al.* (2017) *Can automated NIR technology be a way to improve the sorting quality of textile waste?* RISE: Trash2Cash. Available at: https://issuu.com/trash2cash/docs/report4/1?ff=true&e=30581983/55544808 (Accessed: 11 December 2017).

Weibel-Orlando, J. (2012) 'The Utility Of Employing Integrated Research Analysis Paradigms: A Case Study Of The Textile Industry In Prato, Italy', *Urban Anthropology and Studies of Cultural Systems and World Economic Development*, 41(1), pp. 1–42.

WRAP (2012) *A review of commercial textile fibre recycling technologies*. Oakdene Hollins. Available at: http://www.wrap.org.uk/system/files/private/Commercial%20textile%20fibre%20recycling%20technoloogies%20report.pdf (Accessed: 7 December 2017).

WRAP (2014) *Evaluation of the end markets for textile rag and fibre within the UK*. Oakdene Hollins. Available at: http://www.wrap.org.uk/sites/files/wrap/priv_download/MPD007-015_Evaluation%20of%20End%20Markets_Final.pdf (Accessed: 7 December 2017).

Yuksekkaya, M. E. *et al.* (2016) 'A Comparative Study of Physical Properties of Yarns and Fabrics Produced From Virgin and Recycled Fibers', *Journal of Engineered Fabrics & Fibers (JEFF)*, 11(2), pp. 68–76.

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14.8.2 DIVIDE, SWITCH, BLEND

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Divide, Switch, Blend. Exploring two hats for industry entrepreneurship and academic practice-based textile design research

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Abstract: This paper explores different approaches taken when 'wearing two hats'; that of academic researcher and the industry entrepreneur. It considers the barriers and opportunities in combining these two roles in order to acquire new knowledge. To understand how future researchers could best do this and why this might be desirable, the paper presents Author1's insights from field research experience; wearing both hats within a textile industry context. A literature review, reflective practice and an annotated portfolio method enabled the authors to identify three approaches – *Divide, Switch* and *Blend*. These form a model for researching with any two hats on: *Divide* entails wearing both hats separately on different occasions; *Switch* is wearing both hats but interchanging between the two on a single occasion; *Blend* is wearing both hats simultaneously. The authors conclude that fluidity between approaches and an understanding of the dominant hat is vital.

Keywords: Academic Research, Entrepreneurship, Dual Roles, Textile Design, Two Hats

1. Introduction

Design researchers working with sustainability need to make their research impactful, useful and relevant. Within design research the experience of the individual is a vital consideration (Rogoff, 1995). However, while of value in itself, the subjective component (in this case, the author's additional role as entrepreneur) can cloud research insights.

The paper outlines the tensions and opportunities of combining these two roles, or 'two hats', in three distinctive ways – dividing, switching and blending – in situations, as required. Using personal reflective practice (Schön, 1983) formalising the findings into a table, and finally visualised (Tufte, 2001) through a model as a method of drawing out further insights. Although this paper focuses on one such experience to develop the proposed three ways, other insights from field work with the Author1 PhD research was drawn upon. This has provided a preliminary model for researchers, within and outside of textile design, when wearing any two given hats.

This paper focuses on the experiences of Author1's PhD research in which she wore the hat of an academic textile design researcher and the hat of the textile industry entrepreneur. Author2

provided the original idea for the paper and supported Author1 with the reflection, mapping, structuring, editing and refocus/review processes. Author2 is also a researcher and entrepreneur in the same design field, with significant experience of inhabiting both hats.

The paper is split into two parts. Part 1, *Making the hats*, develops an understanding of the terrain through a short literature and practice review on research that combines research and industry stakeholders. Part 2, *Wearing the hats*, presents an example of Author1's personal experience in the field in which she wore both academic researcher and industry entrepreneur hats within textile design research. Established methods of reflective practice are used here - specifically in textile design – and are applied to provide insights for future entrepreneurial research. The findings present the three approaches for the adoption of the two hats - *divide, switch* and *blend* - to produce a fluid model for combined practice. Finally, special consideration is given to recognising the 'dominant hat' in any given context as a means of maximising insights from both perspectives.

2. Methods

The paper was developed by fusing three key methodological approaches - literature review, case study and reflected practice – in order to formulate the final model.

A short literature review forms the foundation of the first part of the paper. This first of all looks outside of the field of design to explore parallels with other disciplines where academic research and professional practice are combined. This is followed by a review of design research and literature where knowledge from academia and industry are combined.

The second part of the paper is a personal reflection based on field work conducted by Author1 where the hats of both textile design researcher and textile design entrepreneur were worn. For the purposes of this paper only one field experience is discussed; however, Author1 was able to draw upon other, previously completed research tasks. For the clarity of this research paper, the best example has been discussed.

Reflective practice methods (Schön, 1983; Igoe, 2013) enable the incorporation of personal experience (Clandinin and Connelly, 1994) and reflection on experience to enhance learning (Boud, Keogh and Walker, 1985). The project between Author1 and the industry partner discussed in the paper uses a field research methodology (Burgess, 1982) including observation, conversation and documentary evidencing. These were amalgamated with 'designerly ways' (Cross, 2007) and tacit design knowledge (Polanyi, 1958) to generate qualitative data.

Data analysis was achieved using an adapted annotated portfolio method (Gaver and Bowers, 2012; Sauerwein, Bakker and Balkenende, 2018) applying field notes and thick description (Lincoln and Guba, 1985) to photographic documentation (Figure 1). The annotations were then colour coded to establish similarities and differences between the hats. This enabled patterns and insights to be gathered in the form of two tables. Firstly, a table was generated to establish a clear view of when Author1 believed which hat was being worn at which time. Secondly, a table was constructed to form an analysis to establish and refine the three approaches considering the relative strengths and weaknesses put forward by Unluer (2012) as necessary to insider research. Finally, in order to extend understanding of the three approaches, visualisation methods (Tufte, 2001) in the form of a model were employed. It was through the construction of these models that analysis took place to draw out new insights identifying the importance of a dominant hat.

Figure 1. Annotated portfolio method from the trial

3. Context: Understanding the Hats

Researching within an industry setting uses similar methods to researching within an academic institution but with different goals and objectives. Asking similar questions, the academics' interest is situated in the 'know-why' and the industry's in the 'know-how' (Mujumdar, 2004). The following section follows the relationship between university and entrepreneur (3.1), the literature surrounding blending research with entrepreneurship (3.2), the position of insider research (3.3) and industry experience in relation to academic research (3.4). Finally, contemporary context within sustainable and circular design where this approach is increasingly being used (3.5).

3.1 The Relationship between University and Industry

The relationship between universities and industry has shifted in recent years from 'arm's length' to closer contact with particular focus on the science and technology disciplines (Schutze, 2000). Littered with debate about conflict of interest, withholding publishing and compromises, the relationships between the two sectors can be very problematic (ibid). Innovation policy drivers are focused on increasing university commercialisation potential by the creation of university spin-out companies (Fowler, 2017). Referred to as the triple helix, Etzkowitz and Leydesdorff, (1995) have explored the contribution of *university-industry-government* and how the interactions of all three have changed over time, altering dynamics, pushing universities away from the traditional model to contributing to industrial activity.

Ever-increasing pressure placed on universities to obtain funding and resources has paved the way for development of entrepreneurial researchers to make new spaces for their research. EU funding is tied to collaborative networks between academic institutions and industry; these types of research projects are perceived as desirable with higher prospects of obtaining external funding (Mønsted and Hansson, 2010). Focusing more specifically on design research the recent push towards industrial collaboration is shown by the Arts and Humanities Research Council AHRC (2018) partnership with Innovate UK to pursue "knowledge transfer partnerships" helping industry access the expertise from UK Universities.

3.2 The Researcher Entrepreneur

To understand the challenges of donning both research and entrepreneurial hats, it is necessary to look outside the field of textiles, and further still outside of design. Disciplines such as the sciences and healthcare offer a greater scope of experience to learn and benefit from.

The concept of researcher and entrepreneur is one that divides opinion. Within the discipline of science, where traditionally the realms of research and commercialisation were kept separate, scientists are now more open to bridge this gap, some creating their own firms to benefit from their academic discoveries (Etzkowitz, 1983). This has also lead to the rise of Clark's (1998) concept of the 'entrepreneurial university' by which institutions can create revenue from the academic work they produce. The varied interactions between university and industry such as consultancy and contract research, joint research, or training has grown and in these ways researchers are now interacting, rather than following traditional routes such as patents and spins offs (D'Este and Patel, 2007).

The role of the researcher has adapted in which a new hybrid role of scientist/entrepreneur has emerged. This hybrid role identity allows the researcher to split themselves into the academic self and the commercial persona (Jain, George and Maltarich, 2009). This concept has been further developed by Lam (2010) describing scientists fitting into one of four category types:

- Type I 'Traditional Scientists': Boundary Separation and Expulsion

- Type II 'Traditional Hybrids': Boundary Testing and Maintenance
- Type III 'Entrepreneurial Hybrids': Boundary Negotiation and Expansion
- Type IV 'Entrepreneurial Scientists': Boundary Inclusion and Fusion

At either end of the spectrum we can see the extremes of opinion. Type I (traditional) scientists believe that research and industry should remain completely separate. They think that those attempting to bridge this gap would be more suited to research and development in large corporations and any industry involvement in academia would undermine the research objectives. In contrast, Type IV (entrepreneurial) scientists demonstrate the full integration of both roles, accepting the boundaries as completely flexible and sometimes entirely merged. These scientists were able to wear both hats simultaneously and saw the benefits of the two sides combining in which both roles influenced and benefited each other (Lam, 2010).

The concept of creating a hybrid between practice (or entrepreneurship) and research is not new. Clinical research, in the field of surgery, has been regarded as the 'golden key' for developing techniques and understanding in the field. However, combining the 'two faces' of surgical practice and research is described by Huber-Lang and Neugebauer (2011) as 'squaring the circle' which they point out in reality is very difficult without a set of pre-requisites and could be potentially undesirable. In contrast, Fleet *et al.* (2016) argues in the field of counselling the adoption of both roles (councillor and researcher) can be used for the benefit of the investigation. There is, however, challenges when using a dual role approach, such as ethical considerations and bias. Kitchener (1988) argues against dual roles within this domain as the relationship blurs the power and obligation leading to altered expectations with potential negative consequences.

3.3 Insider Research

The concept of the dual role, or wearing 'both hats', often appears in literature as 'insider research'. According to Brannick and Coghlan (2007) the value of this approach within organisational research demonstrates no inherent reasons for this style to pose an issue. Bonner and Tolhurst (2002) identified fundamental advantages for an insider researcher having greater understanding of a situation, allowing for easier communication and better judgment of accuracy. An insider understands how things works in reality and has a great depth of knowledge which might take an outsider much longer to develop (Smyth and Holian, 2008). However, this it is not without disadvantages; often balancing the roles is difficult, unconscious biases and other difficulties are common (Hewitt-Taylor, 2002, Mercer, 2007). In contrast 'the stranger' could more easily critically observe events and situations (Schuetz, 1944). It is by understanding both the challenges and opportunities that the insider research can best succeed (Unluer, 2012, Saidin and Yaacob, 2016, Mercer, 2007).

3.4 Research and Industry experience

Experience of industry as a method to inform research is another way both hats could be worn. The hospitality discipline emphasises industry experience as a central part of the subject. It was raised by Phelan, Mejia and Hertzman (2013) that within the US hospitality faculty, almost half of academic experts will retire by 2023 and the younger successors have notably less industry experience. This has led to as an 'industry-experience gap' or 'theory-practice gap' and has been regarded as an issue within education sector. The importance of finding solutions to connect theory with practice is discussed across the literature (Govender and Taylor, 2015, Cheng, Cheng and Tang, 2010).

Studies also point towards collaboration between academia and industry as a way to form deeper insights into real industrial problems (Bhullar, Nangia and Batish, 2017). Tijssen, Lamers and Yegros (2017) introduce the concept of university-industry crossover researchers, who combine one or more university affiliation and business affiliation in recent years. This can also be referred to as industry turned academic (Santoro and Snead, 2013, Puia *et al.*, 2000). Yet, as Hofbauer (2008) points out in the case of scientists moving between the realms of academia and research, individuals need a high degree of flexibility to do this.

3.5 Design and Industry

Across the field of design there is a wealth of examples as disciplines within the research field are increasingly collaborating with industry. For example, small-scale academic projects creating a knowledge transfer with industry, including jewellery design (Penfold, 2007) and product design (Crabbe, 2008). Using these methods ensures lessons can be learnt and publicly communicated (ibid). Other approaches have been displayed using industry workshops to develop new research ideas and testing academic thinking by exploiting real experience and expertise of the participants (Earley, 2017). Sustainable textile research conducted with industry, through sampling at PhD level has resulted in useful models over the years (e.g. Farrer, 2000; Goldsworthy, 2012; Paine, 2015).

More recently, as the framework of the circular economy as a connected system has been brought to the fore from organisations such as the Ellen MacArthur Foundation, designers are now being asked to look across the whole lifecycle and consider business models, services and systems (Ræbild and Bang, 2017). Emphasised by the circular focus areas of the European Commission Horizon 2020 funding, this is a good example of where this collaborative approach between research and industry is needed.

Examples such as the Trash-2-Cash (2018) project which developed a design-driven material innovation methodology to work with 18 partners academic and business. Similarly, the FIBRESORT project, led by Dutch social enterprise Circle Economy (2018), is working to foster academic insights from industry by collaborating with industrial partners to create a rich environment for insights from both sides. Other examples include Sweden-based Mistra Future Fashion (2018) an interdisciplinary research project working with industry to ensure insights produced are useful and relevant for the industry it wishes to help transform. The research is split into four themes, in which the design theme worked closely on a project with fashion brand Filippa K, to develop and translate research ideas into a commercial context (Disrupting Patterns, 2018). Finally, a very recent research grant scheme from AHRC, Creative Clusters (2018) awarded academic researchers funds to work directly with creative industry partners. Each 'cluster' is hosted by a higher education institution with full involvement of industry, from the research and development, to strategy and governance.

4. Field Research: Wearing the Hats

4.1 Context

Anneka Textiles is a start-up business established by Author1 in October 2016. The business recycles post-consumer waste knitwear, using a mechanical recycling method, to produce materials for small ranges of luxury interior products. In addition, Author1 is also a PhD research student at the Centre for Circular Design (CCD) undertaking a practice-led PhD on the subject of post-consumer textile recycling, specifically focusing on mechanical technology.

4.2 The Field Research

The research took place in September 2018, with a recycling company who use a traditional needle felting technique to produce a recycled felt. Henceforth this business will be referred to as the 'Recycling Company'. Author1 had been in contact and worked with the recycling company multiple times, but in this particular instance Author1 was wearing both hats; PhD researcher (referred to from now as the 'researcher') and Anneka Textiles entrepreneur business owner (referred to from now as the 'entrepreneur'). It was in adopting both roles and through self-reflective analysis that the challenges and opportunities could be understood. These will be discussed later in section 5.

The purpose of the visit was to trial recycling equipment. To explain this efficiently a simplified diagram adapted from WRAP (2012) has been produced, which demonstrates the process for the recycling of textiles. (Figure 2)

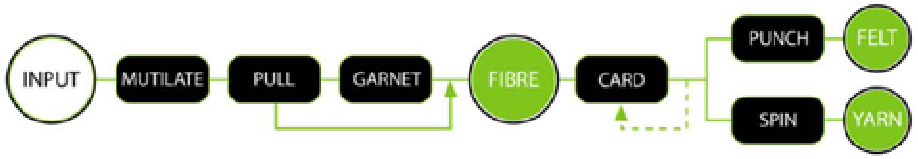


Figure 2. Simplified process of recycling textile, adapted from WRAP (2012)

Pulling is the first stage of returning textiles to fibre, 'opening' or 'pulling' the textiles back to a fibrous state. The result of this first rudimentary stage is fibre and remnants of textile material. Garneting is similar but understood as a more specialised stage ensuring threads are transformed to fully fibrous form (Gee, 1950).

It was when the entrepreneur costed each stage of the process from input to material (Figure 2), garnetting was highlighted as a particularly expensive stage. This increased the material unit price and therefore negatively affected the profit margin of products designed with the material. As with many start-up businesses, limited funding for the development of new materials necessitated searching for solutions to reduce costs.

During a meeting with the recycling company Author1 was made aware they might offer a solution by duplicating the carding stage and thereby avoiding garnetting. A trial was organised to establish:

a) If the pulling machine could successful be used on clothing
b) If after a single card the fibre could be used to produce felt
c) If double carding might improve the fibre to achieve a similar effect to garneting.

200kg of white knitwear was obtained for the trial. White was selected as an additional investigation into the impacts of contamination from oily machinery and other coloured fibres. The hypothesis was that white would easily show any colour or dirt picked up through the processing.

Author1 had previously developed a relationship with the 'manager' and 'director' of the recycling company, as an entrepreneur. The relationship was instrumental for the recycling company to work with her as *both* researcher and entrepreneur. It was this relationship, in combination with the company's interest in new product avenues for their processes – an interest in new recycling methods, as well as an awareness for the need to adapt their business model for a future sustainability - which permitted the trials to take place.

The focus of this paper will be on the two roles - researcher and entrepreneur - during the described trial. It will establish how the author balanced the two roles as both an opportunity and a barrier. Physical results of the trial will only be referenced to in relation to Author1 taking on two roles and not discussed in full.

5. Discussion

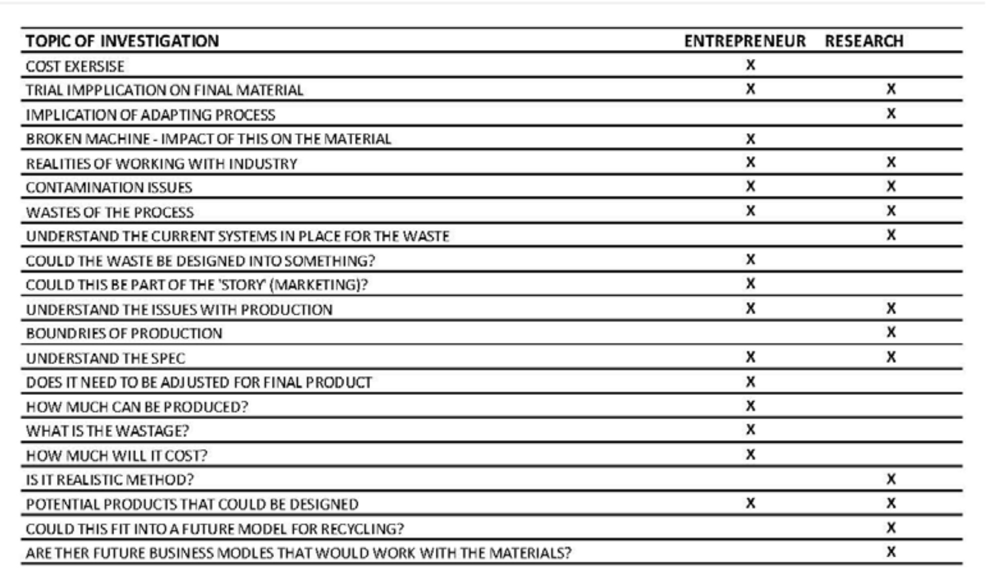
'Wearing two hats' within a single experience can be complicated. The aim of this research paper is to determine the key approaches of taking on dual roles from a personal reflective experience of Author1's design research and design entrepreneurship. The collaboration between researchers and industry particularly in a design context can be tenuous, critical and often an undisclosed dynamic relationship which needs to be addressed. It is the objective of this paper to understand the areas of tension and opportunity derived from wearing *two* hats within the context of design.

5.1 Two Hats

Table 1 (see below) was created through a personal reflection on the field research as described and shows the main topics of investigation. The crosses marked visualise how the interests of the researcher and the entrepreneur aligned and divided established by Author1 personal understanding of how she split herself between the two roles. It was concluded in this case, that the researcher was predominantly concerned with the overarching system in which textiles can be recycled and waste may occur. In contrast the entrepreneur's priority was to understand the cost and design implications of the process.

5.2 Attitudes of the hat wearer

Table 1. Crossover in investigation between 'researcher' and 'entrepreneur'



TOPIC OF INVESTIGATION	ENTREPRENEUR	RESEARCH
COST EXERSISE	X	
TRIAL IMPPLICATION ON FINAL MATERIAL	X	X
IMPLICATION OF ADAPTING PROCESS		X
BROKEN MACHINE - IMPACT OF THIS ON THE MATERIAL	X	
REALITIES OF WORKING WITH INDUSTRY	X	X
CONTAMINATION ISSUES	X	X
WASTES OF THE PROCESS	X	X
UNDERSTAND THE CURRENT SYSTEMS IN PLACE FOR THE WASTE		X
COULD THE WASTE BE DESIGNED INTO SOMETHING?	X	
COULD THIS BE PART OF THE 'STORY' (MARKETING)?	X	
UNDERSTAND THE ISSUES WITH PRODUCTION	X	X
BOUNDRIES OF PRODUCTION		X
UNDERSTAND THE SPEC	X	X
DOES IT NEED TO BE ADJUSTED FOR FINAL PRODUCT	X	
HOW MUCH CAN BE PRODUCED?	X	
WHAT IS THE WASTAGE?	X	
HOW MUCH WILL IT COST?	X	
IS IT REALISTIC METHOD?		X
POTENTIAL PRODUCTS THAT COULD BE DESIGNED	X	X
COULD THIS FIT INTO A FUTURE MODEL FOR RECYCLING?		X
ARE THER FUTURE BUSINESS MODLES THAT WOULD WORK WITH THE MATERIALS?		X

The attitudes of both hats differ and ultimately influence each other as a benefit and a hindrance. This is demonstrated by the crossover or separation of investigation interests (see Table 1). On refection, if the researcher hat had been worn alone the visit might have lasted longer, insuring every part of the process had been witnessed and discussed. The entrepreneur main attention was to ensure the material could be successfully produced and then reflect on the outcomes afterwards with testing and experimentation. This attitude of the entrepreneur, avoiding split decisions and experimenting afterwards, has its advantages for the development of product. Yet, the researcher's requirement to be thorough during the investigation is also valid. It is therefore vital to establish the tensions that might occur between the two roles.

5.3 Differing hat agendas

By studying the patterns which have come out of Table 1 we can see that the entrepreneur is nearly always concerned with the enquiries of the researcher, with only a few exceptions. On closer inspection the exceptions are 'future' based lines of investigation. This has been illustrated in Figure 3 by a 'now, near, far' context (Goldsworthy, 2012). The entrepreneur is firmly situated in the 'now' and will consider the 'near'. In contrast, the researcher is future-focused situated in both 'near' and 'far'.

Figure 3. Illustration of the areas of interest for each role (Researcher/Entrepreneur)

These opposing views create opportunity for both hats to consider the opposing agenda. For example, the researcher without the entrepreneur would have continued to use the garneting method, therefore not considering other options for a future system. Cost, in this case, not considered by the researcher, was highlighted by the entrepreneur and demonstrated the realities of the industry for the researcher hat. Then again, a relentless focus of costs could limit the scope of the research. It is therefore vital to courteously navigate both hats and their agendas. This can be challenging, but by spanning agendas across 'now, near and far' provides a multifaceted and rounded approach.

6. Approaches

Throughout the case study the hats of both researcher and entrepreneur were used differently as the situation demanded. Both hats were constantly being exchanged, at points it became difficult to establish which hat was being worn at which moment and juggling between the two blurred the lines. Yet, the demands of both roles did align, and an understanding was reached to satisfy both sides meaning they could be worn simultaneously. This has shaped the development of the three approaches outlined in Table 2. Opportunities and barriers to each approach has also been reflected.

Table 2. Three approaches and barriers/opportunities of wearing two hats (researcher/entrepreneur)

APPROACH	DEFINITION	BARRIERS	OPPORTUNITIES
DIVIDE	Wearing both hats separately on different occasions	**Unrealistic:** If this approach was used every circumstance	**Experience:** Individual gains the experience of both hats but not at the same time
		Inflexible: Hindering the experience of both hats from influencing one another	**Simplified:** Less complicated approach, could lead to less issues
SWITCH	Wearing both hats but interchanging between the two on a single occasion	**Disregard**: By wearing one hat and not another could lead to missed opportunities	**Informing:** Interchanging between hats can use each role to inform the other
		Confusion: There could be a struggle to understand which hat is being worn and what this means.	**Balance:** This approach is balanced between each role
BLEND	Wearing both hats simultaneously	**Conflict**: Could lead to conflict between the two roles	**New perspective:** Considering both roles at the same time creates a new perspective
		Blurred: Could be unclear what the results mean to each role	**Balance:** This approach is balanced between each role

6.1 Divide

Divide is the most unencumbered of the three approaches. This was demonstrated prior to the investigation when the entrepreneurial hat was exclusively worn, establishing the potential to omit the garnetting stage. It was only at a later date, once the trial had been arranged, that the researcher hat was put on requesting to witness the process. Although this is a very tidy way to compartmentalise spitting the roles, it is unrealistic for every situation in a complex world. For example, the entrepreneur in this instance is assumed to have no interest in being present at the trial. However, in practice being in attendance benefited the entrepreneur creating the opportunity for deeper understanding and implications of the processes.

6.2 Switch

The rigidity of divide, it can be argued, is combated by the switch approach offering more flexibility. Switching between the hats, often quickly and frequently can be used to satisfy both hats priorities. For example, when considering the issues of waste, a line of investigation lead by the researcher hat and also of interest to the entrepreneur. Conversation was led by the manager about this issue meant the two hats were constantly switched dependent on the information given. The flexibility of changing between hats benefited this style of research. Often a single line of enquiry for one hat, for example made by the entrepreneur, would then lead to important insight for the other hat, the researcher.

However, this approach is not without its challenges. Switching between hats was found to be challenging. Determining which hat was being worn at which point led to confusion subsequently meaning more detailed reflection needed to be completed to separate the insights for each side. Additionally, when the researcher arrived at the recycling company, miscommunication meant the pulling stage had already been completed. It was in this moment that the hat was switched. The entrepreneur was excited to see the following stages (carding and needle punching) and as pulling had been successful, the researcher hat was discarded, and no questions were initiated. Retrospectively, this was an opportunity missed and questions could have provided greater insights for the researcher.

Switching hats was found to not always be a conscious decision but executed by external parties. For example, although the recycling company were informed that both hats are being worn their alliance was with the entrepreneur. This was due to her potential to provide business for them. They were happy to help the researcher and answer any of her questions. Yet, the realities of business and what is practical often forced hats to be changed during conversation.

6.3 Blend

Blend is a nuanced approach in which the entrepreneurial and research aspects are treated holistically. Each hat influences the other to provide insights, without the conflict and continuous switching between them. Yet, this is not without its challenges. The distinction between the hats being worn can be blurred causing the wearer to misunderstand insights. For example, the below illustrations of blending the hats by Author1, was not understood at the time but by reflection afterwards.

Contamination of colour and dirt, for the entrepreneur, are two of the biggest barriers for commercial product development. This also interested the researcher as a barrier for the system and therefore the two hats were aligned. Both hats were interested in the results of using a white input to maximise evidence of contamination. For both, there was an element of concern in the design challenge of working with, what was considered, a difficult colour for product design. This was heighted by the challenge of working around the contamination which appeared. Blending the two hats concerns over a single issue threw up challenges and insights as each side influenced the other to generate ideas and solutions.

Furthermore, it was brought to the attention of the entrepreneur that a new needle punching machine was being used was different to that of a previous trial. This meant an altered method was employed to produce the felt, which for both the entrepreneur and researcher, could dramatically impact the appearance and function of the material. This situation provided an opportunity to understand the adaptability of the entrepreneur – for both the entrepreneur herself and for the researcher hat. The researcher could reflect on the entrepreneurial role and the real challenges faced when working in the industry. In doing this meant both hats were being worn together, blending the two sides for the benefit of each.

6.4 Fluidity

Understanding the three approaches, along with the barriers and opportunities, is crucial to successfully wearing both hats. By reflecting on the field research, it was found that a mix of approaches 'switch' and 'blend' were adopted by Author1. In addition, the 'divide' approach was used prior to the trial. By reflecting on this experience and considering all three approaches it was found that the boundaries between the three were often blurred. Therefore, to effectively wear both hats a combination of *divide, switch* and *blend* is required dependent on the situation. This has been visualised in a triangulation model (Heale and Forbes, 2013), accepting all three methods can be interchanged fluidly (Figure 4). This enables the greatest potential to overcome the listed barriers and exploit the opportunities of each approach.

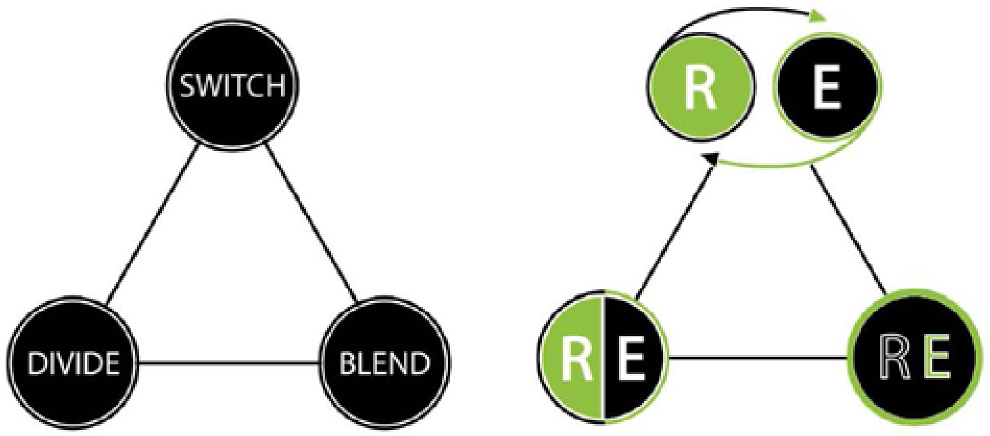


Figure 4. Triangulation model between dual role approaches (Researcher and Entrepreneur)

6.5 Dominance

By understanding the reasons for a fluid interchange of approaches is key for the individual to identify insights. It was found by analysing the experience of Author1 that there was always a 'dominant' hat within any given situation (Figure 5).

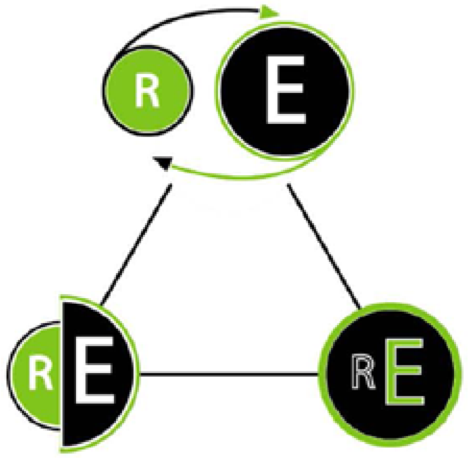


Figure 5. Triangulation model detail emphasizing the dominant hat

This was demonstrated by the developed relationship with the recycling company over two years prior to the trial. It was important to both researcher and entrepreneur to sustain this professional relationship. This involved small talk as well as personal conversations, whilst the industrial processes ran their course. This relationship permitted questioning and deeper understanding of the process, leading to discussion about other design projects the recycling company had worked on. The entrepreneur was interested in other design examples, but it was the researcher hat which was brought to the fore to understand the different end products and how these might fit into a larger system. This illustrates a complex situation in which both hats were being worn together with one becoming more dominant than the other.

The concept of the dominant hat can easily be applied to both *switch* and *divide.* When using both these approaches the hat in play is clearly understood as dominant. This becomes more complex when the *blend* approach is used. In this case, each hat influences the other and it is the fight for dominance that provides the most valuable insights. It is concluded that the domination or submission of a particular hat can force a change in approach. Therefore, the ability to fluidly change is the key to successfully wear two hats, driven by the power play between the sides.

7. Conclusion

This paper firstly looked outside of the design field, to complete a concise literature review establishing the terrain of the topic. This led to deeper understanding which the authors used to help them reflect on the field research study. This paper has provided a model from within the context of design for the adoption of dual roles - referred to as two hats - within an academic research and entrepreneurial context. Although from the design discipline, this could be adapted for use within any field when wearing two different hats. Through reflection of Author1's personal experience three approaches were produced - *divide, switch* and *blend* - as a method to wear both hats effectively. *Divide* entails wearing both hats separately on different occasions; *Switch* is wearing both hats but interchanging between the two on a single occasion; *Blend* is wearing both hats simultaneously.

The findings demonstrate that each approach can be adopted successfully by optimising the opportunities and overcoming the barriers in a given situation. It is the depth of understanding of these barriers and opportunities which allows the individual to use each approach effectively. Furthermore, to fully benefit from all three approaches it has been concluded that fluidity was fundamental to the success of wearing both hats. The ability to alternate, as each situation demands, is advocated as the key method to overcome the barriers of each - *divide, switch* and *blend.* Finally, by understanding the power-play of the *dominant hat* across the three approaches, the authors were able to understand how *fluidity* of hat-changing can successfully lead to obtaining broader insights.

This paper has limitations. The model might benefit from other field research across different contexts to broaden the results. Using a personal reflective method was determined as appropriate means to consider this topic and develop a model; further research to develop this model would benefit from contributions across the disciplines in this under-researched area.

References

AHRC (2018) *Innovation - Arts and Humanities Research Council.* Available at: https://ahrc.ukri.org/innovation/ (Accessed: 7 November 2018).

Bhullar, S. S., Nangia, V. K. and Batish, A. (2017) 'Channels of interaction and past collaborative experience as imperatives in academia–industry collaboration', *Technology Analysis & Strategic Management*, 29(10), pp. 1210–1224. doi: 10.1080/09537325.2016.1277694.

Bonner, A. and Tolhurst, G. (2002) 'Insider-outsider perspectives of participant observation', *Nurse researcher*, 9(4), pp. 7–19.

Boud, D., Keogh, R. and Walker, D. (eds) (1985) *Reflection: turning experience into learning*. London: Kogan.

Brannick, T. and Coghlan, D. (2007) 'In Defense of Being "Native": The Case for Insider Academic Research', *Organizational Research Methods*, 10(1), pp. 59–74. doi: 10.1177/1094428106289253.

Burgess, R. G. (ed.) (1982) *Field research: a sourcebook and field manual*. London: Unwin Hyman (Contemporary social research series, 4).

Cheng, M. M. H., Cheng, A. Y. N. and Tang, S. Y. F. (2010) 'Closing the gap between the theory and practice of teaching: implications for teacher education programmes in Hong Kong', *Journal of Education for Teaching*, 36(1), pp. 91–104. doi: 10.1080/02607470903462222.

Circle Economy (2018) *Circle Economy – practical, scalable implementation of the circular economy*. Available at: https://www.circle-economy.com/ (Accessed: 21 November 2018).

Clandinin, D. J. and Connelly, F. M. (1994) 'Personal experience methods', in *Handbook of qualitative research*. Thousand Oaks, CA, US: Sage Publications, Inc, pp. 413–427.

Clark, B. R. (1998) 'The entrepreneurial university: Demand and response [1]', *Tertiary Education and Management*, 4(1), pp. 5–16. doi: 10.1080/13583883.1998.9966941.

Crabbe, A. (2008) 'The Value of Knowledge Transfer Collaborations to Design Academics', *The Design Journal*, 11(1), pp. 9–28. doi: 10.2752/175630608X317887.

Creative Clusters (2018) *Creative Industries Clusters Programme, AHRC Creative Economy Programme*. Available at: https://ceprogramme.com/cicp (Accessed: 21 November 2018).

Cross, N. (2007) *Designerly ways of knowing*. Basel: Birkhäuser.

D'Este, P. and Patel, P. (2007) 'University–industry linkages in the UK: What are the factors underlying the variety of interactions with industry?', *Research Policy*, 36(9), pp. 1295–1313. doi: 10.1016/j.respol.2007.05.002.

Disrupting Patterns (2018) 'Disrupting Patterns: Designing for Circular Speeds'. Chelsea College of Arts, 23 November. Available at: https://www.eventbrite.co.uk/e/52052886585?aff=efbneb (Accessed: 21 November 2018).

Earley, R. (2017) 'Designing Fast & Slow. Exploring fashion textile product lifecycle speeds with industry designers', *The Design Journal*, 20(sup1), pp. S2645–S2656. doi: 10.1080/14606925.2017.1352776.

Etzkowitz, H. (1983) 'Entrepreneurial Scientists and Entrepreneurial Universities in American Academic Science', *Minerva*, 21(2/3), pp. 198–233.

Etzkowitz, H. and Leydesdorff, L. (1995) 'The Triple Helix -- University-Industry-Government Relations: A Laboratory for Knowledge Based Economic Development', *EASST Review*, 14(1), pp. 14–19.

Farrer, J. (2000) *Wool: from straw to gold: an ecological assessment of the lifecycle of wool from cradle to grave and beyond resulting in yarns composed of 100% post consumer waste*. Royal College of Art. Available at: https://researchportal.port.ac.uk/portal/en/theses/wool(7e0cff0d-33df-4717-9172-24ef43f85720).html (Accessed: 2 October 2017).

Fleet, D. *et al.* (2016) 'A case for taking the dual role of counsellor-researcher in qualitative research', *Qualitative Research in Psychology*, 13(4), pp. 328–346. doi: 10.1080/14780887.2016.1205694.

Fowler, N. (2017) *Walking The Plank of The Entrepreneurial University: The little spin-out that could?* Doctor of Philosophy. Uppsala University, Faculty of Science and Technology. Available at: http://uu.diva-portal.org/smash/record.jsf?aq2=%5B%5B%5D%5D&c=21&af=%5B%5D&searchType=LIST_COMING&query=&language=sv&pid=diva2%3A1066548&aq=%5B%5B%5D%5D&sf=all&aqe=%5B%5D&sortOrder=author_sort_asc&onlyFullText=false&noOfRows=50&dswid=-7972 (Accessed: 2 October 2017).

Gaver, B. and Bowers, J. (2012) 'Annotated portfolios', *interactions*, 19(4), p. 40. doi: 10.1145/2212877.2212889.

Gee, N. C. (1950) *Shoddy and Mungo Manufacture: Its Development, Ancillary Processes Methods and Machinery*. 1st edition. Emmott.

Goldsworthy, K. (2012) *Laser-finishing: a new process for designing recyclability in synthetic textiles.* phd. University of the Arts London. Available at: http://ualresearchonline.arts.ac.uk/11638/ (Accessed: 31 January 2018).

Govender, C. M. and Taylor, S. (2015) ‘A WORK INTEGRATED LEARNING PARTNERSHIP MODEL FOR HIGHER EDUCATION GRADUATES TO GAIN EMPLOYMENT’, *South African Review of Sociology*, 46(2), pp. 43–59. doi: 10.1080/21528586.2015.1009857.

Heale, R. and Forbes, D. (2013) ‘Understanding triangulation in research’, *Evidence - Based Nursing; London*, 16(4), p. 98. doi: http://dx.doi.org.arts.idm.oclc.org/10.1136/eb-2013-101494.

Hewitt-Taylor, J. (2002) ‘Inside knowledge: issues in insider research’, *Nursing Standard (Royal College of Nursing (Great Britain): 1987)*, 16(46), pp. 33–35. doi: 10.7748/ns2002.07.16.46.33.c3239.

Hofbauer, K. G. (2008) ‘Academic institutions and industry: bridging the gap’, *Expert Opinion on Drug Discovery*, 3(4), pp. 369–373. doi: 10.1517/17460441.3.4.369.

Huber-Lang, M. and Neugebauer, E. (2011) ‘The dual role of academic surgeons as clinicians and researchers - an attempt to square the circle?’, *Patient Safety in Surgery*, 5(1), p. 16. doi: 10.1186/1754-9493-5-16.

Igoe, E. (2013) *In textasis : matrixial narratives of textile design*. Royal College of Art.

Jain, S., George, G. and Maltarich, M. (2009) ‘Academics or entrepreneurs? Investigating role identity modification of university scientists involved in commercialization activity’, *Research Policy*, 38(6), pp. 922–935. doi: 10.1016/j.respol.2009.02.007.

Kitchener, K. S. (1988) ‘Dual Role Relationships: What Makes Them So Problematic?’, *Journal of Counseling & Development*, 67(4), pp. 217–221. doi: 10.1002/j.1556-6676.1988.tb02586.x.

Lam, A. (2010) ‘From “Ivory Tower Traditionalists” to “Entrepreneurial Scientists”?: Academic Scientists in Fuzzy University—Industry Boundaries’, *Social Studies of Science*, 40(2), pp. 307–340. doi: 10.1177/0306312709349963.

Lincoln, Y. S. and Guba, E. G. (1985) *Naturalistic Inquiry*. 1 edition. Beverly Hills, Calif: SAGE Publications, Inc.

Mercer, J. (2007) ‘The challenges of insider research in educational institutions: wielding a double-edged sword and resolving delicate dilemmas’, *Oxford Review of Education*, 33(1), pp. 1–17. doi: 10.1080/03054980601094651.

Mistra Future Fashion (2018) *Mistra Future Fashion*. Available at: http://mistrafuturefashion.com/ (Accessed: 21 November 2018).

Mønsted, M. and Hansson, F. (2010) ‘Creating Space for Research: The Charismatic Entrepreneur as Research Director’, *Creativity and Innovation Management*, 19(1), pp. 47–56. doi: 10.1111/j.1467-8691.2009.00539.x.

Mujumdar, A. S. (2004) ‘Academic Research Vs Industrial R &D: A Comparison’. Powerpoint. Available at: https://www.arunmujumdar.com/file/Selected%20Presentations/Academic_Vs_Industrial_R&D.pdf (Accessed: 8 January 2019).

Paine, H. (2015) *Laser Shaping: A method for controlling the elastic behaviour of stretch fabrics for a targeted and graduated compressive effect on the body*. PhD Thesis. Royal College of Art.

Penfold, G. (2007) ‘Diversification, Design, Strategic Planning and New Product Development: A Jewellery Industry Knowledge Transfer Partnership’, *The Design Journal*, 10(1), pp. 3–11. doi: 10.2752/146069207789318036.

Phelan, K. V., Mejia, C. and Hertzman, J. (2013) ‘The Industry Experience Gap: Hospitality Faculty Perceptions of the Importance of Faculty Industry Experience’, *Journal of Hospitality & Tourism Education*, 25(3), pp. 123–130. doi: 10.1080/10963758.2013.826950.

Polanyi, M. (1958) *Personal knowledge: towards a post-critical philosophy*. London: Routledge.

Puia, G. M. *et al.* (2000) ‘The career transition from practitioner to academic’, *Career Development International*, 5(2), pp. 106–111. doi: 10.1108/13620430010318990.

Ræbild, U. and Bang, A. L. (2017) ‘Rethinking the Fashion Collection as a Design Strategic Tool in a Circular Economy’, *The Design Journal*, 20(sup1), pp. S589–S599. doi: 10.1080/14606925.2017.1353007.

Rogoff, B. (1995) ‘Observing sociocultural activity on three planes: participatory appropriation, guided participation, and apprenticeship’, in Wertsch, J. V., del Rio, P., and Alvarez, A. (eds) *Sociocultural studies of mind*. Cambridge: Cambridge University Press, pp. 139–164. doi: 10.1017/CBO9781139174299.008.

Saidin, K. and Yaacob, A. (2016) ‘INSIDER RESEARCHERS: CHALLENGES & OPPORTUNITIES’, in *Proceeding of ICECRS. International Seminar on Generating Knowledge Through Research*, Malaysia, pp. 849–854. Available at: https://www.researchgate.net/publication/317080260_INSIDER_RESEARCHERS_CHALLENGES_OPPORTUNITIES (Accessed: 9 November 2018).

Santoro, N. and Snead, S. L. (2013) ‘“I’m not a real academic”: a career from industry to academe’, *Journal of Further and Higher Education*, 37(3), pp. 384–396. doi: 10.1080/0309877X.2011.645457.

Sauerwein, M., Bakker, C. and Balkenende, R. (2018) ‘Annotated Portfolios as a Method to Analyse Interviews’, in *DRS2018. Catalyst for Change*, University of Limerick: Scribd, pp. 1148–1158. Available at: https://www.scribd.com/document/382349704/DRS2018-Vol-3#download (Accessed: 24 July 2018).

Schön, D. A. (1983) *The reflective practitioner: how professionals think in action*. London: Temple Smith.

Schuetz, A. (1944) ‘The Stranger: An Essay in Social Psychology’, *American Journal of Sociology*, 49(6), pp. 499–507. doi: 10.1086/219472.

Schutze, H. G. (2000) ‘Industrial Innovation and the Creation and Dissemination of Knowledge: Impications for Universitity-Industry Relationships’, in OECD, *Knowledge Management in the Learning Society*. OECD Publishing.

Smyth, A. and Holian, R. (2008) ‘Credibility issues in research from within organisations’, in Sikes, P. J. and Potts, A., *Researching Education from the Inside*. Routledge, pp. 33–47. Available at: https://researchbank.rmit.edu.au/view/rmit:10876 (Accessed: 9 November 2018).

Tijssen, R., Lamers, W. and Yegros, A. (2017) ‘UK universities interacting with industry: patterns of research collaboration and inter-sectoral mobility of academic researchers’, *Centre for Global Higher Education working paper series*, 14. Available at: https://www.researchcghe.org/perch/resources/publications/wp14.pdf (Accessed: 7 November 2018).

Trash-2-Cash (2018) *Trash2Cash EU funded project, taking waste & making new fibres, Trash-2-Cash*. Available at: https://www.trash2cashproject.eu/ (Accessed: 21 November 2018).

Tufte, E. R. (2001) *The Visual Display of Quantitative Information*. 2nd edition edition. Cheshire, Conn: Graphics Press USA.

Unluer, S. (2012) ‘Being an Insider Researcher while Conducting Case Study Research’, *Qualitative Report*, 17. Available at: https://eric.ed.gov/?id=EJ981455 (Accessed: 7 November 2018).

WRAP (2012) *A review of commercial textile fibre recycling technologies*. Oakdene Hollins. Available at: http://www.wrap.org.uk/system/files/private/Commercial%20textile%20fibre%20recycling%20technoloogies%20report.pdf (Accessed: 7 December 2017).

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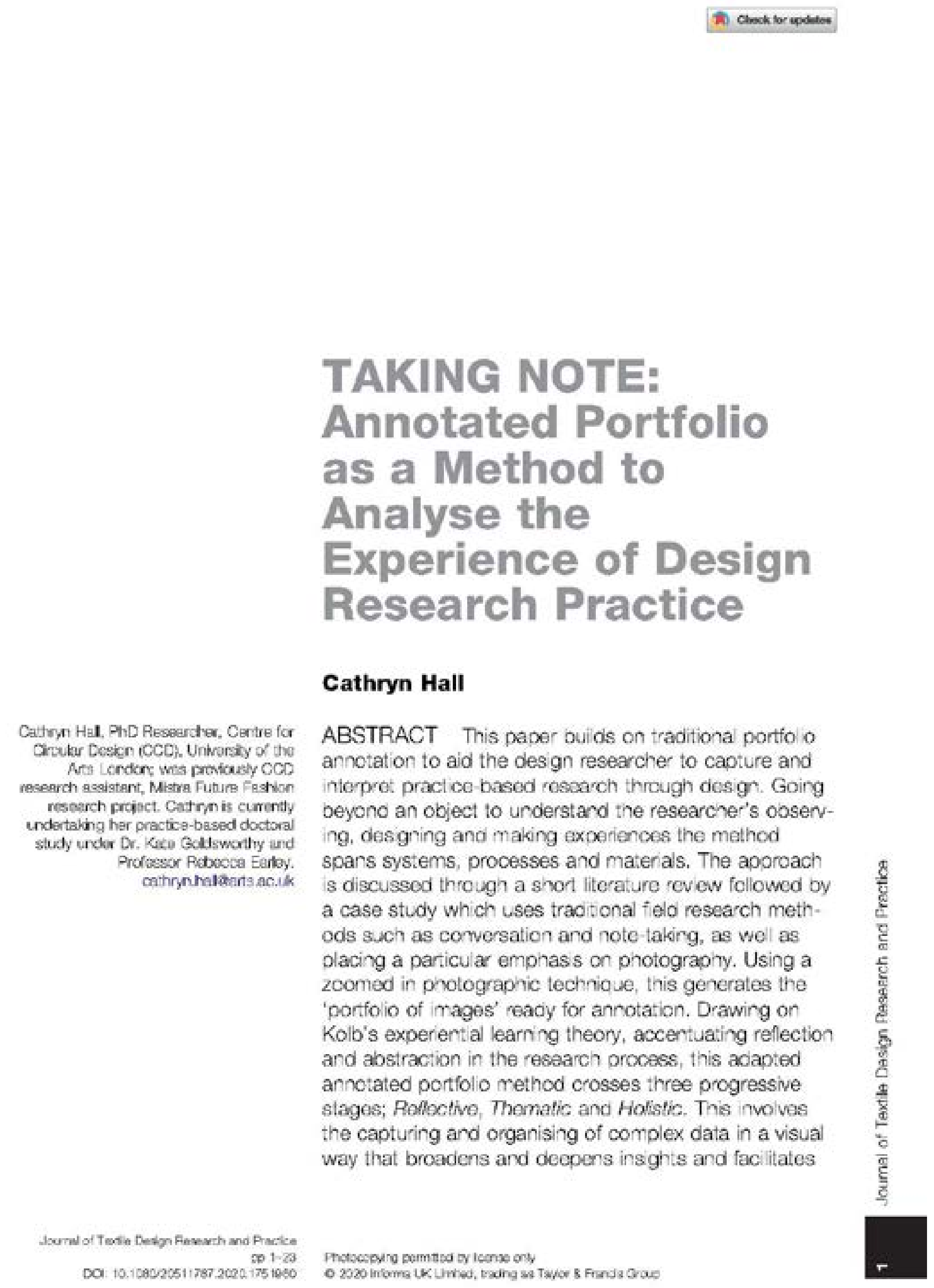
14.8.3 TAKING NOTE



TAKING NOTE: Annotated Portfolio as a Method to Analyse the Experience of Design Research Practice

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ABSTRACT This paper builds on traditional portfolio annotation to aid the design researcher to capture and interpret practice-based research through design. Going beyond an object to understand the researcher's observing, designing and making experiences the method spans systems, processes and materials. The approach is discussed through a short literature review followed by a case study which uses traditional field research methods such as conversation and note-taking, as well as placing a particular emphasis on photography. Using a zoomed in photographic technique, this generates the 'portfolio of images' ready for annotation. Drawing on Kolb's experiential learning theory, accentuating reflection and abstraction in the research process, this adapted annotated portfolio method crosses three progressive stages; *Reflective*, *Thematic* and *Holistic*. This involves the capturing and organising of complex data in a visual way that broadens and deepens insights and facilitates

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peer communication. This provides an approach to enable researchers to bridge the gap between academic research and design practice. It is hoped that the method proposed in this paper not only aids the abstraction through to creation of new knowledge for the design researcher but could also have relevance to other disciplines.

KEYWORDS: Annotated portfolio, experience, methods, textile design, industry, research through design

1. Introduction

Koskinen et al. (2011) assertion that "good design research is driven by understanding rather than data" forms the basis for this paper's proposition, which presents the annotated portfolio approach as a method for designers to more deeply understand the research situations they are a part of. It is an adapted approach, building on existing literature, to recognise the role of the designer's research 'experience' which might include observing, designing and making towards the creation of new knowledge. Historically, this approach has been used to support the analysis of objects with text. Yet more recently it has been brought to the field of Research through Design (RtD) with examples such as supporting analysis of designer interviews (Sauerwein, Bakker and Balkenende, 2018).

This paper is split into two parts. Firstly, a short literature review of the annotated portfolio approach, outlining the body of knowledge upon which this paper builds. Secondly, a case study of the author's practice-based Ph.D. research is presented as a way to contextualise the discussion. This was formed of multiple field experiences visiting and testing textile recycling practices in industrial facilities. Although only one main example is given in this paper, the method itself has been developed by the author across multiple iterations in order to investigate best practice for textile recycling processes similar to the one presented here. For example, visiting the wool recycling industry in Prato, Italy (Hall, 2018) and testing non-woven recycling in the UK (Hall and Earley, 2019).

Using a field research approach (Koskinen et al., 2011), conversation, note-taking and primarily photography were used to capture memories of the experience. This results in a 'portfolio' of key images of the experience around which annotations could be added. The images in this case act like an object, by becoming an abundant source of information about the event captured. This is contextualised using Kolb's 2015 experiential learning theory suggesting that 'learning' is achieved by an individual across four stages: experience, reflection, abstraction and experimentation. The original annotated portfolio approach presented by Gaver and Bowers (2012), it is argued here, combines the middle two of Kolb's stages: reflection and abstraction. By reflecting and abstracting the researcher can grasp and transform information in order to 'learn'. In this adapted method the annotated portfolio allows the 'abstraction' of data that has been observed and experienced to provide a means for effective analysis.

The method discussed here is presented across three progressive stages – *Reflective, Thematic and Holistic* – enabling insights to be captured, grasped and deeply understood for analysis. Visualisation, in the form of photographs and accompanying annotations, is used as a tool to effectively deal with the complex and often large volumes of annotations. These visuals create an additional layer of analysis and importantly aid clarity, which might benefit the researchers understanding and the communication of the research results to peers. It is hoped that this approach might not only aid designer-researchers but also other stakeholders across a wider context of disciplines to produce tangible data from any research experience; leading to the generation of new knowledge.

2. Context

RtD is a discipline, according to Zimmerman and Forlizzi (2014), which has expanded design practices and processes to generate new knowledge. Zimmerman, Forlizzi and Evenson (2007) argue that RtD within the field of Human Computer Interaction (HCI) can involve making prototypes, products, and models to understand a particular situation and to frame the research problem. Designers make these artefacts to reveal and become embodiments of possible futures (Zimmerman and Forlizzi, 2014). However, the RtD approach has been criticised by Koskinen et al. (2011) for failing to appreciate the many things at work behind effective design research. They call this 'constructive design research', in which the process of construction takes the centre stage as a means to generate knowledge. They present this as three key approaches that can integrate design-specific work methods into research: Lab, Field and Gallery. The field approach, Koskinen et al. (2011) outline, can be particularly informative when there is no obvious translation of a design object's meaning. Researchers using this approach, they argue, follow design within its context.

Within the area of HCI Gaver (2012) describes the move of designers bringing artefacts and systems through to field testing to address possibilities and problems. This, he reflects, can produce 'topical, procedural, pragmatic and conceptual insights'. This is expanded by Gaver and Bowers, (2012) by their proposition that design theory is embedded in the design examples which underpin them. Communicating in this way escapes from the rigidity of a scientific criteria of the contribution of new knowledge. Löwgren (2013) supports this, advocating that design researchers look inside their own discipline for research methods, and annotated portfolio is one such method which achieves this.

2.1. Annotated Portfolio

The creation and annotation of portfolios is common practice for the designer within education and industry. This approach was brought to the discipline of RtD by Gaver and Bowers (2012) in an attempt to address the issue that "works do not speak for themselves" (Bowers 2012). The method endeavours to capture design theory through an artefact. This, Gaver (2012) asserts, means that a designed object embodies the decisions and rationales of the designer which in turn forms the theory. He argues that these decisions and rationales are best captured in the form of annotations, short bodies of text around an image which explain and validate the design processes. When combining multiple annotated images these become a 'portfolio' which helps to build bridges between larger research issues. By annotating a portfolio, Gaver explains, it draws attention to important details and features which might otherwise be overlooked. These permit the capture of 'family resemblances'– a combination of similarities and differences – that not only inform but are mutually informative to one another. They are, in effect, inextricably linked. Yet fundamentally, as Gaver (2012) points out, it is the objects we create that are the 'definite facts' of RtD. The focus of this approach is placed on creating context to help design researchers analyse what has worked and why, providing what Löwgren (2013) describes as a level of abstraction in the creation of new knowledge. This is referred to as intermediate-level knowledge, which can be used to begin the process of bridging the gap between design practice and academic research.

In its original form the method involved attaching short notes to still images. As HCI designers Gavin and Bowers (2012) individually annotated photographs of HCI products and brought them together to create a body of design work, the annotated portfolio was formed (see Figure 1).

Gaver and Bowers (2012) emphasised that there is no one way to create an annotated portfolio. Others have used this approach by summarising the annotations in a body of academic text (Hobye, Padfield and Löwgren, 2013) or using them collaboratively between team members (Kelliher and Byrne, 2015). Annotations have also been used to reflect on the process narrative; discussing design choices as they occur over time or as a form of reflection and critique to progress successful design ideas and leave others behind (Pandey, Srivastava and Børsting, no date Srivastava and Culén, 2017). Finally, in the field of textiles, an annotated portfolio of material samples was used to extract insights for the development of business model concepts (Pedersen, Earley and Andersen, 2019).

Although the approach is in its infancy, Sauerwein, Bakker and Balkenende (2018) have adapted the original method of an annotated portfolio as an aid for the analysis of interviews. They have successfully interviewed designers specifically in relation to designed objects to identify the relation between 3D printing and sustainability. In this example it is not only the object discussed but also the qualitative data produced from the interview that is used to produce the annotated portfolio. They argue that the approach not only can support the abstraction of intermediate-level knowledge from the objects in question but also the communication of the insights emerging from interviews regarding design processes. This was achieved across three stages. Firstly, interviews are summarised into annotations and assigned to an image of the object under investigation. Secondly, colour coding is applied to establish categories and themes. Then, dotted lines are added to establish connections between annotations. These connections, they argue, would lead to a better understanding of the dominant themes and eliminates redundant themes (Figure 2).

Finally, multiple interviews are brought together by Sauerwein, Bakker and Balkenende (2018), to create a portfolio with annotated images from which categories and themes can be analysed. This use of the approach, particularly with the additional layer of colour coding, formalises the way that design researchers are able to draw out insights. Although - as repeatedly emphasised by both Gaver (2012) and Bowers (2012) - there is no single way in which to annotate a portfolio, the commonality is found in the information and insights obtained by performing the process. Until this point, however, no-one had provided any methods for analysis to draw together the insights and connections from the annotations; Sauerwein, Bakker and Balkenende (2018) address this gap. Although their approach provides scope for clearer connections between objects, they admit

Figure 1
Annotated Portfolio. Source: Gaver and Bowers (2012).
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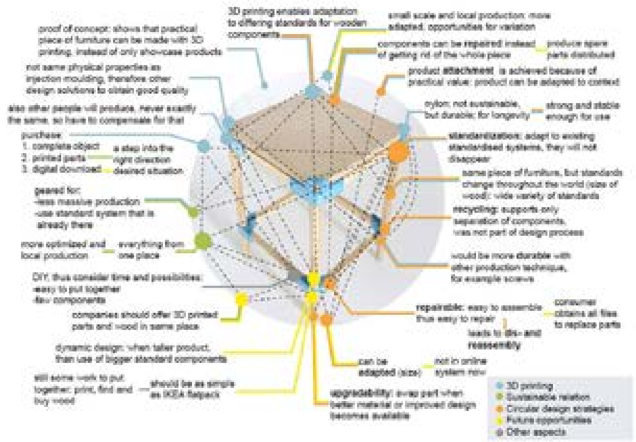

Figure 2

Coloured and connected annotations. Source: Sauerwein, Bakker and Balkenende (2018).

Figure 3

Visual annotations about a specific topic. Source: Sauerwein, Bakker and Balkenende (2018).

that the dotted lines stage might be confusing for outsiders. For further clarity they suggest that new diagrams with selective annotations should be produced based on the research question (see Figure 3).

3. Approach

This paper presents an adapted method to abstract 'intermediate-level knowledge', whereby the design 'object' is replaced with the field 'experience' of the researcher. In this chapter designerly field research methods (Koskinen et al., 2011) are discussed (3.1) and contextualised using Kolb's 2015 experiential learning theory (3.2). Finally, visualisation will be examined (3.3) as the key process used in the forming of this method.

3.1. The Field Approach

Traditional field research methodology (Burgess, 1984) is often borrowed by designers and rooted in industry to explore a design problem in a social context (Koskinen et al., 2011). This paper explores the inverse, by looking for solutions within an industrial context. Combining traditional field methods such as observation, conversation and documentation, alongside design led prototyping to enable the designer to imagine new things and not solely observe what exists (Koskinen et al., 2011).

The field approach put forward by Koskinen et al. (2011) is used by the author, as they suggest, to bring the designer into a naturalistic setting with a focus on the design in context. Koskinen et al., (2011) describe this approach as design ethnography that uses prototypes during fieldwork to create a dialogue, as is often applied in product design. Within the research presented in this paper, it is the experience of collaborating in an industrial setting in the field that positions the researcher in such a way that they are able to consider wider and future systems, alongside practice-based material sampling and development.

Both observation and conversation were used as a tool to deepen the understanding of the field and generate meaningful qualitative data. This data was documented using a mix of note taking, thick description (Denzin, 2001) and most successfully photography, which has been highlighted as tool in social research. In particular Collier's (1957) 'photo elicitation' was used to prompt memory and reduce misunderstandings. The photographs taken were produced using a zoomed-in technique, a focused activity engaging the individual and avoiding barriers such as the photo-taking-impairment effect (Henkel, 2014). This is where images of whole objects reduce memory of the object being photographed. Thus, memories of the experience are engendered within the photos, allowing for investigative and data driven enquiry, with reflective notes to be made after the event.

3.2. Experiential Learning and Reflection

The value of learning by experience has been widely studied particularly within education. Kolb's (2015) experiential learning theory identifies the process by which knowledge creation emerges through the continual transformation and application of experience. Usher and Solomon (1999) distinguish 'experiential learning' as knowledge derived through abstraction using methodological approaches such as observation and reflection. Similarly, Houghton and Ledington's

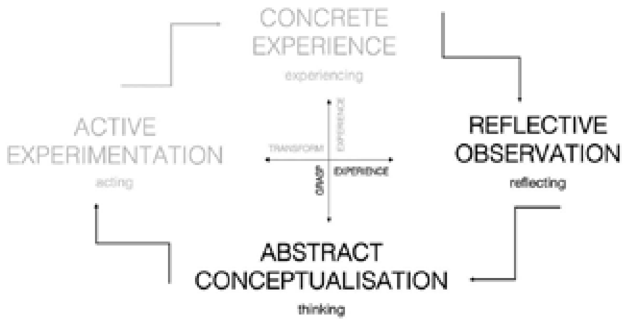

Figure 4
Experiential Learning Cycle highlighting the two key stages used in the annotated portfolio method. Adapted from: Figure 2.5 in Kolb (2015).

(2004) 'engagement approach' recognises experiences in real-world environments as essential to enhancing knowledge and creative problem solving.

This approach is framed using experiential learning and in particular Kolb's (2015) model which is presented in four stages. Firstly, the experience itself is followed by reflection. Then comes abstraction of insights and finally experimentation on what has been learnt. Kolb suggests that knowledge creation is the result of 'grasping' and 'transforming' the experience. *Grasping* in this context refers to the individual taking in the information. *Transforming* is therefore how the individual interprets and acts due to the experience. Within the context of this paper, stage one (the experience) is exhibited through the case study for which the learning is undertaken - the field research. The annotated portfolio approach spans the middle two stages – reflection and abstraction (Figure 4).

Reflection forms a key role in the annotation as the designer is immersed in the experience of a combination of reflective practice (Schōn, 1983, Igoe, 2013) with tacit knowledge (Polanyi, 1958) and designerly ways of knowing (Cross, 2007). All of which are used to draw data from the images after the event. Following reflection, abstraction takes place through the act of annotation. Finally, although outside of the scope of this paper, stage four - experimentation - would be implemented to complete the learning cycle and generate new knowledge. The same experiential theory has been used by the author in developing the method presented in this paper. The author has used Kolb's (2015) four stages - experience, reflect, abstract and experiment - across multiple industry collaborations. Through each iteration of using an annotated portfolio the author was able to test and improve the method to form the version presented here.

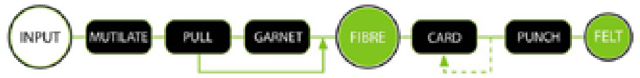

Figure 5
Simplified process of recycling textile into felt.

3.3. Visualisation

As with most annotated portfolio approaches the visual, often an image of an object, plays a vital role. In this approach the visual goes beyond just an image and is used as part of the 'abstraction' (Kolb 2015). Through the creation of many different stages of visualisation, specifically layering and separating information (Tufte, 2001), the approach provides clarity. This is combined with visual thinking methods in design (Ware, 2008) such as colour-coding and visual pattern making (organisation into a table format), which provide the space to make sense of the data created. Finally, it allows the designer to establish more easily the family resemblances (Gaver and Bowers, 2012) and connections (Sauerwein, Bakker and Balkenende, 2018) between annotations, which forms the key element of the approach.

4. Case Study: In the Field

The paper focuses on textile research based within the framework of a Circular Economy. The most recent Ellen McArthur Foundation (EMF) report 'towards a new textiles economy' calls for radical improvement in recycling, alongside increased collaboration and alignment with industry to create wide system changes (EMF, 2017). It is within this context that this research is situated.

Although this paper will refer to multiple field visits within the larger context of the author's Ph.D. thesis, to maintain clarity the focus has been placed on the one described below. The case study is presented only briefly to ensure that the method presented, rather than the case study content, remains the focus of the discussion.

The field visit referred to was arranged in collaboration with a single recycling company, from now referred to as 'the recycling company'. They specialised in a traditional needle punching technique, a common route for the recycling of unwearable textiles. A simplified diagram has been produced of this recycling process from input to final material indicating the areas of research inquiries (Figure 5).

A trial was arranged to test available machinery at the recycling company. This was specifically established to understand if the garnetting stage, a more specialised version of pulling that enables the return of textile garments back to their original fibrous state (Gee, 1950), could be avoided due its high financial cost. The four lines of inquiry were as follows:

1. Could the garments be pulled using the recycling company's machine?

2. Would the fibre produce a good quality felt material after a single carding process?
3. Could duplicating the carding process achieve a similar effect to garnetting?
4. What were the implications for the felt material that was produced?

This particular case study is set within a larger Ph.D. project, in which the mechanical recycling system of unwearable textiles is being investigated from a design perspective, with the aim of understanding the current system, the development of recycled textiles and their applications. Therefore, wider areas of inquiry were also being considered.

The development of the approach presented in this paper was catalysed by many failed attempts made by the author to generate tangible data out of her own field research. Much of the Ph.D. research has been accomplished within an industrial field that involved visiting factories, speaking with busy professionals, and negotiating the testing of recycled materials. In this setting, having conversations on the move made it difficult to capture thorough field notes. Quick picture taking was used as a method to aid the memory of the experience in lieu of these detailed notes. Often the most crucial insights would not be considered until after the event, frequently on the journey home or weeks later when looking through the pictures. Capturing, drawing together and reflecting on this data in the moment and afterwards placed a burden on the author's memory and prompted her search for a formal method.

5. The Method

This section will discuss the annotated portfolio approach as used to abstract design insights from designerly field practice. To complement Gaver and Bowers' emphasis on annotating a design *object*, this paper places the researcher's experience of the design process as central to deriving insights. This is a new approach which, to the author's knowledge, has not been proposed before. It is presented across three stages – *Reflective*, *Thematic* and *Holistic* (Table 1). Each of these stages builds on the previous one creating a new layer for analysis, and these are outlined in detail below.

As previously noted, this paper focuses on the method rather than the content drawn from the case study. The figures in this paper are presented here to demonstrate the weight and placement of annotations visually. Although the text might be read for context this is not the focus.

Table 1 Three approaches for experience based annotated portfolio

THREE STAGES	
REFLECTIVE	Self-reflective information about what happened and why
THEMATIC	Themed insights from zoomed-in experiments
HOLISTIC	Over-arching conclusions (systems)

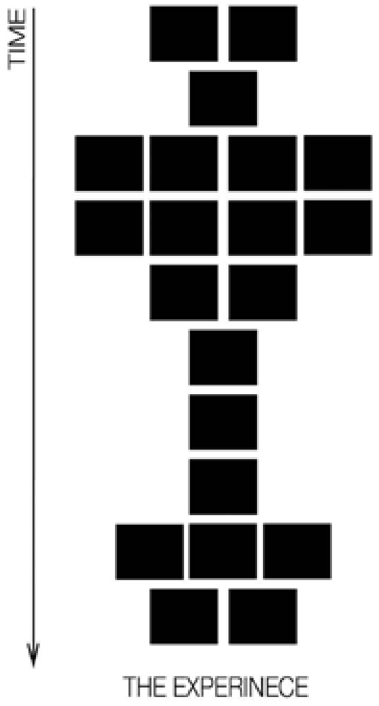

Figure 6
Experience-based annotated portfolio laid out across time.

5.1. Creating an Annotated Portfolio for Experience

In order to create an annotated portfolio a visual is required. However, when it comes to capturing experience, this can be more complicated than just a single image. Often a sequence of images is needed to provide an overview of what happened. This can initially involve gathering a large number of photographs and then reducing them to an essential series. For clarity and organisation these should be laid out in a vertical timeline format; beginning to end. After which similar images can be placed horizontally to form clusters of detail (Figure 6).

After this, annotations can be added from a variety of sources – field notes, memories or tacit knowledge – and are placed as close as possible to the relevant image. This allows for connections to be made between the experience, the image and the annotation itself for the sake of clarity. This is illustrated in Figure 7.

5.2. Reflective

Annotating an experience using photographs allows for the capture of thoughts, memories, questions and insights during, as well as

Figure 7
Experience-based annotated portfolio.

Table 2 Reflective approach categories

	REFLECTIVE APPROACH
INVESTIGATION	Questions generated by and answered by the trial
DATA	The process and material prototyping, observed insights and understandings
REFLECTION	Thoughts and comments. Anything noted outside of the main focus and how this relates to the experience

after, it has taken place. Often insights are not considered at the time and can be extracted as a form of reflection. It was found that annotations were often created in response to the following enquiries:

- What was the investigation? What did you want to find out?
- What events happened? What did you learn?
- Why/How did you learn this? What can you take forward?

It is these three clusters of questions that help form a guide for the researcher as they begin annotating; they also enable classifications for analysis. These have been simplified into three categories - *Investigation, Data and Reflection* (see Table 2 and Figure 8).

Figure 8
Colour coded annotations – Investigation, Data and Reflection.

Figure 9
Table of Annotations.

As shown in Figure 9 when the annotations have been created, colour coding can be used to classify each annotation into one of three categories. Compared to the analysis of a single object, an experience is inevitably more complex to capture and therefore increased annotations are to be expected. This forms a complex visual, and the more annotations, the more important it is to organise the data. In addition to colour coding the data can then be organised into columns, much like a table, corresponding to the three categories for analysis (see Figure 9). To maximise clarity, annotations need

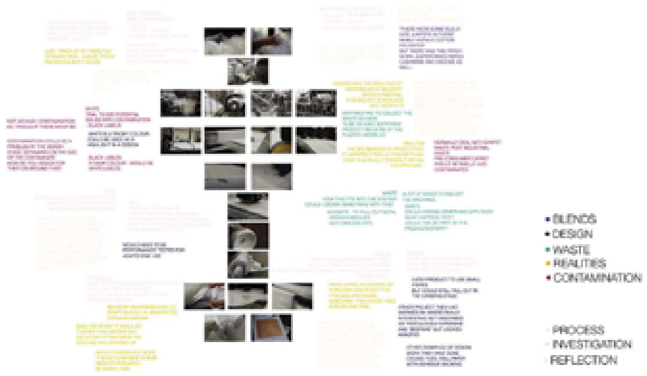

Figure 10
Thematic annotated portfolio of an experience.

to stay horizontally aligned with the relevant photograph. This allows the researcher to make connections which otherwise might go unnoticed.

5.3. Thematic

The Thematic stage builds specifically on Sauerwein, Bakker and Balkenende's (2018) categorisation by theme. New colours - different from those used for colour coding the reflective stage - are assigned to the annotations which fall under a particular theme. These are often influenced by the over-arching research questions being asked. Annotations at this stage may need to be split into sections of colour or repeated if they fall across multiple themes. Not all annotations will be relevant for the selected themes and may remain under the generalised 'Reflective' categories previously introduced. These can be removed (although not forgotten) as shown in Figure 10. Through this Thematic stage, additional annotations can be introduced as memories are invoked. This analysis can be viewed as a work-in-progress, a tool which can be built on over time. As with the Reflective stage, the visual created can remain complex and therefore needs organisation.

When the annotations are transferred to a table (Figure 11) this new visual diagram can be analysed like a bar chart. The instant visual information immediately highlights where the insights predominantly lie. As in Figure 11 we can see that the majority of insights were related to the theme of 'Realities'.

5.4. Holistic

Finally comes the Holistic stage; this follows the traditional annotated portfolio method (Gaver and Bowers, 2012) and involves collecting

Figure 11
Thematic annotated portfolio of an experience in a table/bar chart format.

multiple annotated experiences to be compared and contrasted. In this example the design researcher has applied the same annotated portfolio approach (Reflective and Thematic) to two further related experiences to form Experiences 1, 2 and 3. This included colour coding and visualising into a table as described above. It is important when applying the themes that they are consistent across each annotated experience. The themes can then be holistically analysed as the name of this stage suggests. At this point, the already complex visuals are being effectively brought together to handle what might otherwise be felt to be an overload of information (Figure 12).

Out of the table that has been created in the Thematic stage all three tables need to be combined so that connections can be made. It now becomes vital to keep all themes simultaneously visible as the focus on a single theme might limit salient insights. It is through the action of organising and dealing with complex information in this way that the most interesting findings can be uncovered.

As shown in Figure 13, when transferring information from each experience into a table, the author found it necessary to keep annotations in rows that correspond to their respective experience; 1, 2 or 3. This forms the basis of the Holistic approach and produces an instant bar chart visual and allows for an easy comparison between each experience before the annotations themselves can be analysed.

6. Discussion

This section provides discussion of the method's context and further considers how the method has adapted object as experience. It concludes by considering the limitations of the method.

6.1. Annotated Portfolio for Experience in Context

Sauerwein, Bakker and Balkenende's adapted annotated portfolio approach, presented at the Design Research Society Conference in Limerick in 2018, inspired the method presented here to capture experiential data and facilitate new insights. The method presented draws on the key aspects of Gaver and Bowers' (2012) original method, using images and bodies of text to aid analysis. It continues

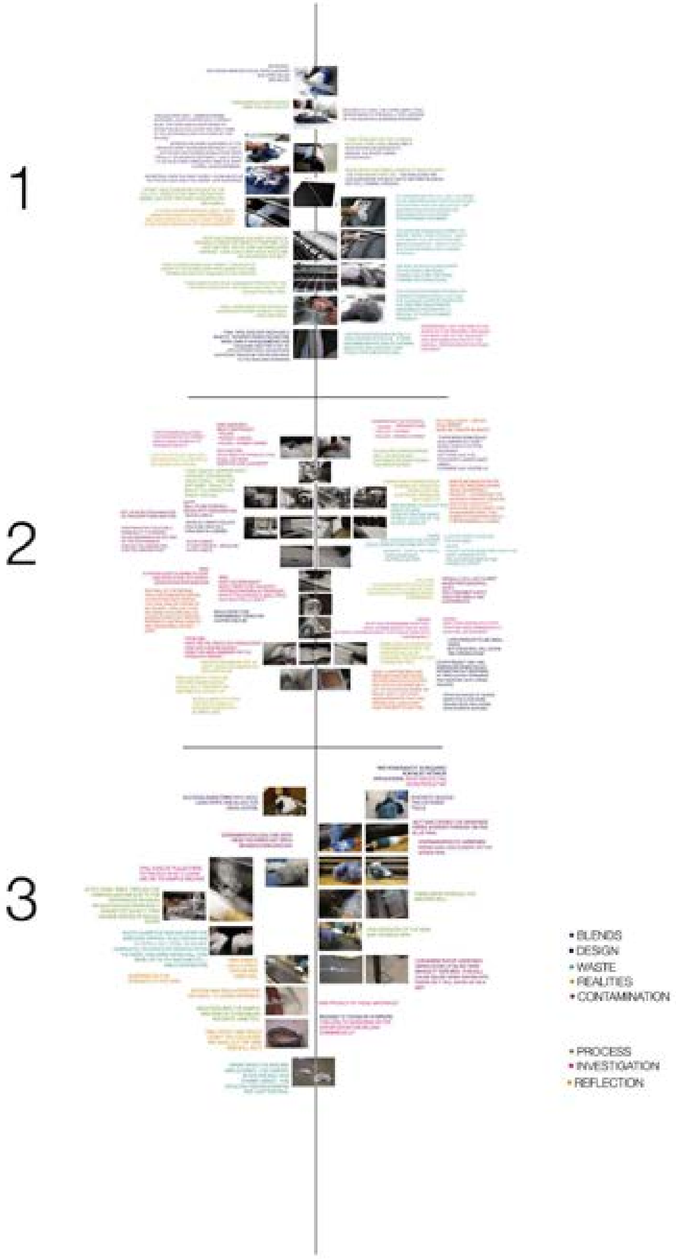

Figure 12
Holistic annotated portfolio.

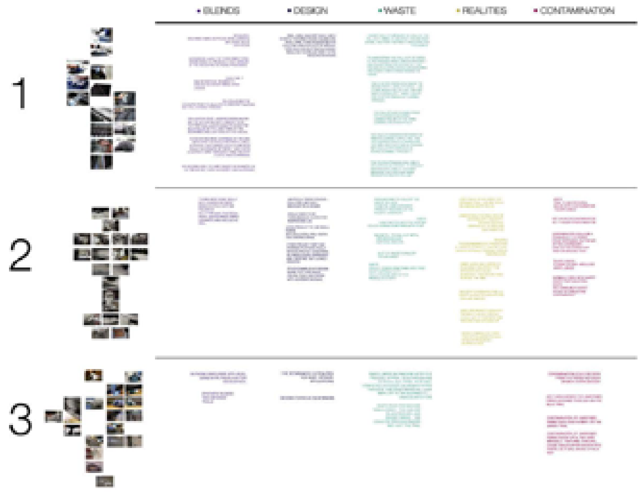

Figure 13
Holistic annotated portfolio of an experience in a table/bar chart format.

by building on Sauerwein, Bakker and Balkenende's (2018) colour-coding technique to create clear visuals and develop connections for abstraction. From this base, the method is adapted for the purpose of understanding experience. Specifically, it brings together multiple types of information: pictures, field notes and reflective practice such as thick description and memories resulting from reflection after the event. Furthermore, the method creates clarity and coherence of annotations by organising them visually into a table/chart format.

The three stages, it is argued here – Reflective, Thematic and Holistic – force the designer-researcher to produce a data set and create a method for deeper analysis. The first stage forces a deep reflection on the event. The second step pulls together the information, enabling connections to be found to generate themes. Finally, the research can be drawn together with other experiences to find further commonalities. This forms what Löwgren (2013) describes as intermediate knowledge, in which insights and findings might be uncovered. Each stage has been developed in order to create a deeper understanding of the experience towards the creation of new knowledge.

An example of the kind of connections and fresh insights that can be drawn from this visual approach is summarised below and illustrated in Figure 14.

During the reflection stage of the case study presented, the focus of the investigation was on the design of the recycled material, specifically the types of end products that the company produced. The researcher, in this case, was told about a couple of different projects the recycling company had worked on in which recycled ceiling tiles and wallpaper were created. These types of end products were,

DESIGN
WHAT CAN BE DESIGNED WITH THIS?
WHAT SYSTEM WOULD THIS FIT INTO?
IS THERE A BUSINESS MODEL THAT COULD WORK WITH THIS MATERIAL?

OTHER EXAMPLES OF DESIGN WORK THEY HAVE DONE: CEILING TILES, WALLPAPER WITH ADHESIVE BACKING

OTHER PROJECT THEY HAD WORKED ON WHERE REALLY INTERESTING BUT DESCRIBED AS 'RIDICULOUSLY EXPENSIVE' AND 'BESPOKE' BUT LOOKED AMAZING!

I BUILT A RAPPORT WITH THE MANAGER WHILE WE WAITED. WE DISCUSSED HIS DAUGHTER. THIS LEAD TO OFFERING ME A LIFT TO THE STATION WHERE WE SPOKE ABOUT THE OTHER DESIGN PROJECTS THEY HAD WORKED ON. I WOULD NOT HAVE THOUGHT TO ASK THIS.

Figure 14
Connections.

however, reported to be bespoke and very expensive. After the reflection stage it was noted by the researcher that this information was established during a friendly chat on the car ride to the station and not during the formal factory visit or information exchange that took place beforehand. The insights gained in this situation, therefore, were not limited to the factual information provided by the recycling company. The process of using this method allowed the author to understand how and when information had been disclosed. In this example it was via a casual chat after the formal visit, which emphasises the importance of personal relationships in the research process.

Visual thinking within design (Ware, 2008) plays a vital role in the success of this approach throughout all three stages proposed. By organising the annotations visually this creates a deeper understanding of the experience on multiple levels, harnessing the visual pattern finding part of our brains to create the connections. It is these connections, argues Gaver and Bowers (2012) that form a main advantage to this method and overcome some of the limitations in prior approaches, such as Sauerwein, Bakker and Balkenende (2018).

6.2. Object as Experience

One could argue that Gaver and Bowers' original concept of the annotated portfolio assumed the experience or the process of creating an artefact to be entirely embedded in the object itself. Although the author does not disagree with this statement, not every design process results in an object or product. For this reason, designerly insights arising out of design and making processes can be lost. In this paper the 'field' where the product – or this case textile – is being developed is the site where the researcher actively participates, requesting prototyping in collaboration with industry. This spreads the focus across systems, processes and materials. It is this mixed *experience* of the researcher that is rich with insights and which has the potential to generate new knowledge. Although field research is used in this paper as a case study, design researcher experiences are broad and this approach might be used across many modes such as observing, designing and making. The *experience*, therefore, should be considered either in place of – or in addition to – the *object* to be annotated.

Shifting the focus from a designed *object* to a design *experience* creates the space for different levels of annotation to be incorporated

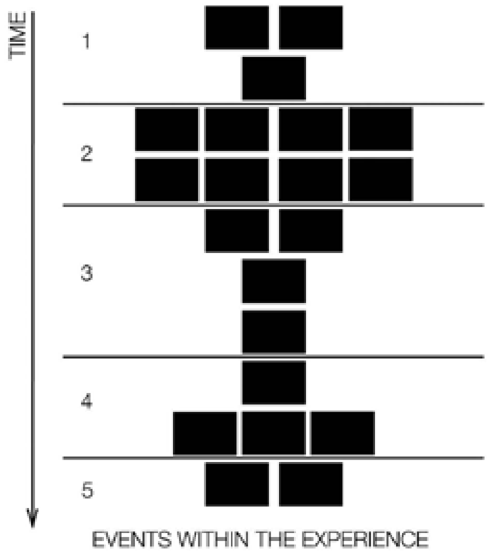

Figure 15
Simplified illustration of splitting an portfolio of experience into events.

since, as the author argues here, an *experience* is made up of multiple events. Figure 15 shows an illustration of how an experience might be split into events.

While each event could be analysed separately to form a portfolio, the complex nature of experience is often not as clear-cut as the simplified illustration in Figure 15 suggests. This is because the multiple events running through the experience often influence each other and it can be difficult to clearly separate them. Therefore, events should be understood as discrete but also accepted as part of a 'meshed' experience (Igoe, 2013). The author recommends the analysis of the experience as a whole without segregating it. If the experience is viewed as a series of interwoven events, although this creates a more complex portfolio, it will allow connections between similarities and differences to be more easily identified. Finally, once annotations are completed the result can be combined with additional annotated experiences to form an expanded portfolio for deeper analysis.

6.3. Limitations

Although this adapted method of annotated portfolio, for the experience of the design researcher, has been demonstrated to be a useful tool there are also limitations to this approach which must be discussed. The approach relies on the researcher being able to capture the relevant and key images during the experience. Reflection afterwards forms a crucial part in the generation of annotations. In this way the images are no more than an aid to reflection, meaning a missed image would not automatically cause missed insights. Reflection can still occur without the image, although would admittedly make the process more difficult.

One might argue that by taking detailed field notes, the researcher could go straight from notes to a table, thus omitting the annotation altogether. The author would argue in this case that thorough note-taking is not always appropriate in the moment. In this case study the author was unable to capture the detail whilst walking around the factory in conversation with professionals. Kolb's model emphasises the need to 'grasp' and 'transform' and avid note-taking might distract from the 'experiencing' and thereby obstruct this part of the process.

An experience is inevitably personal therefore its scope and boundaries need to be defined by the individual researcher. Thus, the images need to capture what is relevant to the research topic. Researcher bias is a limitation that needs to be addressed as in any field research. Bonner and Tolhurst (2002) identify the advantages of being an 'insider' researcher through an increased understanding of the situation, creating easier communication and better accuracy. Of course, unconscious biases as Hewitt-Taylor (2002) highlights, cannot always be avoided. The three-step method, as presented and argued here, becomes more important and might be used to overcome any snap judgements and conclusions made about a research experience. It is the process of reflecting and organising information in a method, such as this, that allows the researcher to produce more considered conclusions and try to overcome some of these challenges.

The process of organising the information is one of the most important parts of the approach. However, this lays open the risk of error when dealing with such a complex wealth of information. Error is more likely as annotations are moved into clearer visual formats. However, it is through this process, making sense of the information, that the analysis can be completed. Any researcher using this approach should take care to avoid errors, as with any research that is data heavy.

7. Conclusion

This paper has provided a new method of addressing how researchers can understand their experiences and produce tangible data in which to analyse and generate new knowledge. The method proposes placing annotations around a timeline of multiple key images of a research experience. This is then organised through three progressive stages to maximise the understanding of insights: Reflective, Thematic and Holistic. This approach addresses one of the issues raised by Sauerwein, Bakker and Balkenende (2018) in their version of an annotated portfolio method that the connections between annotations can be complex for both the researcher and their peers to understand. This method makes it possible for the researcher to capture, grasp and more deeply understand the situations and experiences that they are a part of and to communicate them more effectively. This aids the bridging of the gap between academic research and design practice.

It is hoped that this method provides a useful way in which designers across their disciplines can extract knowledge from their research experiences. Although the context of this paper is design focused this method is not limited to the design discipline and could be appropriated by other research fields. The method demonstrates a formal way of combining images, field notes, memories and reflections within researcher experience. Finally, it is noted that this paper has not considered if the three stages (reflective, thematic and holistic) could be used as individual approaches. This could be explored in further research.

Acknowledgements

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References

Bonner, A. and Tolhurst, G. 2002. "Insider-outsider perspectives of participant observation", Nurse researcher, 9(4), pp. 7–19.

Bowers, J. 2012. 'The logic of annotated portfolios: communicating the value of "research through design"', p. 10.

Burgess, R. G. 1984. *In the Field: An Introduction to Field Research*. London: Allen & Unwin.

Collier, J. 1957. "Photography in Anthropology: A Report on Two Experiments," *American Anthropologist*, 59(5): 843–859.

Cross, N. 2007. *Designerly Ways of Knowing*. Basel: Birkhäuser.

Denzin, N. 2001. *Interpretive Interactionism*. Thousand Oaks, CA: SAGE.

EMF. 2017. *A New Textiles Economy: Redesigning Fashion's Future*. London: Ellen Macarthur Foundation and Circular Fibres Initiative. Available online at: https://www.ellenmacarthurfoundation.org/\assets/downloads/publications/A-New-Textiles-Economy_Full-Report.pdf (Accessed: 3 January 2018).

Gaver, B. and Bowers, J. 2012. "Annotated portfolios," *Interactions*, 19(4): 40.

Gaver, W. 2012. "What should we expect from research through design?", in *Proceedings of the 2012 ACM annual conference on*

Human Factors in Computing Systems - CHI '12. the 2012 ACM annual conference, Austin, TX, USA: ACM Press, p. 937.

Gee, N. C. 1950. *Shoddy and Mungo Manufacture: Its Development, Ancillary Processes Methods and Machinery*. 1st edition. Manchester: Emmott.

Hall, C. and Earley, R. 2019. "Divide, Switch, Blend: exploring two hats for industry entrepreneurship and academic practice-based textile design research," *The Design Journal*, 22(sup1), pp. 19–35. doi: 10.1080/14606925.2019.1595848.

Hall, C. 2018. 'MIXING IT UP IN PRATO: identifying innovation hotspots within mechanical textile recycling', in Global Fashion Conference. What's Going On? A discourse on Fashion, Design and Sustainability, London: GFC. Available online at: https://docs.wixstatic.com/ugd/eb22a2_4a7b43538fbf45a7bc753a8a8ofb6aad.pdf (Accessed: 31 May 2019).

Henkel, L. A. 2014. "Point-and-Shoot Memories: The Influence of Taking Photos on Memory for a Museum Tour," *Psychological Science*, 25(2): 396–402.

Hewitt-Taylor, J. 2002. "Inside knowledge: issues in insider research", Nursing Standard (Royal College of Nursing (Great Britain): 1987, 16(46), pp. 33–35. doi: 10.7748/ns2002.07.16.46.33.c3239.

Hobye, M., Padfield, N. and Löwgren, J. 2013. "Designing Social Play Through Interpersonal Touch: An Annotated Portfolio", in *Nordic Design Research Conference proceedings. Nordic Design Research Conference* 2013, Copenhagen-Malmö. Available online at: http://muep.mau.se/bitstream/handle/2043/15811/hobye_etal_nordes_2013.pdf?sequence=2&isAllowed=y (Accessed: 5 December 2018).

Houghton, L. and Ledington, P. 2004. "The Engagement Approach to Real-World Problem Solving: Toward a Coherent Soft-Systems-Based Theoretical Platform for Real-World Problem Solving," *Systemic Practice and Action Research*, 17(5): 497–510.

Igoe, E. 2013. In *Textasis : Matrixial narratives of textile design*. Ph.D. Thesis. Royal College of Art.

Kelliher, A. and Byrne, D. 2015. "Design futures in action: Documenting experiential futures for participatory audiences," *Futures*, 70: 36–47.

Kolb, D. A. 2015. *Experiential Learning: experience as the Source of Learning and Development*. 2nd edition. Upper Saddle River, NJ: Pearson Education, Inc.

Koskinen, I., et al. 2011. *Design Research through Practice: From the Lab, Field, and Showroom*. San Francisco, CA: Elsevier Science & Technology.

Löwgren, J. 2013. "Annotated Portfolios and Other Forms of Intermediate-level Knowledge," *Interactions*, 20(1): 30–34.

Pandey, S., Srivastava, S. and Børsting, J. [no date] 'Annotated portfolios as process narratives'. University of Oslo. Available online at: https://www.uio.no/studier/emner/matnat/ifi/INF5591/h15/9591_paper.pdf (Accessed: 8 January 2019).

Pedersen, E. R. G., Earley, R. and Andersen, K. R. 2019. "From singular to plural: exploring organisational complexities and circular business model design," *Journal of Fashion Marketing and Management: An International Journal*, 23(3): 308–326.

Polanyi, M. 1958. *Personal Knowledge: Towards a Post-Critical Philosophy*. London: Routledge.

Sauerwein, M., Bakker, C. and Balkenende, R. 2018. 'Annotated Portfolios as a Method to Analyse Interviews', in *DRS2018. Catalyst for Change*, Scribd: University of Limerick, pp. 1148–1158. Available online at: https://www.scribd.com/document/382349704/DRS2018-Vol-3#download (Accessed: 24 July 2018).

Schön, D. A. 1983. *The Reflective Practitioner: how Professionals Think in Action*. London: Temple Smith.

Srivastava, S. and Culén, A. L. 2017. 'DESIGNING FOR THE SECOND-HAND USE OF CONSUMER GOODS', in *Proceedings of the International Conference Interfaces and Human Computer Interaction*, pp. 193–206. Available online at: https://www.duo.uio.no/bitstream/handle/10852/56753/secondHand-Final-%20IHCI.pdf?sequence=1&isAllowed=y (Accessed: 5 December 2018).

Tufte, E. R. 2001. *The Visual Display of Quantitative Information*. 2nd edition. Cheshire, CT: Graphics Press USA.

Usher, R. and Solomon, N. 1999. "Experiential learning and the shaping of subjectivity in the workplace," *Studies in the Education of Adults*, 31(2): 155–163.

Ware, C. (2008). *Visual Thinking for Design*. Amsterdam: Morgan Kaufmann (Morgan Kaufmann series in interactive technologies).

Zimmerman, J. and Forlizzi, J. 2014. 'Research Through Design in HCI', in Olson, J. S. and Kellogg, W. A. (eds.) *Ways of Knowing in HCI*, pp. 167–189. New York: Springer New York.

Zimmerman, J., Forlizzi, J. and Evenson, S. 2007. 'Research through design as a method for interaction design research in HCI', in *Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '07. the SIGCHI conference*, San Jose, CA: ACM Press, p. 493.

A New Way to Play

Textile recycling and the Circular Economy

Cathryn Anneka Hall

Cathryn Anneka Hall is a MA Textile Design graduate of Chelsea College of Arts and has been at Centre for Circular Design since 2015 – first as a research assistant and currently as a PhD candidate. Her research explores design for mechanical textile recycling for the circular economy, conducted with industry partners. Cathryn's expertise is circular design research in both teaching and consulting with industry partners.

Don't be nervous. Circularity is the captain and she is picking her players – nobody wants to be picked last. We are consistently reminded that Chemical Recycling, although appearing to be the best player on the team, can hog the ball and won't involve any of the other players. We still need training in Re-use and more practice shots with Re-manufacture, but it is Mechanical Recycling that is truly stuck on the side lines. Could there be a new way to play?

Textile recycling was born from a desire to reclaim wool and was quickly adapted to recapture cotton and then polyester. In 2006, the 'Well Dressed?' report condemned recycling technology for not progressing in over 200 years (Allwood *et al.*). Since this we have aspired to reach high-quality textile-to-textile recycling and chemical technology has boomed. In the wake of this invention we now find ourselves in a transition period, one where Chemical Recycling has not yet reached commercialisation. All the while academics start to call for new policies to advance chemical processes alone (e.g. Dahlbo *et al.*, 2018) leaving Mechanical Recycling on the bench. However, it is this established and now forgotten Mechanical Recycling industry that is still dealing with the worlds textile waste. At this point do not be mistaken in thinking I am arguing against the development of Chemical Recycling. Rather I will argue that recycling, like the circular economy, is a team sport. We need both Mechanical and Chemical Recycling to play together.

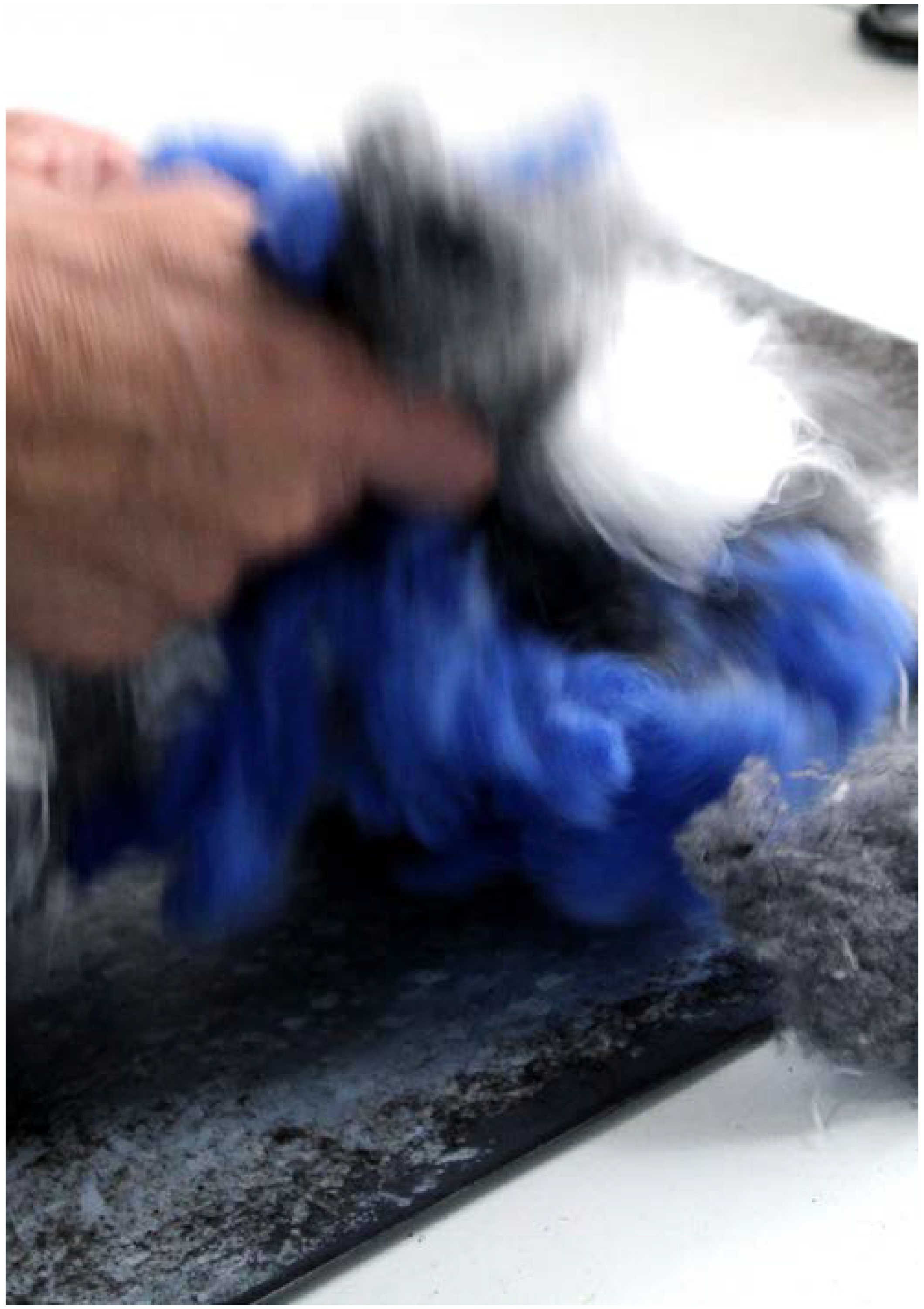
THE PROBLEM WITH MECHANICAL RECYCLING

The Mechanical Recycling of textiles is the process of ripping fibres from their cloth. It is because of this harsh process that recycled fibres reduce in length and therefore it is more difficult (but not impossible) to spin them into yarns (Merati and Okamura, 2004:640). Therefore, to process and extend the lives of the recycled fibre, it is often necessary to blend them with longer virgin ones. This practice has been conducted since the invention of recycling to return our textiles into clothing amongst other applications. For Chemical Recycling blending is not required, although much like in virgin textile production blending is used to create functional, creative and economic textile materials. Therefore, it often faces the same challenges.

THE PROBLEM WITH CHEMICAL RECYCLING

Chemical recycling is celebrated for its ability to return textile fibres to the same quality as virgin. This works particularly well with synthetic materials such as PET (polyethylene terephthalate, commonly known as polyester).

For wool, this chemical process is at lab stage and transforms the proteinous building blocks of the fibre into resins or wood-based adhesives but not textile applications (Bell *et al.*, 2017; Quartinello *et al.*, 2018). For cotton, chemical recycling has progressed in some cases to small-scale manufacturing levels. However,



Testing blends of mechanically recycled fibre.

the regenerated cellulosic textile generated from the process is different from the virgin cotton input. In simple terms, if you were to send a cotton shirt to a chemical recycling process the resulting fabric would be more like a viscose when it came out the other side. It is therefore not a direct replacement (WRAP, 2019; Östlund, Sverige and Naturvårdsverket, 2015). For example, the H&M Conscious Exclusive $20 dress made from partly Circulose® (2020) a chemically recycled cotton. The dress' composition is described as 100% viscose of which 50% is FSC certified wood and 50% is Circulose® recovered from post-consumer denim.

UNINTENDED CONSEQUENCES

The chemical recycling of wool textiles into resins, or cotton textiles into 'viscose like' fabrics is most certainly not something to be avoided. Rather I might suggest we need to consider the consequences of the systems we implement. We are reminded by Zink and Geyer (2017) of the 'Circular Economy Rebound' effect - the creation of materials that do not replace new production. If recycled materials are of lower quality or produced to solely enter new markets, they could create further demand.

> For the circular system to work, all players must work toward the team goal. The quality of Mechanically Recycled material must be upheld, and Chemically Recycled materials must directly replace virgin production.

IS TOGETHER BETTER?

The challenge of transitioning towards a circular economy remains. The two technologies, mechanical and chemical, are both imperfect in their own ways, but a shift towards team thinking is starting to emerge. During the Beyond Green: Zero Waste symposium (2016) Isaac Nicolson (working for Recovertex, a mechanical cotton recycler) described a future in which both mechanical and chemical technologies might work together. This counteracts the rhetoric that chemical is the substitution for mechanical. They can share the position switching at halftime to promote their own strengths on the field. This collaborative approach is now seen across large scale projects, such as Fibersort (2020a) by Interreg North-West Europe combining both technologies.

The approaches championed for resource longevity centre around promoting material loops (RSA, 2016). Goldsworthy (2014a: 1) highlights that we often forget that materials can outlive us, reminding us to take the long view. Sandin and Peters (2018) also acknowledge this potential. They propose a cascading approach, firstly through mechanical systems then, ultimately, flowing into chemical ones. For example, woollen textiles cascading across multiple applications, such as a knitted jumper to a woven upholstery fabric to a non-woven insulation product. Finally, the fibres would flow into a chemical system to be used as a resin, outside the textile remit. The problem of continued circulation, in this open loop, falls to another industry to solve.

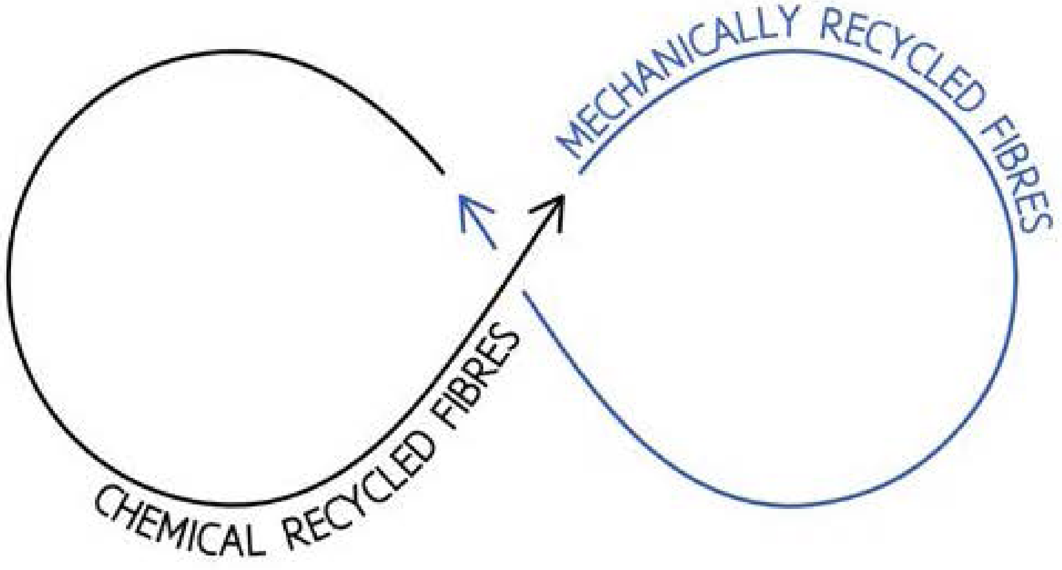


Illustration of a combined textile recycling system using both mechanical and chemical recycling technology.

Beyond linking the two systems together, what if the limitations of both Chemical and Mechanical Recycling could be used to support one another in a closed loop? Consider cotton: we have established that the resulting cellulosic material from the Chemical Recycling process is not a direct replacement for our cotton textiles. Therefore, in order to produce replacement a mechanical method is required. But these fibres need to be blended with longer virgin ones.

> So, what if our future chemically recycled fibres replaced virgin content as the blending agent? By using the chemically recycled cellulose (in replacement of virgin fibres) this would not only aid the mechanical recycling process but result in a fully recycled textile.

The blending of these two cellulosic materials, without contamination, ensures that the final textiles can, at the end-of-life, flow back into the chemical process. Recycling textile fibres in this combined way, illustrated in the graphic, means materials flow back and forth between both Chemical and Mechanical Recycling systems. This, ultimately, will extend the life of our textile resources. After all, in this circular economy game both processes are on the same team, sharing the same goal. Might this be the new way to play?

Notes

https://www.annekatextiles.co.uk/

Allwood, J. M., Laursen, S. E., Rodriguez, C. M. de and Bocken, N. M. P. (2006) Well dressed? the present and future sustainability of clothing and textiles in the United Kingdom. Cambridge: University of Cambridge, Institute for Manufacturing.

Bell, N. C., Lee, P., Riley, K. and Slater, S. (2017) Tackling Problematic Textile Waste Streams. Aylesbury UK: Oakdene Hollins Ltd. Available at: https://www.resyntex.eu/images/downloads/N%CBell TACKLING PROBLEMATIC TEXTILE WASTE STREAMS.pdf (Accessed: 4 December 2017).

Beyond Green: Zero Waste (2015) Beyond Green: Zero Waste - Circle Economy - Pakhuis de Zwijger. Available at: https://vimeo.com/148536718 (Accessed: 30 October 2017).

Circulose® (2020) CIRCULOSE. Available at: https://circulose (Accessed: 18 August 2020).

Dahlbo, H., Aalto, K., Eskelinen, H. and Salmenperä, H. (2015) 'Increasing textile circulation - Consequences and requirements', Sustainable Production and Consumption. doi: 10.1016/j.spc.2016.06.005.

Fibersort (2020) Fibersort: Overcoming barriers for long term implementation. Amsterdam, The Netherlands: Interreg North-West Europe and Circle Economy. Available at: https://guides.co/g/fibersort-overcoming-barriers-for-long-term-implementation-case-study/73034 (Accessed: 18 March 2020).

Goldsworthy, K. (2014) 'Design for Cyclability: pro-active approaches for maximising material recovery', Making Futures, 3. Available at: http://ualresearchonline.arts.ac.uk/5871/2/Cyclability%20Diagram.pdf (Accessed: 3 October 2017).

Merati, A. A. and Okamura, M. (2004) 'Producing Medium Count Yarns from Recycled Fibers with Friction Spinning', Textile Research Journal, 74(7), pp. 640-645. doi: 10.1177/004051750407400715.

Östlund, Å., Sverige and Naturvårdsverket (2015) Textilåtervinning: tekniska möjligheter och utmaningar. Stockholm: Naturvårdsverket.

Quartinello, F., Vecchiato, S., Weinberger, S., Kremenser, K., Skopek, L., Pellis, A. and Guebitz, G. (2018) 'Highly Selective Enzymatic Recovery of Building Blocks from Wool-Cotton-Polyester Textile Waste Blends', Polymers, 10(10), p. 1107. doi: 10.3390/polym10101107.

RSA (2015) Lessons from the Great Recovery 2012-2015. Available at: https://www.greatrecovery.org.uk/resources/rsa-report-lessons-from-the-great-recovery-2012-2015 (Accessed: 14 November 2017).

Sandin, G. and Peters, G. M. (2018) 'Environmental impact of textile reuse and recycling - A review', Journal of Cleaner Production, 184, pp. 353-365. doi: https://doi.org/10.1016/j.jclepro.2018.02.266.

WRAP (2019) Fibre to fibre recycling: An economic & financial sustainability assessment. UK: WRAP. Available at: https://www.wrap.org.uk/sites/files/wrap/Fibre-to-Fibre-report.pdf (Accessed: 4 February 2019).

Zink, T. and Geyer, R. (2017) 'Circular Economy Rebound', Journal of Industrial Ecology, 21(3), pp. 593-602. doi: 10.1111/jiec.12545