LASER-FINISHING:

A NEW PROCESS FOR DESIGNING RECYCLABILITY IN SYNTHETIC TEXTILES

A thesis submitted to the University of the Arts London in application for the Degree of Doctor of Philosophy

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Submitted: June 2012

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ABSTRACT

The main aim of this project was to find new tools and finishing techniques for designing recyclable, aesthetic 'surfaces' within the context of a 'closed cycle polyester economy' (Livingston, 2003). This can be explained as a mechanism of industrial ecology where all waste can be reused in a perpetual material metabolism or system.

Of the total textile fibre produced globally, up to 65% is lost, post-consumer, to landfill, incineration or composting. Of this, at least 50% is said to be recyclable (Laursen et al, 2005). In particular polyester, a synthetic fibre group derived from oil, is responsible for as much as 79% of the global synthetic fibre market, at 31.9 million tonnes in 2009 (Engelhardt, 2010), and therefore represents a significant proportion of this textile waste. Polyester is a thermoplastic material and as such is fully recyclable, thus making a closed cycle polyester economy a theoretical possibility. Therefore sending it to landfill is an unnecessary waste of a non-renewable resource. However, if this textile fibre is used without an understanding of its material make-up, this inherent recyclability can be inhibited.

Many design approaches to recycling are end-of-life interventions that can be described as 'extended life techniques' rather than 'design for recycling'. In order to design fully recyclable polyester textile products, potential barriers to recycling needed to be identified and 'designed out' at the production stages.

Current processing and finishing methods such as chemical coatings or lamination, commonly used in the industry's ever growing desire for performance and functionality, often create barriers to this continuous cycle, by mixing materials with different reprocessing needs into an irreversible state. These complex hybrid materials leave a legacy of waste and prevent inclusion in future fabrications (Allwood et al, 2006). If polyester textile products are preserved as monomaterials during their production they can be returned for reprocessing into virgin quality material over several cycles through chemical repolymerisation. The research set out to find new, technological alternatives to these traditional finishing techniques which could be employed to preserve monomateriality in polyester materials in order to work within the boundaries of a Cradle to Cradle metabolism (McDonough & Braungart, 2002).

Laser processing was selected as the most appropriate tool for development, because of its ability to manipulate thermoplastic materials through heat and its potential for flexible control through digital means. The resulting prototypes showed that several finishes which would normally need chemical coatings or adhesives could be achieved without any added agents.

In summary, this research contributes to knowledge firstly by proposing a new model for designing 'Cradle-to-cradle (C2C) textile products' that can contribute to a future closed-loop material economy and secondly by presenting a new application of laser-welding technology as a tool for the finishing of 100% polyester textiles which can be repolymerised at end-of-life.

ACKNOWLEDGEMENTS

I would like to thank my supervisors for their help and support throughout this project. My Director of Studies, Prof. Stephen Scrivener, and my supervisors Rebecca Earley and Prof. Kay Politowicz for their invaluable expertise and insight. I could not have wished for a better team. Also to the extended team at TED (Textiles Environment Design) who provided a dynamic and supportive environment within which so many inspiring conversations took place.

I would also like to thank the technical staff of Chelsea College of Art and Design and Goldsmiths University and in particular Michael Stickland and Andrew Weatherhead for their support and expertise during the early stages of the design work, and for their willingness to allow experimentation on some very expensive equipment.

Furthermore, thanks to the Advanced Materials and Processing department at TWI, Jo Lewis, Dr. Roger Wise and Dr. Ian Jones in particular, who gave valuable access to their technology in order to carry out my practice experiments and produce prototypes, and without whom I could not have completed this project.

I am grateful to the University of the Arts London and the AHRC for the doctoral scholarship, to the Materials KTN for the SPARK award which funded technology access and for the advice of the MaDE mentors, Linda Barron, Geoff Hollington and Ed Matthews.

In addition, special thanks to Carol Derby, Director of Environmental Strategy at DesignTex, New York for convincing me that there was value in my original proposal and that industry was looking for new solutions, and to Ros Hibbert of Line, London for invaluable experience during ten years of working within her design consultancy which provided a basis of understanding of the finishing and manufacturing industries.

Thank you also to staff at Central St Martins College of Art & Design, in particular Anne Smith, Dr. Janet McDonnell and Carole Collet, for their generosity in supporting the completion of this thesis during my time working with the Textile Futures team and to Peter Close for his impeccable proof reading.

Last but not least, I would like to thank my family who have given unwavering support throughout a very long journey. Without the help and support of all of the above mentioned people this work would not have been possible.

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1 INTRODUCTION

1.1 PREFACE

My fascination with thermoplastic materials and their transformative properties began during my studies at Duncan of Jordanstone College of Art & Design, while studying for my first degree in Printed Textiles. My final project (1996) included an exploration of thermoplastic material experiments where surface effects and finishes were created through hand techniques which used heat to transform the material's surface. This interest developed during my subsequent study on MA Textile Futures at Central Saint Martins College of Art and Design where my Masters project (2000) pushed these techniques further as a way to add value to recycled materials through design intervention and formed part of a project which looked at developing strategies for redesign.

At the same time I was working on research and development projects for the finishing industry through Line Consultants (1999-2005) and contributed to the publication 'Textile Innovation' (Hibbert, 2001), which opened my eyes to the scale and environmental impacts of the finishing processes I observed in a globally active industry.

I continued to incorporate these themes into my design practice (2002-2007) through a mixture of self-initiated and commissioned work where I began to use the laser as tool for imparting the heat required to manipulate the surfaces of the thermoplastic materials I was working with. The focus of my work at this time was the development of 'upcycled' textiles whereby, through refinishing low-value waste materials, I aimed to impart value through design. See figure 1.1 - 1.6 for examples of work completed during this time.

It was my involvement with the first practice led research projects 'Material' (Earley and Fletcher, 2001) and '5Ways' (Earley and Fletcher, 2003) to consider these themes, which planted the seed for the basis of this doctoral project where my previous experience comes together as a body of practice led research.

The PhD studentship itself was part of a larger research project (Worn Again: rethinking recycled textiles) funded by the AHRC and located within the TED (Textiles Environment Design) Research Cluster at Chelsea College of Art and Design. The Worn Again project aimed to investigate textiles recycling, looking to the textile design researcher/practitioner to propose significant change through the creation of high quality artefacts. The project offered the research community in this field a 'model for practice-based research for the upcycling of textiles' (Earley, 2011).

The project intended to explore both the 'hard' and 'soft' aspects of sustainable textile design, with the established principles of material and processes being considered, but also the technical and conceptual ideas. At the outset the project was concerned with incorporating four eco design strategies: Ethical Production; New Technology; Long Life / Short Life, or 'Fast' and 'Slow' Textiles and Design for Systems and Services. Applicants for the PhD studentship were invited to look at 'new technology' and recycling as a starting point and this was the basis for the following investigation.

1.2 AIMS & OBJECTIVES

The main aim of this project was to find new tools (finishing techniques) for designing recyclable, aesthetic 'surfaces' within the context of a 'closed cycle polyester economy' (Livingston, 2003).

In order to do this, potential barriers to the recycling of polyester textile materials needed to be identified and 'designed out' of the production stages through the development of new textiles, produced using appropriate clean engineering and finishing technology and made specifically for recycling.

To achieve the above aims the following objectives were identified:

- To conduct a review of the global textiles recycling industry (in particular polyester).
- To understand the role of design in current material recycling systems.
- To investigate and, where necessary, collaborate with industrial partners to develop new applications of clean finishing technology in order to produce a collection of innovative 'recycled and recyclable' textiles.
- To identify new synergies between material systems, production processes and design, through research and studio practice, and propose new models for 'designing-in' recyclability.

1.2.1 The Research Problem & Research Questions

The central research problem addressed within this thesis is:

How can synthetic textiles be designed for a 'closed loop material economy' utilising digital production processes?

In attempting to address this central research problem the following key questions are explored:

- What new finishing techniques might be enabled through use of laser technology?
- How might the laser be used to upcycle textile waste materials?
- How does design currently work within a life-cycle approach to recycling?
- How could a designer work within a 'C2C' framework considering materials as borrowed resources?
- How is polyester currently recovered and reprocessed?
- What are the key attributes of a fully recyclable polyester textile and what are the barriers to recyclability?
- How might this project fit within a future vision for manufacturing of local, interconnected, responsive production?

MultiSheer 100% recycled PET panel fabric produced to commission and exhibited at 'Design for Life: Eco Conscious Craft & Design for the Home ', The Yard Gallery, Nottingham, 2006

Photography: , Kate Parkin, 2006

FIGURE 1-1 MULTISHEER PROJECT, 100% RECYCLED PET PANEL FABRIC, 2006

MultiSheer 100% recycled PET panel fabric produced for exhibition at 'London Design Festival', The Royal Festival Hall, 2007

Photography: Full Focus, 2007

FIGURE 1-2 MULTISHEER PROJECT, 100% RECYCLED PET PANEL FABRIC, 2007

MultiSheer 100% recycled PET panel fabric (detail) produced for exhibition at 'London Design Festival', The Royal Festival Hall, 2007

Photography: Full Focus, 2007

FIGURE 1-3 MULTISHEER PROJECT, 100% RECYCLED PET PANEL FABRIC, 2007

MultiSheer 100% recycled PET garments produced for exhibition, 'Well Fashioned: Eco Style in the UK', Crafts Council Gallery, London, 2006

Photography: Sam Adam, 2006

FIGURE 1-4 MULTISHEER PROJECT, 100% RECYCLED PET GARMENTS, 2006

MultiSheer 100% recycled PET garments produced for exhibition, 'Well Fashioned: Eco Style in the UK', Crafts Council Gallery, London, 2006

Photography: Sam Adam, 2006

FIGURE 1-5 MULTISHEER PROJECT, 100% RECYCLED PET GARMENTS, 2006

MultiSheer 100% recycled PET lighting produced for exhibition at 'ReDesign 06: The Good and Gorgeous', London Design Festival, 2006

Photography: Goldsworthy, 2006

FIGURE 1-6 MULTISHEER PROJECT, 100% RECYCLED PET LIGHTING PIECE, 2007

1.3 METHODS

The research method adopted was based on that of 'productive problem solving' as described by Scrivener (2002) and outlined in table 1.1.

Methodologically, the approach was essentially practice-based. Central to this is what can be described as a 'craft approach' to exploring new technologies. Emphasis was placed on 'hands on interaction' with materials and processes and the importance of personal creative knowledge and experience. Collaboration and discussion with technology specialists and engineers was also a key aspect, along with visualisation, mapping & dissemination throughout the process.

This was developed from the researcher's own approach to practice and was informed by art and design practice based researchers Schon (1983), Scrivener (2002) and Bunnel (2004).

The origin of this research was based on tacit knowledge developed though hands-on interaction with synthetic materials (polyester) over five years working as a maker in this material. During this time working with synthetic materials I had established a connection between the behaviour I experienced (in the heat response of thermoplastics, both textile and solid) with transformation, recyclability, monomateriality and using new technology as an enabler. If polyester fibres were made of the same chemical ingredients as polyester plastics (which were fully recyclable in 2005 unlike the fibres) then there must be a way to recycle fibre again and again through a similar process. This was an expression of a proposition that emerged intuitively as a result of the making process.

As a designer I felt that this personal understanding of materials could only have been derived from personal experience with materials through making. I had long been fascinated with the designer's role in the redirection of material waste streams back into use, however, it seemed that although recycling was becoming more widely explored by designers, the resulting product was often not itself recyclable. In the scheme of material cycles this seemed to be a short view solution and not something which could be a solution in the long term.

At this time there was an emerging industry based response, in particular to the 'forward-recycling' of polyester materials (such as Eco Circle)[1] but this cycle seemed unattainable and mysterious from a design perspective. If a designer wanted to design a product suitable for this cycle, it was unclear exactly how they might be able to achieve this.

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[1] www.ecocircle.co.jp/

Often, on the journey from raw material to product, fully recyclable resources are transformed and inextricably fused together to create material mixes or ‘monstrous hybrids’ as coined by McDonough and Braungart (2002) which prevent inclusion in further cycles and ensure a one-way route to landfill. For Eco Circle technology to create a true ‘polyester economy’, designers would need to approach working with these materials differently, designing them with the recycling system in mind at the outset. Suren Jelinski et al (1992) and Erkman (2007) descibe a need for this approach in their papers on ‘Industrial Ecology’, even suggesting that new roles will emerge in the future purely for the interpretation of material systems so that we can work better with them.

We are surrounded by evidence that this is not what happens in our current approach to design. Projects such as Chris Jordan’s ‘Intolerable Beauty’ (2005) and ‘Midway’(2009) and Ed Burtynski’s ‘Oil’ (2011) capture the impact we are having on the wider ecosystem through their photography and Annie Leonard’s ‘Story of Stuff’ (2010).

A second hunch I had at that time was that there might be new tools or technologies which could enable this new relationship with and understanding of materials. My studio practice had begun to incorporate the use of heat-based tools (transfer printing, laser cutting, heat marking) which were all suitable for use with thermoplastic (recyclable) synthetics.

In order to answer the research questions I needed initially to step away from my practice and become more informed on the technical details. After this first stage of research practice was continued alongside further theoretical research which continued throughout the project.

1.3.1 Productive Problem Solving

The project involved ‘problem seeking and solving‘ through a negotiated exploration of intuitive and reflective decision making related to emergent outcomes. The generation of ideas, synthesis of theory, technology and design concepts, peer-review, exhibition of work and presentation of ideas were integral aspects of the creative process and research methodology. The following table (1.1) maps the thesis process onto a model for creative-production doctoral projects as outlined in Scrivener (2002).

The resulting work can be described as following these norms, however due to the nature of the practice element this journey was not linear in progress, but cyclical, as characterised in Schon’s theory of ‘reflective practice’ (1983).

A problem is identified	Finishing creates a barrier to recycling which can be a perpetual closed loop (in the case of polyester which represents 45% of global fibre use) (Engelhardt, 2010)
The problem identified is recognised by others	Wang (2006), McDonough & Braungart (2002), Fletcher (2007) DEFRA (2007 and 2009) Laursen et al (2005), Murray (2002), Slater (2003)
A solution (evidenced through artefacts) to the problem would be useful	In order to improve recycling rate of polyester and therefore reduce waste
The solution is new or an improvement on previous solutions	The solution is a new method of finishing (MonoFinishing) which can be used to replicate traditional multi-material finishes
The solution (evidenced through artefacts) demonstrates that the problem has been solved	The artefacts produced are all 100% monomaterial and therefore recyclable, and visually replicate traditional finishes
The knowledge exemplified in the artefact can be formally described	The technology used works by using heat to manipulate the thermoplastic materials employed
This knowledge acquired has wider applicability	This thinking could be applied to different fibre groups, not only synthetics, and outside of textiles
This knowledge acquired is transferable	Although developed with textiles in mind this technology could also be useful for other industries
The formally described knowledge exemplified by the artefact is the primary research outcome	The primary outcome is the development of the finishing techniques
The problem setting and solving process is self-conscious, rational and reflective	As set out in the thesis account

Table 1-1 Productive Problem Solving analysis

Scrivener (2002) states, 'There is no generally agreed methodology for producing the outcomes tested above. The primary research methodology is problem solving itself, which often, in practice, cannot be prescribed fully. There are, of course, methods, techniques and tools that can assist the researcher, but in most cases problem finding and solving relies to some extent on ineffable intellectual processes. However, although there is no overarching methodology there is an overarching ethic of self-conscious, informed, systematic, and reflective problem selection and solution'.

'If we are to give greater attention to the process of creative production, then this should focus on the recording and reporting of these moments of reflection, including intended and unintended consequences and responses to them. The systematic recording of making and reflection in action and practice would play a crucial role in supporting the practitioner's reflections on action and practice and in making the whole creative-production project more accessible, both to the researcher and those to whom the project is communicated' (Scrivener, 2002).

In this case the systematic recording of making and reflection emerged as a visualisation and mapping process. This visual response to and communication of the process of making alongside theoretical research was key to moving the work forward and clarifying both the problem and the solution, and was reflected in the structure and organisation of the thesis.

1.3.2 Processes For Understanding

Feeding this process were three intersecting methods of research (understanding) which developed and informed each other as the project emerged. Very simply defined, these were different processes which helped to transform insights into knowledge and drive the work forward:

Understanding Through Enquiry [Theory]
The aim of this analytically focussed activity was to understand the situation under investigation. Following a review of the literature, data relating to the topic of interest was collected through primary and secondary sources with a view to revealing areas of potential development. This element of the project began with a study of current recycling practices involving polyester in all its forms. Topics reviewed included textile technology, polymer engineering, scientific and technological developments in recycling practices and material processing, and recent developments in textile, product and polymer design.

During the research numerous discussions and correspondence with engineers, designers, academics and consultants in relevant fields were conducted by telephone, through email or in person, and assistance regarding material samples and equipment access was sourced. Apart from reading specialist papers and researching commercial developments on the internet, methods have involved the collection of factual, physical and photographic material involving technical training, interviews with experts in associated fields, visits to exhibitions and trade shows.

Written material specific to the field of study has been emerging at an increasing rate since this research began. One highly effective method of staying in touch with emerging developments and design in this area has been to sign up to the many available 'blogs' and newsletters now accessible online. These have been crucial to developing a 'global view' of this highly mobile subject area, and although not definitive, they have often pointed to the most relevant areas for further investigation.

Visits have been used primarily to gain an understanding of processes usually not seen by the designer, such as recycling processes and polymer engineering. These included a PET sequin manufacturer in the UK, London Metropolitan University's Polymer Engineering Department (to attend a short polymer engineering course), a US based contract furnishing manufacturer using recycled polyester, 3D printing technology at ICI and the first laser-welding facility to be installed in Europe at the Shared Technology Resource Centre in Wales. These visits have increased my understanding and in turn influenced my creative exploration of the material.

Exhibitions, trade shows and conferences have been attended such as; 'Premiere Vision', Paris; 'Heimtextil', Frankfurt; 'Salone Satellite', Milan; and the 'London Design Festival' among others. They have been significant sources of information, and have helped to inform the practice review elements of the thesis in particular. Subject-related conferences of particular relevance included 'Material Innovation', RCA; 'Fabricating Technology', Edinburgh University, 'Green Textiles', Leeds University; 'Green Polymers', IOM3; and 'Avantex', Frankfurt. It was through conversation at one of these events that access to the focal technology was secured.

Understanding Through Making [Practice]
Although developing a reflective practice was often counter-intuitive and cumbersome when compared to the speed and intuition of commercial practice, it resulted in some key insights. Designs were prototyped both in the studio and, when appropriate, in collaboration with industrial partners. This part of the process involved the collation and development of technical processes through process experimentation and studio design work. It took the form of a collection of test sheets and data, and sample development, sketches, photographic records and prototype products.

Importantly, the experimental work responded to the information acquired during the technical investigation and vice versa. The two approaches interlinked to create a united structure and although the technical and aesthetic represent two strands of research, one informed the other in a reflexive process. Both aim to fill a gap in terms of the absence of previous study in the field. Both help bring to light the issues that need to be tackled by industry and design when considering the future recycling of synthetic textiles and, ultimately, challenging preconceptions surrounding such recycled materials.

Photographic documentation was used for illustration and classification of results (mapping) throughout the practice stage of the project and made up a significant record of the design experimentation and technical investigation.

Understanding Through Sharing [Dissemination]
Feedback was sought through outward-facing activities such as exhibitions, conferences and teaching. Initially this was intended for the early stages of the research only, however dissemination continued, and was invaluable, throughout the whole process. Developing ideas were presented to selected groups as part of a regular peer review process, including the TED team, as part of their ongoing project workshops. This served as a sounding board for design development in particular prior to and

immediately after the Ever & Again interim exhibition[2] in September 2007, where work was presented for public scrutiny and several key industry contacts were approached to view and respond to the work. This was followed with a 're-design' stage where prototypes were further developed and tested within the group.

Dissemination was also taken outside the group in the form of public exhibitions and conference participation, as well as through features and articles published during the course of the project, and communication via my website and blog.

1.4 MAPPING THE PROJECT

Alongside these three key research methods 'mapping' and 'visual analysis' were used throughout to gain insights into the research undertaken and to reflect on the practice element of the project which ran in parallel to the theoretical research and often seemed to have a life of its own. Through the mapping process, key insights gained helped to direct the project and reframe the 'problem' until the final scenario was formulated.

These maps and insights are used throughout the thesis to structure the argument and communicate the project rationale.

Maps and visualisations of data and studio work emerged throughout the process and are presented in the following chapters; however two key visualisations are presented here in the introduction to illustrate (1) the chronological development of the theory and practice elements and (2) the emergence of an evolving argument or context throughout the project.

The central focus of the methodology was to establish a way of working iteratively with both theory and practice.

Table 1.2 is a summarised representation of how this methodology fed into the thesis and practice resulting in key outcomes and models (highlighted in bold) and maps the processes for understanding against the developed practice elements (chapters 3 & 7)

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[2] www.everandagain.info/

	UPCYCLING BY DESIGN	**DESIGN FOR RECYCLING**
THINK Understanding through Enquiry [Theory] **[Key Maps]**	From linear to loops Recycling review Recycling hierarchy mapped with Lifecycle thinking **[Recycling Strategies]**	C2C theory True recycling = biodegradation / repolymerisation **[Material Metabolisms]** Design for recycling – defining the properties of the system Monomateriality **[Recyclability Matrix]** Digital manufacturing tools & systems
MAKE Understanding through Making [Practice] **<u>Practice Projects</u>**	Exploration of technology tools / CO_2 laser **<u>ReSurfaced</u>** **<u>Twice Upcycled</u>**	Technology tools / laser welding 3D / garment construction with integrated finishing **<u>MonoFinishing</u>**
SHARE Understanding through Sharing [Dissemination]	E&A Exhibition / Conferences / VIP Feedback / ReDesign Workshops / E Neuberg interview (2011)	Green Scin Exhibition / Warp Factor 09 Exhibition / Loughborough Conference / Science Museum Exhibition / Tilburg Exhibition / VF Corp Summit / Bangalore Conference / AILU Conference
INSIGHT [Analysis]	End-of-life recycling strategies can only extend the life of materials For true recycling loops to occur recyclability needs to be assessed at the start of the lifecycle (through design)	Laser to replace traditional finishing techniques / **Comparison Tables** Could combine with product construction & recycling for total 'system'

Table 1-2 Methods analysis

1.4.1 Research & Argument Map

The argument evolved from a synthesis of research, practice and reflection: The 'research & argument map' (fig 1.7), describes 'packages of work' undertaken throughout the project and syntheses made relating to research and practice. Key design work and models are highlighted in relation to the evolution of the lifecycle models to which the work relates.

It shows the progression from a linear system, or at best end-of-life recycling approach, into a closed loop system model which could ultimately be part of a larger open-networked materials system. Key insights developed from the mapping and practice shown in the research map are highlighted alongside the relevant studio briefs.

The structure of the thesis has been based around these insights and represents three key cycles of theory, making and reflection. The work revealed key ideas (theory in tandem with practice) and brought me to the final practice element described in chapter 7.

For example, research around the lifecycle of polyester textile products was synthesised with research into recycling hierarchies and overlaid with design strategies. When combined, the three elements (theory, practice and dissemination), clarified the shift in studio work from 'upcycling by design', the focus of early studio work, to a 'design for recycling' approach in the later design briefs.

These models will be discussed in detail in the following chapters.

Cycles of making and practice have informed my understanding of the emerging knowledge and vice versa. This creative and integrated approach is described by Spiller below;

> It is widely understood that digital technologies are capable of reversing the usual economies of scale and dismantling traditional supply chains ….. the emergence of affordable, digital manufacturing heralds an era of customisation and responsive, localised production, even in the home-territories previously occupied by craft production……..There are great possibilities for further research that combines the creative, integrated approach with the expertise of engineers, technologists, economists and manufacturers. It is perhaps the high level of human engagement with materials and technologies involved in the process of designing and making which places makers in a unique position to contribute to the development of human oriented and individually customised design production (Spiller, pp4&5).

THEORY

PRACTICE

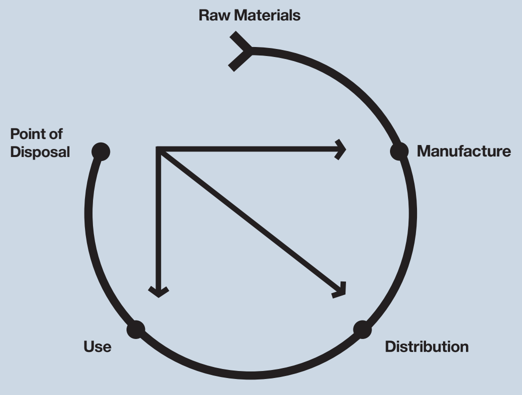
Now

Upcycling by Design

Limited materials with limited life-cycles.

Although return journeys can be designed in at the end-of-life, this approach only postpones the arrival of the discarded material at landfill where it may never biodegrade, may degrade very slowly or may add harmful materials to the environment as it breaks down.

An end-of-life approach with disposal as the starting point.



ReSurfaced

Laser finishing for upcycling (mixed fibre waste).

Twice Upcycled

Laser finishing for upcycling (100% polyester waste)

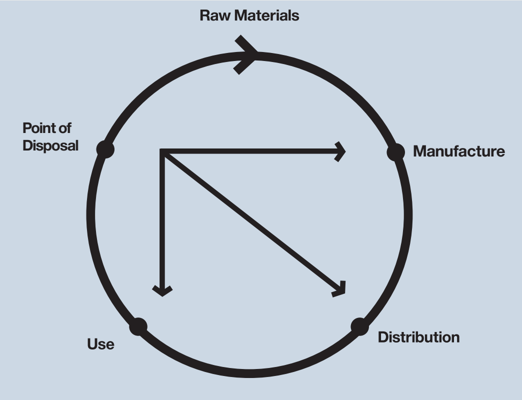
Near

Design for Cradle-2-Cradle

Limited materials with unlimited life-cycles.

By considering the barriers to recycling as part of the design brief, connected loops can be built into the material's future life from the outset. In a closed-loop, materials would never lose their value and would be designed to be recycled indefinitely.

An integrated approach enabling C2C material systems.



Mono Finishing

Laser technology for the finishing of recyclable textiles.

Mono Garments

Laser technology for the finishing and construction of recyclable textile products.

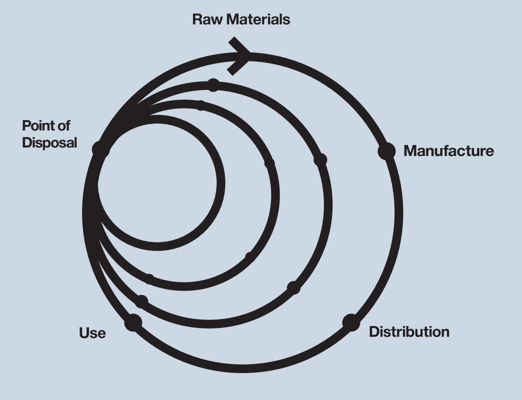
Future

Design for Material Ecologies

Unlimited materials with unlimited life-cycles.

A genuinely sustainable future depends on creating interconnected loops, or cycles, for all industrial commodities. These cycles would be part of a scaled-up system of material exchange which is open and dynamic, including all material resources in an infinite industrial ecology.

Opening the material network and enabling industrial ecologies.



Mapping the project journey.... from an end-of-life approach toward an integrated materials ecology.

Graphics: Laura Gordon, Franklin Till, 2012

FIGURE 1-7 RESEARCH AND ARGUMENT MAP

1.5 STRUCTURE OF THESIS

The thesis describes the relationship between the practice and the theoretical elements, and follows the argument map (fig 1.7). It is not a chronological expression of the journey taken, but each chapter describes part of the journey which informs the thesis as a whole. Each chapter represents a key insight which fed directly into the development of the final practice in chapter 7.

Chapter 1 introduces the thesis aims and objectives and outlines the methodology adopted. This is a reflective practice method based on Scrivener's 'productive problem solving' theory. The introduction also outlines the adaptation of reflective practice which uses a continuous 'visualisation and mapping' process to direct the study.

Chapter 2 contains the initial research into recycling in the textiles industry and outlines the context for the study, asking 'How does design currently work within a life-cycle approach to recycling?'. Life-cycle thinking, C2C theory, waste hierarchies and design strategies currently responding to this field are introduced. This theoretical content is synergised and reflected upon through a key visualisation, model 2: Recycling Design Journeys (fig 2.5).

Chapter 3 describes early practice relating to the original brief of developing upcycled textiles through the use of new technologies, addressing the question 'How might the laser be used to upcycle textile waste materials?' The two collections outlined include 'ReSurfaced', a collection of mixed fibre shoddy waste material upcycled through a process of surface embellishment and 'Twice Upcycled', a collaborative project with Rebecca Earley, involving the multiple-reinvention of a polyester shirt through design intervention. Techniques were developed for this project which include technology previously accessed (CO2 laser) as well as an emerging technology and subsequent focus of the remaining PhD practice (laser-welding).

Chapter 4 aims to focus the study on a 'C2C' approach for the use of polyester fibre asking 'How could a designer work within a 'C2C' framework considering materials as borrowed resources?' Model 1: Material Metabolisms (fig 4.2) maps the material landscape according to raw material type and lifecycle. By introducing the history and new developments in the 'C2C' recycling of this fibre (which represents 45% of global fibre use) and examining the barriers to this 'true-recycling', a brief for the major practice experiments is set, based around the concept of monomateriality. Design for recycling is outlined and explored through examples.

Chapter 5 reviews the industry of polyester recycling including developments since the first recycled polyester fibre emerged in the 1970's. How is polyester currently recovered and reprocessed? It concludes by introducing the latest breakthrough in this field, a C2C process which can convert waste polyester back into virgin material via a chemical process of repolymerisation. This is the process for which the following design brief is formed.

Chapter 6 develops the design brief further by unpacking the complex nature of material constructions and asks 'What are the key attributes of a fully recyclable polyester textile and what are the barriers to recyclability?'. This research is visualised through model 3: 'Recyclability Matrix' (fig 6.1) and defines the specific requirements for designing monomaterial, recyclable textiles. This chapter brings the thesis to a point where the brief for the work described in chapter 7 was formed, thus closing the loop on the journey of the project.

Chapter 7 describes the main practice project, 'MonoFinishing', and sets out the methods for experimentation and sampling. It answers the question 'What new finishing techniques might be enabled through use of laser technology?'. It reviews the selected technology (laser processing) and sets out the design of the practice element. It finally analyses the results of sampling and experimentation by mapping the resulting finishes achieved and comparing them to traditional processes which could be replaced.

Chapter 8 concludes the thesis and presents the contributions made and further planned work. 'How might this project fit within a future vision for manufacturing of local, interconnected, responsive production?' It also introduces discussion of the implications and potential further developments for the resulting practice and presents the concept of an 'open networked polyester economy'.

1.6 CONTRIBUTIONS TO KNOWLEDGE

This research has made contributions to knowledge in the field of 'recycling design for textiles', in the following ways:

Firstly by proposing a new model for designing 'C2C textile products' that can contribute to a future closed-loop material economy. It does this by making a synthesis that has not been made before, whereby theories of 'design for recycling' are synthesised into a model for designing new recyclable textile structures.

Secondly by presenting a new application of laser-welding technology as a tool for the finishing of 100% polyester textiles which can be repolymerised at end-of-life. This can be explained as 'applying a technique in a new area': laser welding (previously explored in textiles only for garment seaming) is applied to the construction of complex monomaterial systems and the surface engineering of recyclable synthetic textiles.

Furthermore the research shows that the recyclability of polyester textile products can be preserved through this new digital finishing process, which is beneficial in the following ways:

- Fabric surface manipulation can be controlled more accurately through digital input.
- Complex 3D constructions can be formed with selective welding through multiple layers.
- Gloss surface patterning can be achieved without any extra materials or coatings.
- New types of nonwoven constructions can be produced through welded web constructions.
- Strong bonded layers can be achieved without the need for adhesives.
- Dimensional / padded materials for upholstery could be produced as a single component, thus enabling easier disassembly and repair.
- The final product retains recyclability through repolymerisation at 'end-of-life'.

Further Insights from research:

- Recycling alone is not a satisfactory solution to the problem of landfill unless a 'long view' is taken. i.e. Materials can be infinitely recycled (as in nature) not merely downcycled.
- In order to design for any particular 'materials system' a designer must understand the rules of that system. This can be difficult to achieve in the usual commercial timeframes and methods.
- Visualisation and mapping are useful tools for understanding this field of research and communicating it for designers.

2 TEXTILES & RECYCLING: A HIERARCHY OF DESIGN APPROACHES

2.1 INTRODUCTION

This chapter considers current recovery options within the UK textiles recycling industry, and maps them against a hierarchy of ‘end-of-life’ design interventions. The final section provides an overview of design examples to illustrate each of the described approaches.

The main research question explored here is:

- How does design currently work within a life-cycle approach to recycling?

This chapter is focussed primarily on post-consumer waste recovery, however the thesis as a whole is concerned with both post-consumer and post-industrial recovery, which are described in section 2.2.2, and does not differentiate between different sources of waste, focusing rather on the material qualities of the waste produced.

The impact of textiles as a highly problematic waste stream is well documented. ‘Volumes of clothing, purchased annually in the UK, have increased by around one third [since 2000]’, (Allwood et al, 2006) and this embedding of ‘fast fashion’, into our current consumer landscape, has resulted in a parallel emergence of ‘fast landfill’.

The emergence of a ‘recycling industry’ is an attempt to transform an essentially linear industry into a more cyclical one, with more responsibility being taken by industry for its waste.

According to the Well Dressed Report (Allwood et al, 2006) there has been almost no technology innovation in textiles recycling for over 200 years and there has been a huge increase in the percentage of mixed-fibre textile waste created through blending and finishing processes, driven by the ever-increasing demand for performance and functionality. This leads to a legacy of waste and prevents high-value reclamation.

Design has been engaged as a tool to transform this waste back into use through intervening at the point of disposal.

2.2 RECYCLING OF TEXTILES WASTE

The wastefulness of the textiles industry has been well documented and analysed through several key publications and government studies during the course of this project. Waste volumes from the [clothing and textiles] sector are high and growing in the UK with the advent of 'fast fashion'. On average, UK consumers send 30kg of clothing and textiles per capita to landfill each year (Allwood et al, 2006, p2).

The most recent study from DEFRA (2009) illustrated in fig 2.1, shows that as of 2007 in the UK:

- 2 million tonnes of textile waste (including clothing, carpets and footwear) is generated annually (of which approximately 1 million tonnes is clothing)
- 24% (523k tonnes) is collected for reuse and recycling in the UK and overseas
- 47% (1 million tonnes) enters the Municipal Solid Waste (MSW) stream to landfill
- the remainder is unaccounted for (14%), reused as secondary textiles (9%), trade waste (2%) or directly given away (4%).

An analysis of the benefits of Recycling and Reuse from studies by DEFRA (2007 and 2009) is illustrated fig 2.1 and 2.2. The best end-of-life options for clothing were identified as reuse and recycling. These perform better in energy and waste terms compared to other options e.g. Energy from Waste.

2.2.1 Clothing Recycling And Reuse Technologies

> An increasing amount of waste is generated each year from textiles and their production. For economic and environmental reasons it is necessary that as much of this waste as possible is recycled instead of being disposed of in landfill sites. Considering the diversity of fibrous waste and structures, many technologies must work in concert in an integrated industry in order to increase the rate of recycling (Wang, 2006).

The quantity of textiles collected for reuse and recycling, in the UK, grew substantially between 2003 and 2008, from 324,000 to 523,000 tonnes. The volume of textiles discarded as municipal solid waste decreased from 1,165,000 tonnes to 1,081,000 tonnes. Hence the overall reuse and recycling rate increased from 22% to 33% while total volumes discarded increased by 8%. UK sorting is that which is segregated by grade, not just separated from non-textiles (DEFRA, 2009).

Most clothing collection that is destined for reuse or recycling takes place through 'clothes banks', charity shops or collections for jumble sales. Current levels of reuse and recycling of clothes are low despite the excellent work of charity shops and the availability of textile banks, and the economics of reuse and recycling are deteriorating, according to DEFRA (2007).

End Use	2005		2008	
	Tonnage (000s)	Percentage	Tonnage (000s)	Percentage
Resale in UK	41	12.7	106	20.2
Export reuse	174	53.7	316	60.5
Wiper grade UK	28	8.6	17	3.3
Export for wiper	6	1.9	21	4.0
Recycling - UK	34	10.5	10	1.3
Export for recycling	20	6.2	28	5.9
Waste	21	6.5	25	4.7
Total	**324**	**100%**	**523**	**100%**

FIGURE 2-1 SUMMARY OF THE FATE OF TEXTILES IN THE UK, 2008 (DEFRA, 2009, P12)

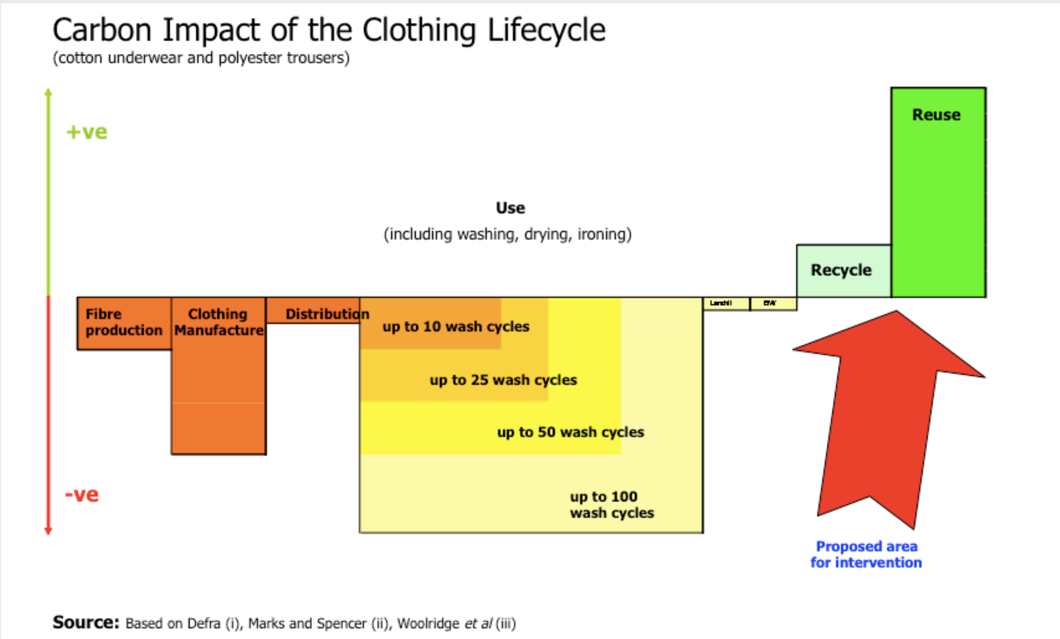


FIGURE 2-2 CARBON IMPACT OF THE CLOTHING LIFECYCLE

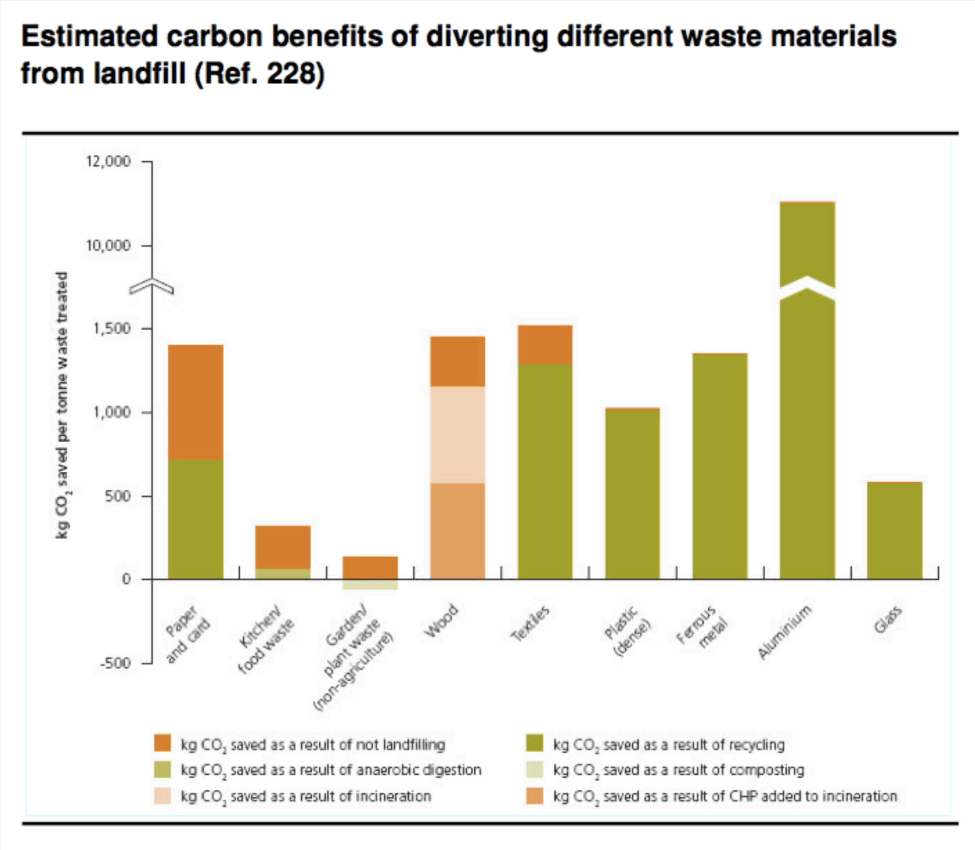


FIGURE 2-3 CARBON BENEFITS OF DIVERTING WASTE, BY MATERIAL

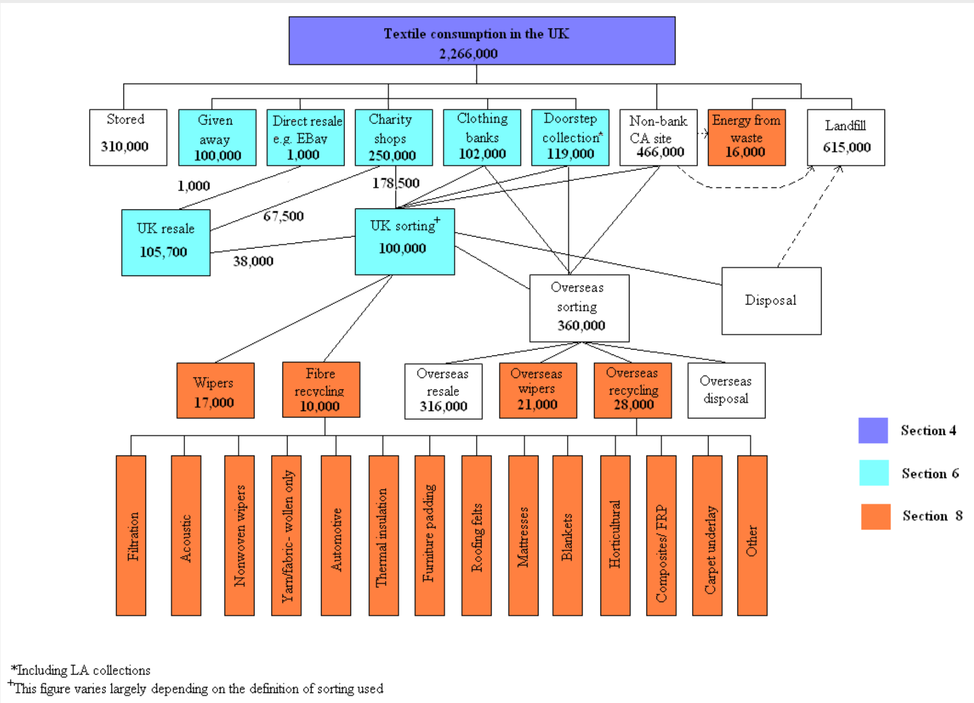


FIGURE 2-4 TEXTILE CONSUMPTION IN THE UK (DEFRA, 2009)

Approximately 523 000 tonnes of the two million tonnes of textile and clothing waste in the UK are recycled. However, the economics of textile recycling are deteriorating because the reuse proportion (65%) is declining due to competition from low cost Far Eastern imports in Africa, the traditional market for much collected clothing. Although the recycling proportion (26%) is increasing, sales of flocking or shoddy generates only about 10% of collection costs because there is a lack of value added markets for recycling these grades of textiles.

Disposal costs of residues not suitable for recycling are increasing. In addition, the cessation of the Multi-Fibre Agreement, policed by the WTO, is likely to increase net volumes of clothing purchased (and hence discarded) through reduction in the price of clothing. It will also increase the proportion of recycling rather than resale grades, which will further weaken collection economics and depress the sales of and margins on second hand clothes (DEFRA, 2007, p30).

There have been improvements in the collection and sorting of used clothing and methods of extracting fibres from used clothing (Techtextil, 2007). However, the diversity of clothing composition is a challenge for recyclers. Wool and synthetic materials can be pulled apart and recycled easily, but cotton and cotton blend materials are more difficult because the cotton fibre length is too short for reuse.

> There is great scope for technology development to support a move to reduced impact; technology for sorting used clothing would overcome the high labour cost of this operation in the UK; fibre recycling technology has had relatively little attention in 200 years and has significant scope – both for extracting fibres with less shortening and for fibre separation from blended products; novel coatings and smart functions may support increased product life and reduced need for care in use, although they may also impede material recycling; new longer lasting fibres would support durability. (Allwood et al, 2006, p69)

There is a significant benefit to be achieved through recycling clothing, thereby off-setting new production. For every kg of new cotton clothing displaced by second hand clothing, approximately 65 kWh is saved; and for every kg of new polyester clothing displaced by second hand clothing, approximately 90 kWh is saved (DEFRA, 2007, p89). Additionally, more jobs in the wider economy could be created from developing value-added markets for recycled textiles.

> Under the Landfill Allowance Trading Scheme, textiles are deemed to be 50% biodegradable. Therefore diverting household textiles from landfill by recycling or reuse reduces the use of landfill allowances. In 1991, the Textile Recycling Association established the Recyclatex Bonded Textile Scheme, a regulatory body designed to help local authorities, charities and other organisations that want to set up services to aid the recycling and reuse of clothes and shoes. It includes the provision of textile banks with a regular agreed collection timescale, regular payments and collections from charity shops also agreed (DEFRA, 2007, p90).

2.2.2 Recovery Options For Textile Materials

The point at which materials become waste can be classified as either post-industrial or post-consumer recovery:

Post-industrial Recovery or process-scrap waste is derived from industrial processes. Very little of this type of waste goes from manufacturing to landfill. For reasons of economic viability, around 95% of this waste is recycled back into production in closed-looped internal systems.

Post-consumer Recovery or post-use recovery, which originates from household waste after a completed useful life, makes up the majority of textile waste, which goes to landfill. The post-consumer recovery of products and materials consists of a varied sequence of operations, including collection, inspections and testing, selection, grading and sorting before any recycling procedures can begin. This process can be more or less demanding depending on the type of recovery used.

2.2.3 Reprocessing Options For Textile Materials

Typically recycling practices are further categorised into the following groups;

Direct Recovery (re-sale, re-distribution or reuse) is an almost immediate and straightforward operation and is not dependant on material content or properties.
Process Recovery implies more detailed operations including cleaning, disassembly and reassembly, or chemical processing. Within this group, operations can be further divided (Wang, 2006). The recycling of textile materials in this way requires the metabolism of the material to be acknowledged.

2.2.4 Synthetic-Specific Reprocessing Options For Textile Materials

For polymer based materials, chemical or thermal processes are used, in which fibres are re-polymerised into a chemical feedstock and then re-spun in the normal way.

Primary approaches involve recycling a product into its original form. **Secondary recycling** involves melt processing a plastic product into a new product that has a lower level of physical, mechanical and/or chemical properties. **Tertiary recycling** involves processes such as pyrolysis and hydrolysis, which converts the plastic wastes into basic chemicals or fuels. **Quarternary recycling** refers to the burning of the fibrous solid waste and reclaiming energy by using the heat generated.

All of these approaches exist for fibre recycling.
Further definitions of recycling were presented in a recent Cambridge publication, which identified recovery options currently in use in the UK (Laursen at al, 2005).

2.3 MAPPING A HIERARCHY OF RECYCLING STRATEGIES

The previous ways of classifying textile waste recovery and reprocessing approaches, discussed in sections 2.2.2 – 2.2.4, were felt to be inadequate for developing potential design interventions. The following mapping of potential strategies against a life-cycle model provided a more direct visual way to communicate and navigate the recycling landscape in order to create a meaningful design brief.

As part of initial analysis, I undertook a review and critique of the complex landscape of recycling practices for textile waste in the UK. The initial literature searches attempted to unpack the complexity of the textile recycling and associated industries. Several key studies served as the grounding for this review:

- Hierarchy of Waste Options
- Lifecycle Thinking [C2C Material Metabolisms] (McDonough & Braungart, 2002)
- Well Dressed – review of UK textiles recycling practices (Laursen et al, 2006)

Research also looked into the complex nature of 'recycling' as a concept. It is often used as a catchall term, but in fact is a collection of lifecycle solutions, which vary hugely in energy consumption and end result. By looking at the 'hierarchy of waste options' research and overlaying this data onto a generic 'lifecycle' visualisation for textile products it was possible to see a clear journey around the cycle for each specified route. This helped to formulate the subsequent design briefs for initial design exploration.

The mapping shown in model 2 (fig 2.5) led to the following insights:

- Materials can be viewed not as static resources, but rather as part of a time-based journey, for which designers are custodians for a period – this led to the concept of 'borrowed materials' and a new way to begin my design process (Irwin, 2008).
- The maximum amount of resources and energy can be saved through interventions which redirect materials the smallest distance back around the lifecycle (i.e. avoidance) however only 'true recycling' (biodegradation or repolymerisation) avoids landfill in the long term at material level. All other routes can be described as 'extended life strategies'
- This true recycling can only be achieved through 'designing in' characteristics required for recycling at the outset. Nature is the best example of this, as its products (life) are all designed with compatible material building blocks which can deconstruct (degrade) to feed new life. The closest we have in the man-made materials world is the repolymerisation of polyester.

Recycling, relates to a varied range of design approaches. The illustration below shows the range of activities defined as recycling from product reconstruction to recovery of chemical resources (repolymerisation or biodegradation).

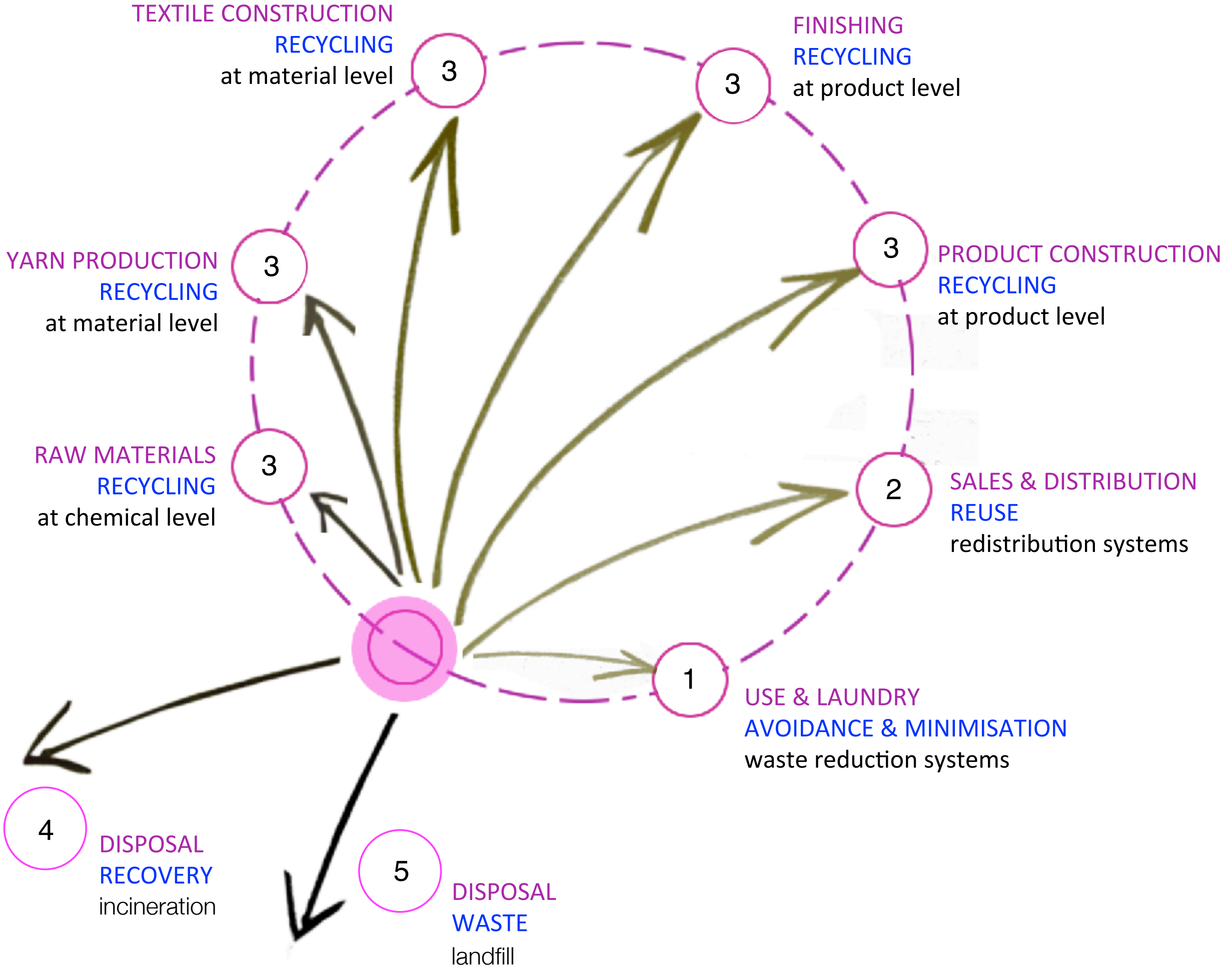
This graphic visualisation has been pivotal in 'mapping' the recycling design landscape in order to analyse the available approaches. A hierarchy of waste options has been overlaid onto a lifecycle model of textile production and corresponding end-of-life design strategies added from research gained in the literature and practice review.

The idea visualised is one of continuous material service, where an endless useful life for raw materials is achievable, never leaving the system. This can be described as 'closed-loop' recycling and should be the end goal of the recycling industry in order to maximise the usefulness of virgin materials and minimise the necessity to extract them. Often, although products are recycled after a single lifecycle, valuable resources are contaminated, wasted or lost.

> They are lost not only for lack of adequate systems of retrieval; they are lost also because many products are 'monstrous hybrids' - mixtures of materials both technical and biological, neither of which can be salvaged after their current lives. (McDonough and Braungart, 2002, p98)

Table 2.1 overleaf, maps lifecycle stages against the established 'waste hierarchy' and also the corresponding design intervention with examples.

This information is elaborated more fully in the following section, 2.4.



Recycling Design Journeys, Analysis of recycling options according to the point of return on the lifecycle.

Graphics: Authors own, 2008

FIGURE 2-5 MODEL NO2 / RECYCLING DESIGN JOURNEYS

2.3.1 Recycling Design Analysis

This table attempts to unpack the complex range of activities incorporated by 'textile recycling'.
Key refrences include Fletcher (2007), Gertsakis and Lewis (2003).
Examples in red relate to authors own work.

	LIFECYCLE STAGE	WASTE HIERARCHY OPTION In order of maximum use of resources	END-OF-LIFE RECYCLING DESIGN APPROACHES	EXAMPLES
	USE & LAUNDRY	1 / Avoidance & Minimisation [WASTE REDUCTION systems]	Using less materials for longer **[Make Do & Mend]** Keep in use through mending & preserving techniques	DIY & Craft Enthusiasts Local Groups
DIRECT RECOVERY	SALES & DISTRIBUTION	2 / Reuse [REDISTRIBUTION systems]	Resale /Redistribution of Garments through second hand clothing markets **[Re-sell or Exchange]** Encourage return post-consumer to charity shops, vintage sales, clothes swapping	Oxfam and other Charities Swaporama Vintage Boutiques / LMB
PROCESS RECOVERY	PRODUCT CONSTRUCTION & FINISHING	3 / Recycling [AT PRODUCT LEVEL]	Remanufacturing/Reconstruction ….at product level **[Upcycling by Design / products]** Remanufacturing &/or Refinishing Adding value through design intervention at product level	Traid Remade Worn Again Alabama Chanin TOP 100 Twice Upcycled
	TEXTILE CONSTRUCTION & YARN PRODUCTION	3 / Recycling [AT MATERIAL LEVEL]	Downcycling / Upcycling……at material level **[Mechanical Downcycling]** Fibre chopping and shoddy production, & mechanical PET recycling etc **[Upcycling by Design / materials]** Adding value through design intervention at material level	Shoddy Production mechanical recycling [PET] MultiSheers ReSurfaced Michelle Baggerman Florie Salnot Luisa Cevese Laura Marsden
	RAW MATERIAL	3 / Recycling [AT CHEMICAL LEVEL]	True recycling [C2C]…… recovery of raw materials or 'nutrients' according to material metabolisms **[Biodegredation]** recovery of bio-nutrients **[Repolymerisation]** recovery of original tech-nutrients	Maurizio Montalti Teijin Eco Circle
	POINT OF DISPOSAL /	4 / Recovery [INCINERATION]	Recovery of energy (once only) Energy can only be used once	
	POINT OF DISPOSAL /	5 / Waste [LANDFILL]	Wasted resources	

Table 2-1 Recycling Design Analysis.

2.4 END-OF-LIFE RECYCLING DESIGN APPROACHES

Many recycling approaches are applied at ‘end-of-life’ as solutions for preserving otherwise waste materials, rescuing them for a further lifetime. In many cases this is downcycling as materials are already mixed to such an extent that they cannot be separated. However beautifully they have been upcycled, these ‘monstrous hybrid’ (McDonough & Braungart, 2002, p98) materials cannot be further recycled at the end of their second life and the problem remains.

The following text discusses the waste hierarchy options presented in the previous table and expands on each concept, relating them to a corresponding ‘end-of-life’ recycling strategy. The impacts described for each hierarchy option, are adapted from Gertsakis & Lewis (2003).

2.4.1 Avoidance & Minimisation

Avoidance and minimisation strategies include a range from consuming less products through to repairing existing ones and extending their time in use. As an end-of-life solution this is not an area where we see much design activity, although DIY culture is beginning to impact here.

- Avoided environmental impacts with this approach include: impacts at every stage of the product lifecycle (materials, energy, emissions and wastes)
- There are no negative environmental impacts to be considered for this approach.
- Social impacts include: a need to change consumer habits
- Economic considerations include: for minimisation strategies, cost savings to both consumer and manufacturer; for avoidance strategies, there is a potential economic loss to manufacturer through a reduction in economic transactions, while consumers still benefit from this approach.

2.4.2 Reuse

By reusing and redistributing products which have been discarded in a useful state of repair, they can be simply redirected to new owners. Charities and more commercial enterprise both play a role here, along with the rising popularity of community based ‘swap parties’ or online auction sites such as Ebay[3] or ASOS’s new ‘marketplace’[4].

- Avoided environmental impacts with this approach include: impacts of materials processing and product manufacture (materials, energy, emissions, wastes); avoided landfill impacts (air emissions, leachate, visual impact)
- Negative environmental impacts to be considered include: transport (use of fuels, air emissions) and cleaning impacts (water & detergents)
- Social impacts include: a need to change consumer habits

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[3] www.ebay.co.uk
[4] www.asos.com (marketplace)

- Economic considerations include: new business opportunities to establish collection and refurbishment services.

2.4.3 Recycling At Product Level [Remanufacture/Refinishing/Upcycling]

Remanufacture is used here to describe any design activity, which converts a waste product into a new form with added value (in the case of upcycling). This relates to a wide range of activities from 'reprinting' discarded garments to a more complete reconstruction, but always starting and finishing with a finished product.

- Avoided environmental impacts with this approach include: impacts of materials processing and product manufacture (materials, energy, emissions and wastes) and avoided landfill impacts (air emissions, leachate, visual impact).
- Negative environmental impacts to be considered include: transport (use of fuels, air emissions), manufacture of replacement parts (materials, energy, emissions, wastes), remanufacturing process (materials, energy, emissions, wastes).
- Social impacts include: need to change waste disposal patterns, i.e. source separation but does not encourage rethinking of consumer habits.
- Economic considerations include: new business opportunities in remanufacturing.

Example: TOP 100[5]
Fashion & textile designers such as Rebecca Earley, have been working with this concept. Earley's Top 100 Project is a collection of reclaimed, reworked and reprinted polyester shirts that can be fully recycled at their end-of-use. Second hand polyester blouses are re-cut and styled, then overprinted using different design themes, intending to increase consumer attachment through a series of unique narratives. They are made to be washed less often and never ironed, and finally at the end of their second life they are 100% recyclable.

Example: Worn Again[6]
Worn Again works with large companies to 'upcycle' their existing textiles waste into new products while developing and integrating closed loop textiles solutions for the future. Their aim is to help companies achieve long-term efficiencies while also helping to achieve sustainability and waste reduction goals. Their services, include the design and development of products from disused textiles, which can be used to replace an existing procurement product made from virgin resources; for marketing purposes; or sold on to customers, providing a new stream of revenue.

Example: Alabama Chanin [7]
Natalie Chanin intiated Project Alabama, in 2000, a revitalisation project that combines old-world craft with remanufacturing (see fig 2.6). In 2006, the project was re-formed as Alabama Chanin to maintain Chanin's uncompromising, community-based vision for the project. Based in Florence, Alabama, a small town in the foothills of the Appalachian

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[5] http://www.upcyclingtextiles.net/
[6] http://www.everandagain.info/
[7] http://vimeo.com/18094535 (accessed 12/06/2010)

mountains, where the designer herself grew up, the company employs local women aged 20 to 70, (former factory workers, retired teachers, widows, stay-at-home mums, and secretaries), to help sew one-of-a-kind, handmade garments for her fashion line. Gathering together to work in circles reminiscent of the region's dwindling tradition of quilting, the women forge friendships while stitching, embroidering and beading Chanin's designs. (Chanin initially used only vintage fabrics found at local thrift shops, but now relies on bulk shipments from the Salvation Army to fill all the orders).

2.4.4 Recycling At Material Level [Reconstruction/Mechanical Recycling]

Mechanical recycling relates to any activity which attempts to take a waste material back to a fibre product without the use of chemicals. This can include everything from quilt-making to shoddy fibre production or melt-recycling of polymers.

This process can also be described as downcycling, which is the practice of recycling a material in such a way that much of its inherent value is lost. An example of this would be recycling plastic bottles into lower-grade plastic that is then used for park benches. However, eventually quality is lost to such a degree that landfill is the only option. For this reason, ‘upcycling’ (adding value through redesign) has become more prevalent, as designers find new ways to embed reuse into products and to extend the life of existing ones without degrading quality.

- Environmental impacts avoided with this approach include: impacts of manufacturing virgin materials (materials, energy, emissions, wastes), landfill impacts (air emissions, leachate, visual impact)
- Negative environmental impacts to be considered include: transport (use of fuels, air emissions), reprocessing (materials, chemicals, water, energy, emissions, wastes, contamination and by-products)
- Social impacts include: need to change waste disposal patterns i.e. source separation but does not encourage rethinking of consumption habits
- Economic considerations include: new business opportunities in reprocessing.

Example: Michelle Baggerman[8]
Michelle Baggerman has succeeded in processing used plastic carrier bags without heating or added chemicals and has turned them into durable but fine threads with which she has woven a new fabric (see fig 2.7). Her goal was to alter plastic shopping bags in a way that would make the material last longer, while remaining recyclable. This lead to ‘Precious Waste’, a textile made entirely out of used plastic shopping bags that were spun into yarns and then woven. The plastic shopping bag can be transformed by pure hand-work into a beautiful and strong material, suitable for a wide range of purposes. When this textile is eventually worn out it can still be recycled in the conventional way, because it is not a mixed material, and can become a new product once again. The woven product is much stronger than the original, which will considerably increase lifespan of this material which takes so long to decompose. Precious waste makes it possible to process poor-quality disposable bags and turn them into sustainable products.

[8] http://bureaubaggerman.nl/

Example: Florie Salnot[9]

This recent graduate designed a technique and some specific tools to enable the Saharawi refugees to produce pieces of jewellery with the very limited resources which were available in their camps, i.e., plastic bottles and sand. The aims of the project were to offer Saharawis a sustainable way for generating income and therefore to reduce dependency on humanitarian aid, and to provide them with an open-source technique and tools with which they can design their own pieces and invigorate their local craft traditions in an original way. The plastic bottle is first painted and then cut into thin stripes with a cutting tool. After that, any type of drawing can be made, by positioning nails into pre-defined holes on a nail board, and submerging into hot sand, thus setting the form. The piece of jewellery then requires a few last steps and fittings to become finalised. It is a very simple technique, which however, has the power to make the non-precious become precious; a great example of upcycling-by-design (see fig 2.6).

Example: Luisa Cevese / Riedizioni[10]

The original 'Upcycler' Luisa Cevese has been innovating with waste materials since 1999. As Head of Research for a major Italian textile company she became aware of the amount and consistency of textile waste. This led her to consider the possibility of a design and production project using scraps as a basic element. Having gained some understanding of the plastics industry and technology, she started to combine textile waste with plastic of different kinds, seeing in this new material an opportunity for development which neither a textile nor plastic producing company could fully exploit. Different kinds of textile waste, plastic with different properties and different production facilities resulted in different finishes. The textile industry creates an enormous amount of waste. This waste is the basic element: large blocks of unusable end pieces, damaged fabric, yarns and threads, salvages, small pieces of uneven cloth, cuts from garments. Riedizioni does not discriminate between natural or man made fibres, the only criteria is to select the textile which is able to produce a constant design out of a discontinuous element (see fig 2.7).

Example: Laura Marsden[11]

Laura Marsden is a textile designer working to develop and promote recycled textiles. During her Masters degree, Laura created a technique which uses waste plastic bags to give them a second life as home and fashion accessories. The technique Laura created is a combination of hand-stitch and needle lace-making with various processes to change the properties and appearance of the plastic bags. This technique is called 'Eternal Lace'. The resulting textile can be sculpted and has many potential uses. Laura is devoted to working with recycling textiles in new, innovative ways and also ensuring that the results challenge preconceptions about undesirable recycled products (see fig 2.6).

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[9] http://floriesalnot.com/

[10] http://www.riedizioni.com/

[11] http://www.lauramarsden.com/

2.4.5 Recycling At Chemical Level [Biodegredation Or Repolymerisation]

The most efficient forms of recycling are fully 'C2C', that is to say that they return materials to their raw components which can then be rebuilt into new materials without downcycling. The best example of this is biodegradation. In this approach biological nutrients are returned to a form which can support new growth thus completing the cycle. In our man-made material world the closest we have to this is repolymerisation where technical nutrients are returned to manufacturing systems for the production of brand new materials. This is not usually seen as an approach which designers can innovate directly with, however Maurizio Montalti's project 'bodies of change' seems to challenge the C2C concept by using biological agents to deconstruct synthetic polymers.

Although there have been recent developments with biodegradable polymers, there seem to be several problems as yet unresolved with this area (Slater, 2003, p34). The problem usually associated with synthetic polymer fibres that are supposedly biodegradable is that, when they break into tiny pieces, toxins resulting from their breakdown remain in the soil contaminating the surrounding land and hence water. Better 'biodegradability' usually implies a faster rate of disintegration, but the increased surface area thus produced increases the rate of the release of toxins and so makes the presence of these materials even more undesirable. The act of trying to recycle polyester is suggested as an environmental cure and efforts to carry out this type of operation for producing fibres are increasing rapidly.

- Avoided environmental impacts with this approach include: impacts of manufacturing virgin materials (materials, energy, emissions, wastes), landfill impacts (air emissions, leachate, visual impact), impacts of fertiliser and pesticide manufacture (materials, energy, emissions, wastes, water conservation), carbon sequestered in land or reprocessed into new polymers
- Negative environmental impacts to be considered include: transport (use of fuels, air emissions)
- Social impacts include: need to change waste disposal patterns
- Economic considerations include: new business opportunities in composting services or repolymerisation industry.

Example: Maurizio Montalti[12]
For this project Montalti worked with a group of scientists to explore the possibilities of using fungi to literally 'eat' synthetic polymers and return them as nutrients to the soil (see fig 2.7). Considering the length of time it usually takes plastic to decompose, and the harm they cause when they do, these experiments could have enormous benefit.

The study of the application of a specific fungus, Phanerochaete Chrysoporium, as a bio-filter has shown a good ability to remove gaseous aromatic compounds, solvents and more generally volatile organic compounds, from contaminated sites. Recent mycological research has demostrated the ability of this model white-rot fungus to cause decomposition in phenolic resins and more generally in degrading plastics, by literally

[12] http://www.mauriziomontalti.com/

feeding on them. In order to translate his research and address issues related to disposability, plastic toxicity, and the possibility of having fungi being able to 'kill' this immortal material, Maurizio focused his attention on a well-known iconic object: the plastic monobloc chair.

The 'Bio Cover' is intended as a tool-product for turning an inanimate synthetic object into a living entity. Feeding on the plastic, the fungus gradually chews and substitutes the material, whereas the expanding biomass acts as a natural purifier, accumulating volatile toxic compounds. Once fully colonised, the user can dispose of the chair by placing it in the garden or literally burying it. The new organic material, once plastic, can be now used as a natural fertiliser, providing extra nutrients to the soil for the growing of new life.

Example: Teijin Eco Circle[13]

Japan disposes of approximately 1 million tonnes of worn clothing every year, with only 12% being recovered in some way. This has prompted the Japanese Ministry of Economy, Trade and Industry (METI) to increase the drive to reduce textiles entering landfill. Voluntary guidelines have been introduced by METI to help establish recycling activities, and funding has been available to improve and develop technologies to recycle fibres. This has resulted in a number of interesting schemes across the country, one of the most successful being Eco Circle.

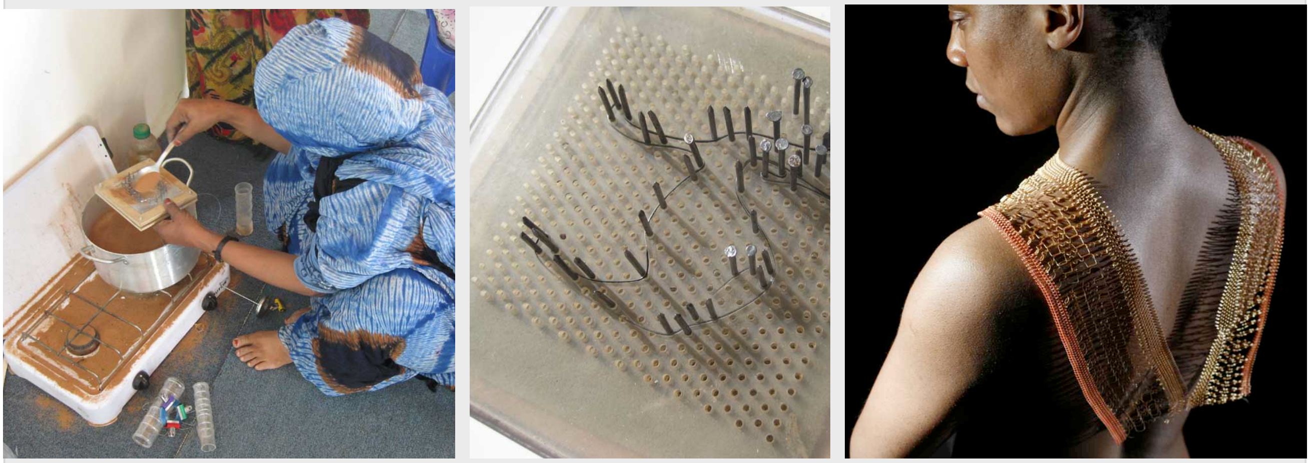
> Eco Circle is a closed-loop recycling system for polyester products, which was developed by Japanese company Teijin Fibres Ltd in 2000. The process firstly breaks down polyester products and granulates them into small pellets. These pellets are decomposed using chemicals and returned into the raw material DMT (dimethyl terephthalate) which can then be polymerised again and finally spun into new polyester fibres (DEFRA, 2009, p21).

This technology is expanded on more fully in chapter 5 as part of a review of polyester recycling.

[13] http://www.ecocircle.jp/

Laura Marsden 2005, Chelsea College of Art & Design, London
Ref: http://www.lauramarsden.com/

Nathalie Chanin, Alabama Chanin, 2009, Alabama
Ref: http://www.alabamachanin.com/



Plastic Gold (2010), Florie Salnot 2010, Royal College of Art, London. A technique to transform discarded plastic bottles into beautiful pieces of jewellery. A craft to empower the Saharawi refugees
Ref: http://floriesalnot.com/

FIGURE 2-6 EXAMPLES OF END-OF-LIFE RECYCLING DESIGN APPROACHES

Luisa Cevese 2000, Riedizioni
Ref: http://www.riedizioni.com/

Precious Waste, (2010), Michelle Baggerman, Design Academy, Eindhoven A textile made entirely out of used plastic shopping bags that were spun into yarns and then woven.
Ref: http://www.michellebaggerman.nl/

Bodies of Change, Maurizio Montalti 2010, Design Academy, Eindhoven. The work consists of a growing ecosystem in which specific fungi act as main decomposers,
Ref: http://www.mauriziomontalti.com/

FIGURE 2-7 EXAMPLES OF END-OF-LIFE RECYCLING DESIGN APPROACHES

2.4.6 Energy Recovery

This is a topic which has been debated widely. Although incineration is a way of reclaiming energy from discarded materials, the downside to this is the destruction of the non-renewable material. 'Matter can neither be created or destroyed'. Incineration is simply taking materials we recognise such as wood, textiles and plastics, and turning them into dioxins, furans and other toxic by products.

This approach can also include anaerobic digestion for bio-gas collection. Both approaches turn waste matter into energy, but lose the value embedded in the original material resource.

- Avoided environmental impacts with this approach include: energy production from other fuel sources (air emissions, waste water, solid wastes), landfill impacts (air emissions, leachate, visual impact)
- Negative environmental impacts to be considered include: transport (use of fuels, air emissions), energy recovery process (energy, water, emissions, solid wastes)
- Social impacts include: possible community opposition to new facilities, does not encourage rethinking of consumption habits
- Economic considerations include: new business opportunities in waste treatment.

2.4.7 Disposal: Textiles And Landfill

Discarded textiles are often put out with the household rubbish and ultimately end up in landfill, which has several disadvantages. Firstly, there will be a cost to the company disposing of material in this way (tipping fees are set to increase dramatically). Secondly, due to environmental concerns, there is an increasing demand to ban oil-based polymers (e.g. synthetic materials) from landfill. Along with the existing plan to ban organic matter (e.g. natural fibres) from landfill this would cover most textile products. Third, land filling oil based polymers, which are created from non-renewable resources, is a waste of energy and materials that could otherwise be reused.

If over 50% of land filled material is considered to be recyclable, then according to referenced figures (DEFRA, 2009), there is the potential to recover approximately an extra 500,000 tonnes of textile waste in addition to that, which is already recovered.

- Avoided environmental impacts with this approach include: energy production from other fuel sources, air emissions, waste water, solid wastes (ash) due to gas recovery and energy generation and carbon sequestration.
- Negative environmental impacts to be considered include: transport, use of fuels, air emissions, landfill impacts, air emissions, leachate, visual impact.
- Social impacts include: community opposition to new landfills, visual / aesthetic impact.
- Economic considerations include: low cost of disposal is a disincentive to recycling.

2.5 SUMMARY

This chapter has aimed to review the current design strategies for dealing with textile waste at the point of disposal. In the main these activities are environmentally viable when compared with alternatives using virgin materials. There are challenges, however, which must be considered. Other than direct reuse, processing such as mechanical, chemical and biological recycling, require the consumption of a certain amount of energy, additional raw materials, and emissions. The resulting product must be commercially viable and in order for it to be successful there must be a consistent supply of waste resources.

Therefore, according to Wang (2006), in order to evaluate the feasibility of a recycling process, the following questions must be asked:

- Do the energy savings and pollutions from the recycling process outweigh the alternatives such as virgin materials, other recycling approaches, waste-to-energy processing?
- Do the products have viable markets and are they cost competitive?

These are difficult questions to assess and require evaluation processes, such as life-cycle analysis. Economics, legislation and consumer attitudes will all put pressure on industry to adapt.

I would add another evaluation component to this list – will the recycling process result in landfill at the end of its recovered life? If so then it is only an extended life technique and not true (cradle-to-cradle) recycling. In order to create effective recycling loops, consideration needs to be given to recycling at the design stage. Therefore the next chapter introduces the concept of 'Design for forward recyling', a strategy which considers how design might better work with materials from the outset to enable recycling at end-of-life.

3 REFINISHING: UPCYCLING BY DESIGN

3.1 INTRODUCTION

The practice element described in this chapter evolved early in the project as a development of my previous design work; that of developing new ways to transform and recycle defined textile waste streams using new technological tools. It represents my 'design responses' to an end-of-life waste recovery strategy and chronologically it was developed before the final practice element, (see chapter 7) which represents the move towards a 'design for recycling' strategy described in chapter 4.

The main research question explored here is:

- How might the laser be used to upcycle textile waste materials?

Two projects, 'Resurfaced' and 'Twice Upcycled', are described in this chapter. The key for both was to add value to otherwise 'downcycled' materials through design interventions (upcycling). My focus was to address the problem at 'end-of-life' after the damage has already been done, the emphasis being on keeping the materials in 'high value' service to increase the demand for future recycling. This research proposes that there is potential for 'design for upcycling', enabled through a new toolbox of technological processes.

Here the use of the CO_2 laser is explored as a tool for 'refinishing', (developing cutting & etching techniques) in order to facilitate subsequent lifecycles by intercepting materials before they become waste or in this case after a downcycling process has already occurred. Previous designers working with this technology are acknowledged (see appendix) and the main aim was to push the use of the CO_2 laser into potential new techniques. Progress was made in developing cut-bonding and etch-bonding techniques not previously seen.

'Resurfaced' was developed for 'Ever & Again; rethinking recycled textiles'[14] an interim exhibition with TED in 2007, as a response to the problem of 'monstrous hybrid products' which are unrecyclable but common in the textile industry.

'Twice Upcycled' was a collaboration with Rebecca Earley, as part of her 'Top 100' project.[15] Refinishing in this context was again explored as a way to 'add value' and to extend the life of the reclaimed materials.

Prior to this body of work, influences were drawn from my Masters Project (2000)[16], and involvement in the 5 Ways Project (Earley & Fletcher, 2003)[17], together with participation in workshops during the first year of the Worn Again Project (Earley, 2005-2009)[18].

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[14] http://www.tedresearch.net/event/ever-and-again-exhibition/
[15] http://www.upcyclingtextiles.net/docs/08_twiceupcycled.html or http://www.tedresearch.net/research/detail/twice-upcycled/
[16] MA Textile Futures, CSM (2000) http://www.textilefutures.co.uk/
[17] 5Ways (2002-2003) http://www.5ways.info/docs/about_us/about_us.htm
[18] Worn Again (2005-2009)

3.2 BRIEF: TECHNOLOGY-DRIVEN UPCYCLING RESPONSES

Murray (2002) states that upcycling is about ‘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.’ So, if one can add value – economic, intellectual, emotional, material – to a product through the process of reuse, it can be called ‘upcycled’.

During the early stages of this project the aim became to upcycle rather than recycle textiles, thus exploring the potential to create an economic argument for a practice that could also benefit the environment and mitigate our current landfill burden. The two design projects described in this chapter were born out of Stage 2 of the ‘Worn Again’ TED project.

> The particular knowledge that only a design researcher can bring to the process of design-led upcycling can be seen as instrumental in this practice, and was demonstrated throughout the project’s three stages. In Stage 1 the designers were introduced to the key sustainable design ideas through workshops that culminated in a final ‘Synergies’ workshop, which began to show how to interconnect or layer the different strategies. Stage 2 saw the designers develop new work for the Exhibition and in Stage 3 the designers reflected on the feedback from the exhibition and reworked their concepts using adapted co-design techniques in a further series of workshops. A theory for upcycling textiles began to be developed and disseminated, which centred on interconnected design thinking, explored through workshop scenarios with a range of external participants (Earley, 2011).

3.3 TECHNOLOGY: LASER PROCESSES FOR THE TEXTILE INDUSTRY

From the range of options available for thermoplastic manipulation, the laser was chosen for its ability to be digitally controlled ensuring maximum accuracy and design detail was possible.

When a laser beam interacts with a textile material the fibres will either melt (with synthetic materials) or combust (with natural materials). Thus the use of lasers is better suited to synthetic materials. Natural fibres will burn and be weakened by the interaction whereas synthetic ones ‘seal’ where cuts occur – essentially ‘finishing’ the edges. This is due to a ‘phase change’ in the material from solid through a transitional phase to a melted ‘liquid’ phase, which again solidifies on cooling. The advantage of using digitally controlled lasers with thermoplastic materials such as PET (polyethylene terephthalate) is that this melting can be highly localised and accurately programmed. This creates the potential for various surface effects to be achieved without the adding of any other materials – simply by controlling the way the laser interacts with the material.

This melting can be used in various ways: to cut through the material, to modify the surface structure or to join two materials together. (When two textile materials of the same thermoplastic polymer are overlaid and melted together by exposure to laser radiation, their constituent polymer chains diffuse through the interface of the two melts.

On cooling, the molecules of these two separate polymers intermix and co-crystallise, creating a reinforced bond at the point of weld (Bartlett, 2006, p13).

> Laser processing of textiles is a well-known industrial process for cutting and marking. Equipment is becoming more accessible and even commonplace in industry and in academic institutions for use by Art & Design and Design Technology departments at both university and school level. As is often the case with emerging technologies, there is a requirement for the potential to be fully understood before the process can be exploited. A number of practitioners, designers and technologists are involved in exciting work that moves the laser process beyond just a cut or a mark in a material (Cutting Edge, 2009).

The following sections review the currently available technology and the relationship of contemporary practitioners and industry to these technologies.

3.3.1 Cutting And Etching (CO2 Laser)

The use of CO2 lasers in industry is well established. They are used for cutting garment patterns, creating lace-like cut-out materials and as an alternative to harmful bleaches in the denim finishing industry. My studio work to this point could be seen as being part of a well documented field of design although it had not previously been explored as a tool for upcycling or recyclability. Previous work had considered only the environmental impacts of its use in production.

3.3.2 Co2 Laser Fusion Welding

Patents as far back as 1977 by ICI (UK) sought to replace skilled but expensive hand sewing of seams with laser welding. The technique used two 300 watt, CO2 pulsed beams to produce a narrow line of point welds or several adjacent lines of continuous welds along the interface of two overlapping textiles to form the back and front of a garment. However this patent was later abandoned due to complications in controlling the process for textile application.

3.4 PRACTICE: (RESURFACED) LASER FINISHING TO UPCYCLE MIXED FIBRE WASTE

The ‘ReSurfaced’ project was developed as a response to the irreversibility of ‘shoddy’ textile waste. It is an end-of-life strategy for adding value to otherwise downcycled materials, borrowing techniques from the plastic food packaging recycling industry.

3.4.1 The Shoddy Problem [& Monstrous Hybrids]

‘Shoddy’ materials cannot be upcycled through repolymerisation nor biodegraded, and often end up ‘downcycled’ as low-grade fibre products such as underlay for carpet, insulation materials or other ‘unseen’ and low value applications. I wanted to explore the potential for ‘upcycling these materials, adding value through design interventon. By treating them as precious resources, was it possible to promote them to a higher value and prevent further ‘downcycling’?

The ‘Ever and Again: rethinking recycled textiles’ exhibition in October 2007 offered an opportunity to confront a dilemma, which had emerged through this study. Research into the potential for closed-loop textile waste streams and cradle-to-cradle design had revealed a problematic group of materials which represented a block to the repetitive recycling of resources.

This group included composite, man-made materials, which could not be recycled because they contained blended fibres from both technical (synthetic) and biological (natural) material metabolisms. Named ‘monstrous hybrids’ by McDonough & Braungart (2002) in their inspirational text ‘C2C: remaking the way we make things’, these materials represented a difficult challenge. This was the focus of the ReSurfaced project described in the following text.

3.4.2 Resurfacing As A Tool For Adding Value By Design (Upcycling)

In order to address these low-grade mixed fibre waste textiles, I looked to the plastics industry and undertook a polymer engineering short-course at London’s Metropolitan University.

> Borrowing from food packaging technology, where a technique existed for laminating recycled plastic with a very fine layer of virgin polymer, I devised a similar process for shoddy. By applying a fine layer of polyester non-woven on to the shoddy and then manipulating this surface through laser techniques developed for the PhD project, the material could be given a ‘new skin’, making it useful for more prominent or high value applications. Thus, a ‘monstrous hybrid’ that had been destined to landfill, although remaining hybrid, with this application, may be upcycled for future lives’ (Neuberg, 2011).

The materials are fused together according to a preset digital pattern which creates a permanent bond between the layers with surface decoration achieved as part of the same process. No adhesives or bonding agents are used in this process. The reuse of existing materials without additives is a key feature of this process, creating a higher value for the materials’ next life. By borrowing techniques from marquetry and surface etching, a new palette of treatments emerged, resulting in a collection of upcycled shoddy textiles for interior applications. Future technological developments may provide ways for these materials to be separated back into their constituent parts and returned to their cyclic origins, but meanwhile, strategies for extending life and creating value from waste will have an important place in preventing further landfill of valuable resources.

This project focused on the concept of life-cycle thinking and the 'upcycling' of materials through design intervention, particularly through the application of new technology. At the time this was the most advanced approach for recycling as it elevated the value of waste beyond other approaches in use.

Bradley Quinn (2009) wrote the following about the work:

> British designer Kate Goldsworthy is something out of the ordinary. Not just because she has a passion for sustainable design, but because she venerates the materials that most textile designers shy away from [non-woven polyesters and the robust felts used to make carpet underlay, insulation, household textiles, medical bandaging and geo-textiles.] These materials are the unseen "work-horses" of the textile world. Because they are rarely used as outward-facing materials, they are almost always hidden from view.
>
> Textiles of this type are manufactured in large volumes, providing a reliable secondary resource for industrial recycling. Yet, few manufacturers have realised that these secondary fabrics could easily be reinvented as sustainable textiles. 'Whether you realise it or not, these materials are a precious resource, and I treat them that way,' Goldsworthy said. 'By revealing their hidden beauty, I can elevate them to a higher status and make them more desirable to consumers.'
>
> The processes Goldsworthy pioneers always take waste as their starting points, and efficiently convert it into source material. But since Goldsworthy is an aesthete, her methods transform trash into treasure, because she is committed to making the finished product look good…. Goldsworthy resurfaces recycled mixed-fibre felt by layering reclaimed non-woven materials on its outer surface. The finish it yields gives the surface a uniquely structured texture that looks as good - if not better - than many bonded fabrics. New technologies make resurfacing a viable and sustainable method of producing 'up-cycled' textile products.

3.5 RESULTS & ANALYSIS

The sampling stage of this project (see figs 3.1 – 3.6) was carried out using the CO2 laser as a tool for transformation. This was a tool I had used previously in design work and had some prior knowledge of working with. CO2 lasers were accessed during 2006-2008 at Chelsea College of Art and Design, and in the Design Department at Goldsmiths. The ability to be allowed to work freely was central to progress being made during experimentation. Access to laser facilities is often on a 'service' basis whereby digital files are sent directly to a bureau and samples sent back when processed. This relies on the designer having a prior understanding of the process which they often do not have. The ability to control, watch and intervene in the process throughout the sampling stage was essential in the development of innovative techniques.

During the sampling phase combinations of cut and etch settings were explored with both single layer and multi layer materials. The impact of CO2 lasers on the cutting, etching and bonding of 100% polyester was observed and recorded.

Different effects were noted and the main parameters of the laser interference (beam scanning speed, marking resolution and power output) were recorded. Parameters were tested to find a 'working' method for producing the desired effect – these parameters were not further tested to find optimum settings – proof of concept was the goal. Further testing could be explored to refine settings.

Direct visual observation was the main means of analysis and is summarised in the table below; The experimentation was carried out as a set of exploratory studies, one leading to another. The classification of the resulting samples was defined at the end of the sampling stage and brought together as shown in table 3.1.

	CUT	ETCH	Single layer	Multi layer	
Finish (Replicating)	Effect		Construction		Notes
Single-layer cut-through	X		X		Waste produced
Multi-layer cut-through (marquetry)	X			X	Waste produced
Single-layer surface-etch (embossing)		X	X		Difficult to control
Multi-layer bond (composite)		X		X	Bond not stable
Single-layer total melt (devore)		X	X		Material state change

Table 3-1 CO2 Experiments / Analysis

Pages from sketchbook. Experiments with recycled PET materials and the CO2 laser, conducted at the design department, Goldsmiths, and Chelsea College of Art & Design London, 2007

Photography: Goldsworthy, 2007

FIGURE 3-1 SAMPLING SKETCHBOOK FOR RESURFACED PROJECT, WITH THE CO2 LASER, 2007

Pages from sketchbook. Experiments with recycled PET materials and the CO2 laser, conducted at the design department, Goldsmiths, and Chelsea College of Art & Design London, 2007

Photography: Goldsworthy, 2007

FIGURE 3-2 SAMPLING SKETCHBOOK FOR RESURFACED PROJECT, WITH THE CO2 LASER, 2007

3.5.1 Single-Layer Cut Through

This was the most basic of experiments and used only as preparation for more complex techniques to follow. Where there was some natural fibre in the material (in the case of shoddy for example) the edges burned and frayed. In the case of 100% synthetic material the edges were sealed and did not burn.

3.5.2 Multi-Layer Cut Through (Marquetry)

When multiple synthetic layers were cut together in a single pass the resulting effect was similar to 'marquetry' or inlay. Top layers could be peeled off to produce lace-like fabrics while the remaining piece retained any 'cut-outs' as an inlaid pattern. If a thick felt was used as a base then these remaining layers became embedded into the surface to create a permanent effect.

3.5.3 Single-Layer Etch (Transparency)

If single layered materials were etched at the correct setting then transparency could be achieved due to the melting of the material. This 'devore' effect was achieved due to the plasticisation of the affected material.

3.5.4 Multi-Layer Etch (Bond)

The etching of layered materials resulted in bonding effects combined with the transparency effect of the single layer experiments.

3.5.5 Complete Melt (Transparency)

An etching process can be used to create a complete transformation of an opaque textile material into a transparent 'plastic'.

3.5.6 The Finished Outcomes & Exhibition

The resulting samples (see figs 3.3 – 3.9) were produced for the interim exhibition of the 'Worn Again' research project (Ever & Again; Rethinking Recycled Textiles) and demonstrated an extended palette of techniques achievable through the use of the CO2 laser which could be used to 'resurface' low-grade recycled materials for a potentially higher-value use (Earley, Goldsworthy and Vuletich, 2010).

Most of the participating designers in this exhibition were in their second year of the research project and had been part of a series of workshops exploring recycling in the context of four key sustainable design strategies that included ethical production; long life/short life; new technologies and systems and services design. The curator, Rebecca Earley, had asked the designers to think about recycling in its broadest sense, in the most innovative and creative of ways, before focusing on creating an exhibit that explored an aspect of the project brief in more detail.

This work was reviewed by Lucy Siegle of the Observer in the exhibition catalogue:

> The importance of technology is notable – this is no whimsical knitting circle. If I had a pound for every occasion someone had regaled me with the way plastic water bottles can be turned into fleece, I'd have enough for an 'IT' bag. We must move beyond this; there are only so many fleeces the world needs. Fortunately Ever & Again does: Kate Goldsworthy notably pushing the material re-creation envelope (Siegle, 2007).

Final prototypes for ReSurfaced project (mulit-layer cut through) with the CO2 laser, conducted at the design department, Goldsmiths, London, 2007

Photography: Goldsworthy, 2007

FIGURE 3-3 MULTI-LAYER CUT THROUGH SAMPLING FOR RESURFACED PROJECT, CO2 LASER, 2007

Early ReSurfaced experiments (mulit-layer cut through) with recycled PET materials and the CO2 laser, conducted at the design department, Goldsmiths, London, 2007

Photography: Goldsworthy, 2007

FIGURE 3-4 MULTI-LAYER CUT THROUGH PROTOTYPES FOR RESURFACED PROJECT, CO2 LASER, 2007

Early ReSurfaced experiments (mulit-layer etch) with recycled PET materials and the CO2 laser, conducted at Chelsea College of Art & Design, London, 2007

Photography: Goldsworthy, 2007

FIGURE 3-5 MULTI-LAYER ETCH SAMPLING FOR RESURFACED PROJECT, CO2 LASER, 2007

Final prototypes for ReSurfaced project (mulit-layer etch) with the CO2 laser, conducted at Chelsea College of Art & Design, London, 2007

Photography: Goldsworthy, 2007

FIGURE 3-6 MULTI-LAYER ETCH SAMPLING FOR RESURFACED PROJECT, WITH THE CO2 LASER, 2007

Final prototypes for ReSurfaced project exhibited at 'Ever & Again; Rethinking Recycled Textiles', Triangle Gallery, Chelsea College of Art & Design, London, 2007

Photography: Goldsworthy, 2007

FIGURE 3-7 MULTI-LAYER ETCH PROTOTYPES FOR RESURFACED PROJECT, WITH THE CO2 LASER, 2007

Final prototypes for ReSurfaced project exhibited at 'Ever & Again; Rethinking Recycled Textiles', Triangle Gallery, Chelsea College of Art & Design, London, 2007

Photography: Goldsworthy, 2007

FIGURE 3-8 EXHIBITION 'EVER & AGAIN; RETHINKING RECYCLED TEXTILES', LONDON, 2007

'Ever & Again', Interim Exhibition of the 'Worn Again' Project, October 2007

Photography: Earley, 2007

FIGURE 3-9 EXHIBITION 'EVER & AGAIN; RETHINKING RECYCLED TEXTILES', LONDON, 2007

FIGURE 3-10 EXHIBITION 'EVER & AGAIN; RETHINKING RECYCLED TEXTILES', LONDON, 2007

3.6 PRACTICE: (TWICE UPCYCLED) LASER FINISHING FOR POLYESTER GARMENTS

In 2008 I began a collaborative project with Rebecca Earley entitled 'Twice Upcycled'. The project was part of 'Top 100', Earley's long running project which used various redesign processes to transform 100 discarded polyester shirts into new product.

Upcycling refers to reuse of a garment where its quality remains the same or is enhanced by the process, attempting to counter the common problem of recycling practices reducing the quality of the original materials, as occurs when glass is recycled.

Here the original shirt had been bought and worn by a consumer, and then handed on to a second hand or charity shop, from where Earley purchased it. This first upcycling occurred through simple reshaping and overprinting. Earley's heat photogram print used a real palm leaf, recycled paper and reactive dyes, to create an overprint that hid any staining or soiling from the garment's first life. A second life is thus given quickly and stylishly to a polyester shirt that would otherwise take more than 200 years to decompose in landfill. Following a period of wear by the same or next consumer, the shirt can be returned and its third life can be created. Two design outcomes were explored in this stage: The Laser Lace shirt (fig 3.14 – 3.16) and the Laser Quilted shirt (fig 3.11 – 3.13).

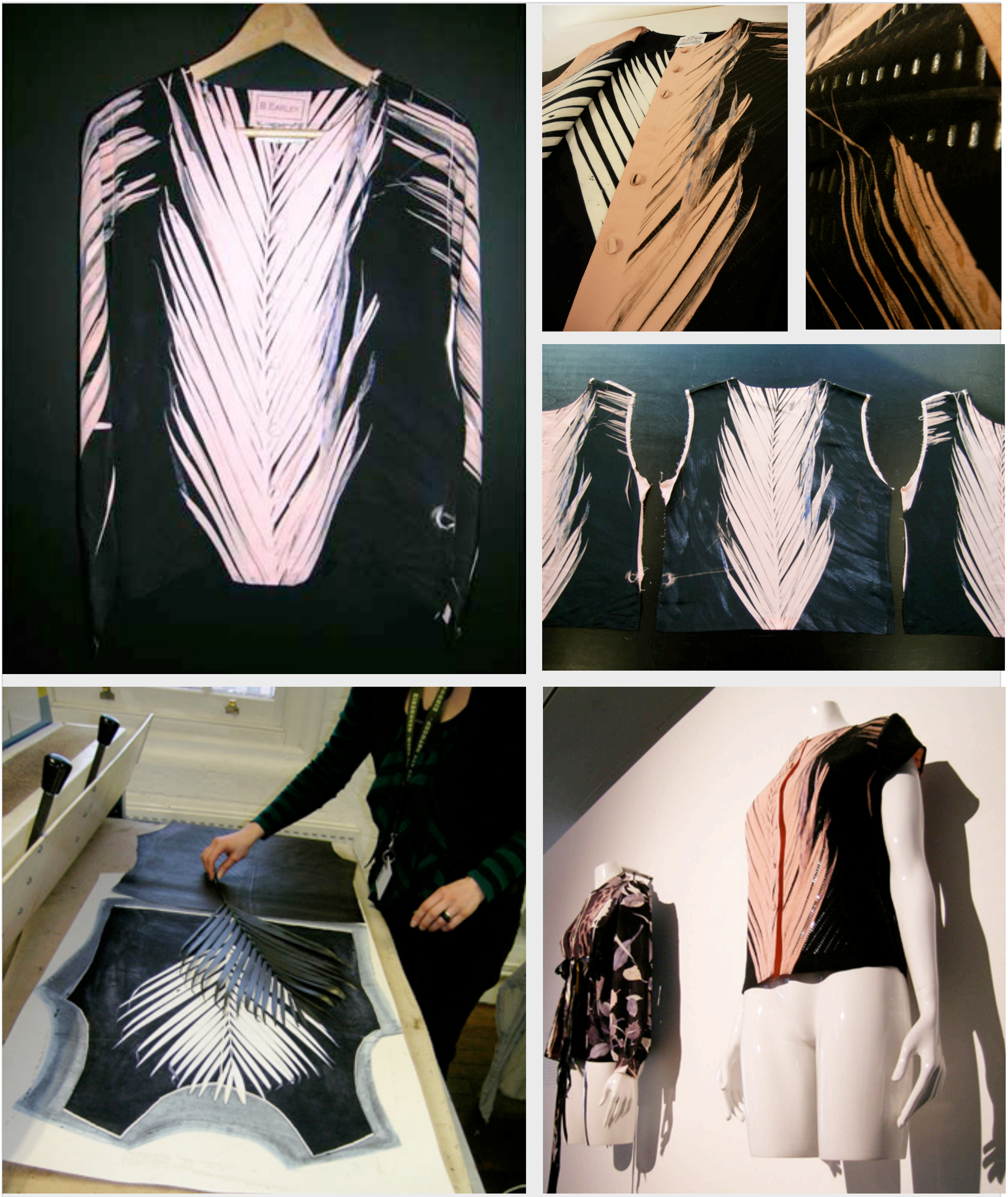
> A range of socially and ecologically aware fashion designers has emerged. Indeed, some companies are challenging how business itself is conducted, not just with a view to their produt but encompassing their entire structural model. Individual researchers have managed to fuse nature and technology to produce highly innovative means of renewing products rather than making entirely new ones, for example Earley [and Goldsworthy's] 'Twice Upcycled' shirt collection (Brown, 2010, p141).

3.6.1 Laser Lace Shirt

The first shirt (fig 3.14 – 3.16) was re-finished to create a lace like effect, using techniques previously developed on the CO2 laser. Areas of melted transparent material were created through laser etching. The pattern was controlled digitally and there were no added agents in the process. The reuse of existing materials without additives was a key feature of this stage. Upcycling was achieved without any material resources and the resulting product retained its inherent recyclability for another lifetime.

3.6.2 Laser Quilted Shirt

For the second iteration, (fig 3.11 – 3.13) the shirt became a quilted garment, where it had been re-cut and lined in recycled polyester fleece, and then laser welded. This was the first experiment with a new laser technology (which became the final focus of the project and is described fully in chapter 7). The materials were fused together according to a preset digital pattern, which created a permanent bond between the layers with surface decoration achieved as part of the same process. No adhesives or bonding agents were used in this process.



Making of the Laser Quilted Shirt for the Twice Upcycled project with Rebecca Earley, 2007

Photography Earley, 2007

FIGURE 3-11 MAKING THE LASER QUILTED SHIRT, TWICE UPCYCLED, WITH R. EARLEY, 2007

Sampling for Laser Quilted Shirt for Twice Upcycled project with Rebecca Earley, 2007

Photography: Goldsworthy, 2007

FIGURE 3-12 SAMPLING FOR THE LASER QUILTED SHIRT, TWICE UPCYCLED, WITH R EARLEY, 2007

Final prototype of Laser Quilted Shirt for Twice Upcycled project with Rebecca Earley, 2007

Photography: Earley, 2008

FIGURE 3-13 FINAL PROTOTYPE LASER QUILTED SHIRT, TWICE UPCYCLED, WITH R EARLEY, 2007

Sampling for Laser Lace Shirt for Twice Upcycled project with Rebecca Earley, 2007

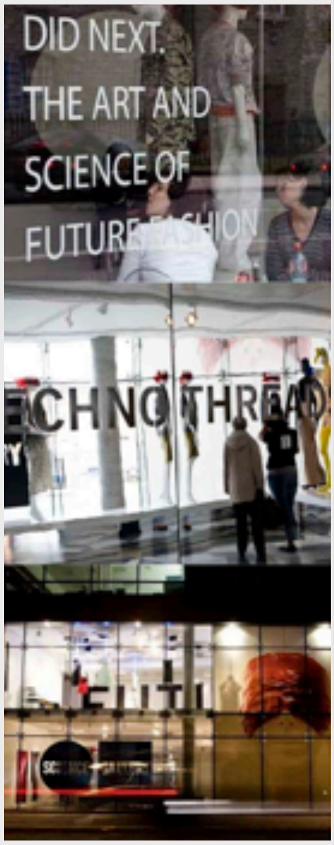
Photography: Goldsworthy, 2007

FIGURE 3-14 SAMPLING FOR THE LASER LACE SHIRT, TWICE UPCYCLED, WITH R EARLEY, 2007

Final prototype of Laser Lace Shirt for Twice Upcycled project with Rebecca Earley, 2007

Photography: Earley, 2008

FIGURE 3-15 FINAL PROTOTYPE LASER LACE SHIRT, TWICE UPCYCLED, WITH R EARLEY, 2007



Twice Upcycled with Rebecca Earley, Exhibited at Techno Threads, Dublin Science Gallery, 2008

Photography: Earley, 2008

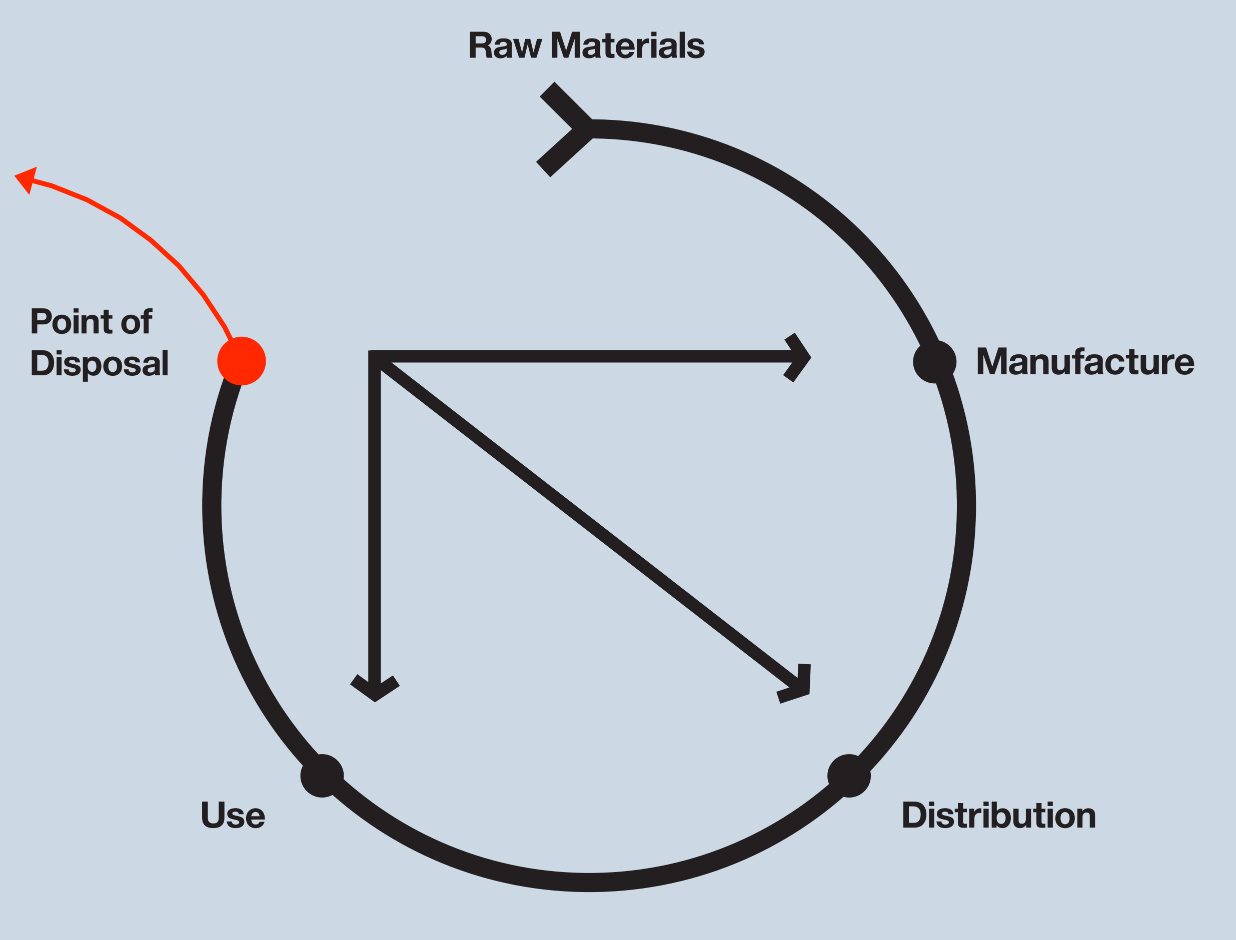
FIGURE 3-16 EXHIBITIONS, TWICE UPCYCLED, WITH R EARLEY, 2007

Upcycling by Design

Limited materials with limited life-cycles.

Although return journeys can be designed in at the end-of-life, this approach only postpones the arrival of the discarded material at landfill where it may never biodegrade, may degrade very slowly or may add harmful materials to the environment as it breaks down.

An end-of-life approach with disposal as the starting point.



Recycling by itself, only postpones the arrival of the discarded material at landfill, where it may never biodegrade, may degrade very slowly, or may add harmful materials to the environment as it breaks down. (Livingston, 2003)

Upcycling by Design

Graphics: Laura Gordon, Franklin Till, 2012

FIGURE 3-17 MATERIAL JOURNEYS / SINGLE LIFE

3.7 SUMMARY

Although innovative finishing techniques using the CO2 laser were produced during this phase of practice, the overriding insight gained from this work was that in order for these techniques to be part of an ongoing polyester economy then recyclability would need to be considered much earlier in the original design stage. Without this, recycling can never be anything more than an end-of-life response, extending the lifespan of material resources rather than effectively recycling the materials in perpetuity.

As we have seen, this insight, which occurred through reflection on the practice, was backed up by the subsequent review of the recycling industry, which is discussed in chapter 2 and led directly to the following revised theoretical approach (chapter 4) and a new design brief (chapter 6).

4 DESIGN FOR FORWARD-RECYCLING

4.1 INTRODUCTION

During the practice elements of the work, the design focus shifted from an end-of-life intervention to an integral part of the design brief. This came about from insights in early practice together with the research insights outlined in chapters 2 and 3. This chapter seeks to explore the potential for 'design for recycling' approaches.

The main research question explored here is:

- How could a designer work within a 'C2C' framework considering materials as borrowed resources?

The challenge is one of design intervention. Design often 'builds in' production processes and finishes to create products which cannot be recycled cost effectively. Traditional textile processes (in particular coating, bonding and fibre blending) created barriers to efficient recycling.

There are examples of brands trying to tackle this in the sportswear and uniform market, for example the Common Threads programme by Patagonia (2005) or the BREW (2008) corporate wear project by DEFRA but there is a general lack of textile design interventions.

As soon as traditional decorative processes are applied, recyclability is removed. The solution needs to provide alternative processes which can preserve monomateriality and therefore recyclability by working with the manipulation of this thermoplastic material without any added agents (adhesives and coatings etc).

The really exciting thing about following a C2C model is that the textile industry could effectively create self-sustaining recycling loops, which recover waste and reuse it in subsequent reincarnations. The function of the designer in this would be to redirect these materials around an interim life cycle before they eventually go back for repolymerisation. [19]

If designers are fully aware of the qualities of the materials they are using then they can be instrumental in directing their products around the appropriate life cycles. In the case of polyester textiles this would include a full understanding of the processing options available, so as to not prevent the material from being reprocessed after its interim lifecycle has ended.

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[19] Repolymerisation; a chemical reaction in which polymers are returned to their original monomers.

4.2 UNDERSTANDING MATERIAL CYCLES

The previous chapters looked at end-of-life recycling solutions, i.e. approaches where the starting point is the waste material. It concluded that, regardless of the recycling route, unless forward recyclability is considered, the ultimate destination will eventually be disposal. In order to facilitate better quality outcomes and 'true recyclability' there also needs to be attention given to recyclability at the start of a product's journey – the design stage. If considered as part of the initial design then recyclability can be built in from the outset.

One of the key factors identified in the proposal above is that if progress is to be made in the quality of recycled textile products then an understanding of the material systems of their origin is needed. Textile waste is made from a complex range of different fibre types. Most of the fibrous waste is composed of natural and synthetic polymeric materials, with the largest groups being cotton, polyester, nylon and polypropylene (see appendix). Of these four fibres all but cotton come from a petroleum-based raw material. Even for renewable fibres such as cotton, production requires energy and chemicals that are based on non-renewable resources, so no fibre comes from wholly renewable resources if you take into consideration its whole life-cycle.

Textile waste is often characterised by function rather than the material group from which it is made, for example, clothing and shoes, filling materials, wiping cloths etc. However, it is the material source that is most relevant when discussing end-of-life possibilities. For my investigation to continue, an understanding of the nature of waste materials was needed, and this was informed by 'C2C' theory, which, as we will see below, classifies materials into two main groups.

4.2.1 C2C: A Theory Of Material Metabolisms

First coined in the 1970's by Swiss Architect Walter R. Sahel, the term C2C was refined at the beginning of the new millennium by German chemist Michael Braungart and architect and designer Michael McDonough, who promised a new way of thinking about making things in their collaborative publication *'The Hannover Principles'* (1992), which they followed up with '*C2C: Remaking the Way We Make Things*' in 2002. A book that has undergone many reprints and is now a cult read.

It describes two distinct material types, which need specific disposal and recycling solutions, and backs up the notion that synthetic materials are well suited to industrial recycling practices. According to the theory, there are two types of material metabolisms, or cycles, which are outlined in the illustration opposite. This is a discourse that celebrates new design and creativity. It promotes a methodology which, rather than focussing on logistics and technology to solve our resource problems, places the designer at the centre of the solution (Goldsworthy & Lang, 2010). Designers working to this end can adopt many different routes to get there, but there are two main strategies which need to be integrated into the very start of the design process, setting a brief which ensures all materials involved in a product's construction can be either:

- returned to the earth where they harmlessly decompose and become food for plants and animals while rebuilding nutrients in the soil
  or
- returned to industrial cycles when no longer useful, thereby supplying high quality raw materials for new products.

The ‘C2C’ framework creates systems of consumption and production in which materials move cyclically into appropriate biological or technological nutrient cycles, consistently replenishing themselves. These are closed cycles in which materials are broken down and used as the ‘nutrients’ for new products. Thus, in this process, ‘waste equals food’.

Raw materials used in manufacturing are categorised according to their impact on the health of humans, animals and the environment, eliminating all elements known to be dangerously harmful, and tolerating some substances that are not ideal but deemed necessary until substitutes are found. For this system to be the most successful, manufacturers need to be committed to selecting raw materials that are not only harmless but are actually beneficial.

In the ‘C2C’ structure, products that will be consumed by humans and animals are made from substances that are part of the biological nutrient cycle, returning to the earth as a nutrient and causing no harm to the environment or the consumer. Products that will be used but not consumed by humans such as cars, appliances, light fixtures, etc., are made from technical nutrients that are not biodegradable, but can be recycled . The ‘C2C’ concept shifts the focus from minimising harm to maximising benefits, working with nature, and at the same time creating products with economic value (Terra Matter, 2006).

For textile designers this means two very different approaches for working with either natural or synthetic materials at all stages of the production cycle. In the case of biological (natural) fibres the key concern is to prevent use of any chemicals which would cause harm if they were leached into natural systems as material is returned to the earth through biodegredation. For synthetic materials the priority is to design products, which can be effectively recycled in perpetuity without loss of quality.

When analysing textile waste we can characterise it in three key groups: biological fibres, synthetic fibres and mixed fibres (both biological and synthetic mixed in a single material).

4.2.2 Industrial Ecology

Industrial ecology is the shifting of industrial process from linear systems, in which resources eventually become waste, to a closed loop system where wastes become inputs for new processes. In order to design for this cyclical system we need new tools, and ways to create perpetual products.

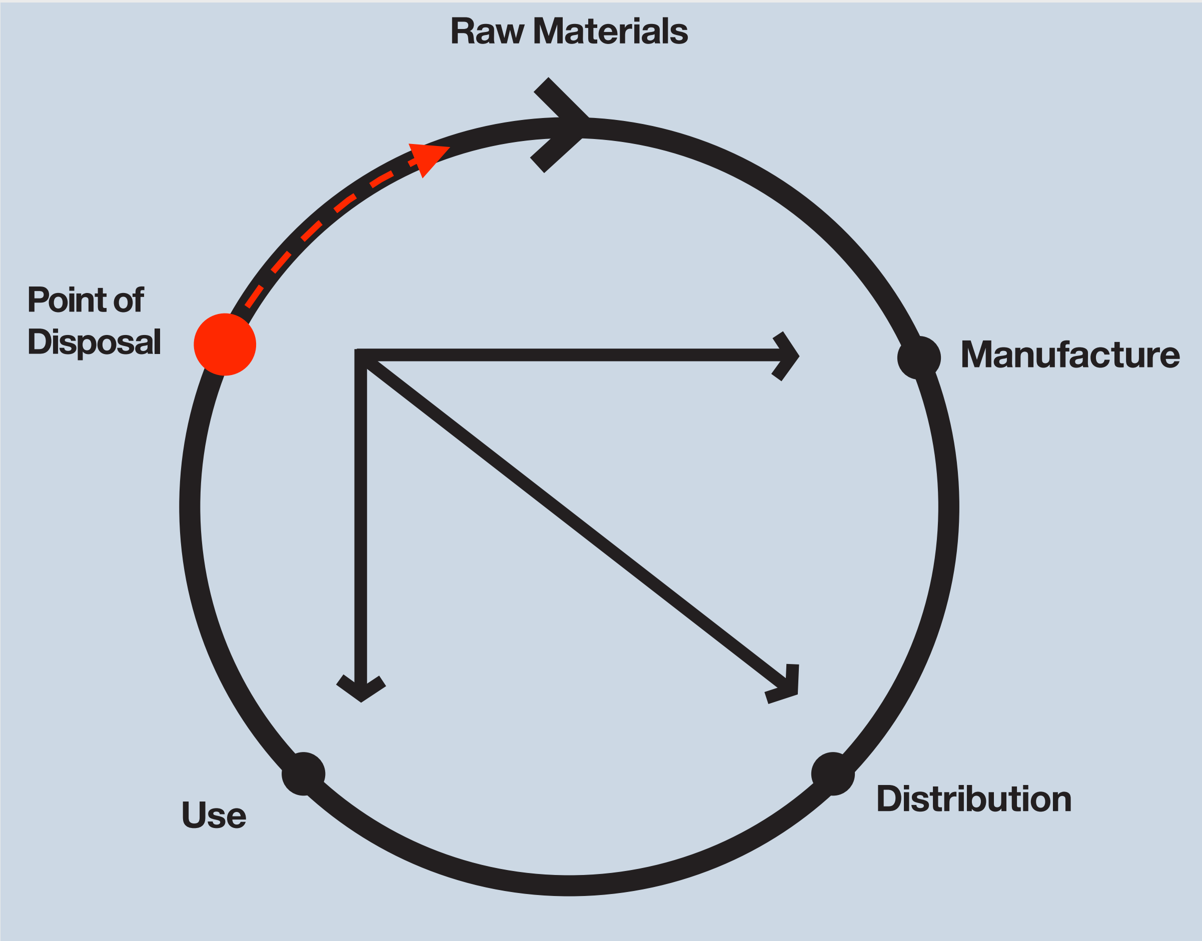
> We are living in a hyperindustrial society where the usage of energy and materials keeps increasing. The biosphere could be a model for the economy. It's both a constraint, but also a source of innovation if you develop sophisticated technologies for really recycling all materials. (Erkman, 2007)

Design for Cradle-2-Cradle

Limited materials with unlimited life-cycles.

By considering the barriers to recycling as part of the design brief, connected loops can be built into the material's future life from the outset. In a closed-loop, materials would never lose their value and would be designed to be recycled indefinitely.

An integrated approach enabling C2C material systems.



A genuinely sustainable future depends on creating closed loops, or cycles, for all industrial commodities. In a closed loop, materials would never lose their value and would recycle indefinitely. (Livingston, 2003)

Design for Recycling

Graphics: Laura Gordon, Franklin Till, 2012

FIGURE 4-1 PROPOSED SYSTEM FOR RECYCLING THERMOPLASTIC MATERIALS

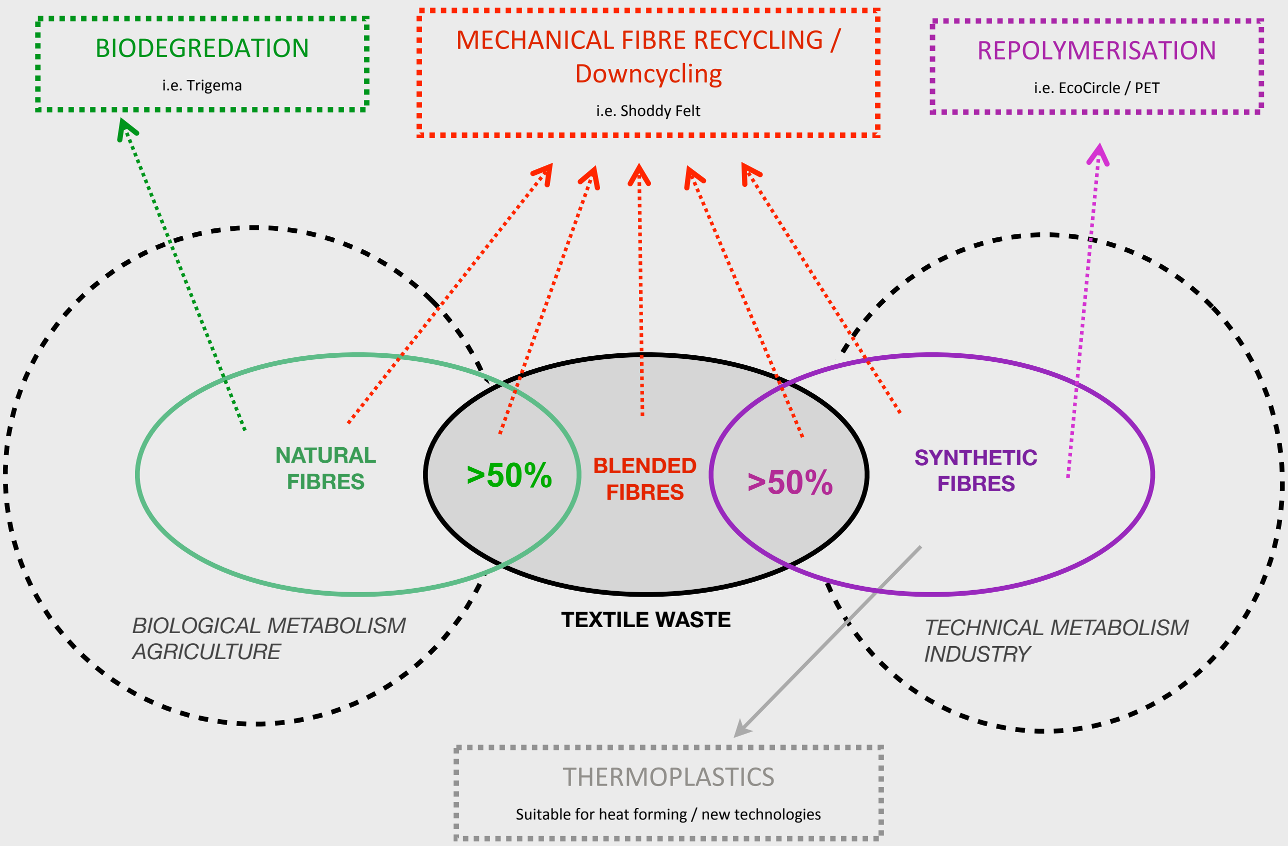


FIGURE 4-2 MODEL NO1 / MATERIAL METABOLISMS

4.2.3 Biological Fibres

Natural fibres and biopolymers belong to a biological metabolism (the cycles of nature). The source material is usually supplied through agricultural methods such as cotton growing, therefore products should be able to biodegrade and become food for biological cycles. This is not to say that biological textiles cannot be recycled but due to the processes required, they tend to be down-cycled into lower quality products.

4.2.4 Synthetic Fibres

Synthetic fibres / polymers belong to a technical metabolism (the cycles of industry). These products are predominantly made from non-renewable resources such as petroleum and should stay in closed loop technical cycles and become valuable nutrients for industry to recycle. It is possible for these materials to be taken back to their original elements in order for the material to be of at least equal quality to the virgin material (and occasionally of higher quality – upcycling).

The polyester 'lifecycle', investigated in depth in this thesis, has a potential final destination of 'repolymerisation', although other mechanical routes (by heat or fibre pulling/shoddy) are also possible. The key to keeping the material flowing in the correct cycle is that a monomaterial state must be maintained.[20]

4.2.5 Blended Fibres

These two subsets relate to intrinsically different materials with varied properties and recycling needs. For the cycles to function one must not become contaminated with the other. If materials from both cycles are present in one product, such as in blended fibres, separation becomes problematic. If we continue to design blended fibre products without finding a solution to the problem of their disposal then this problem will endure.

Textile production has been moving steadily towards blended fibres in order to produce new functionality and this has been a serious barrier to recycling progress. Design needs to find solutions which are 100% mono-material without sacrificing functionality.

[20] acc to Teijin (Miles Merchant interview, 2009) a min of 90% monomateriality is needed

4.3 DESIGNING FOR RECYCLABILITY

The challenge is to design products that either decompose into the earth as nutrients for the soil or can be returned to industrial cycles to supply high-quality raw materials for new products, when their original life is over.

Over the course of the last decade, the fashion and textile design industry has been evolving to meet the fast-changing demands of consumers newly alert to the environmental impacts of their purchases. Recycling, once a niche, craft activity has become a more common response, embedded in many company strategies alongside attempts to reduce waste, carbon emissions and the use of toxic chemicals from all elements in a product's lifecycle. No matter the intention, the eventual result is often products that are unrecyclable or unable to be reused, eventually ending up in landfill.

During recent years, designers have been addressing this often disconnected strategy and seeking to produce better, more sustainable ways of working.

This section provides an analysis of the theory around 'design for recycling' (see table 4.1) as a development of the 'end-of-life recycling strategies' outlined in chapter 4 and expands on the different models by giving examples of existing work in the textile design field.

The analysis is divided into three approaches;

- Design for Remanufacture [at Product Level]
- Design for Recycling [at Material Level]
- Design for C2C [at Chemical Level]

All three approaches are able to work such that one does not exclude the other, but the final practice (chapter 7) is focussed on the third approach and in particular 'design for repolymerisation'.

Thinking in this way completely changed the design brief and created a different set of drivers for design intervention.

4.3.1 Design For Recycling Analysis

	LIFECYCLE STAGE	WASTE HIERARCHY OPTION In order of maximum use of resources	DESIGN FOR RECYCLING APPROACHES		EXAMPLES
	USE & LAUNDRY	1 / Avoidance & Minimisation [WASTE REDUCTION systems]	[DESIGN FOR MINIMUM IMPACT] [Low Launder] Design products which need little care in use. [Zero Waste] Use less material in production i.e. no waste patterns [Dematerialisation] Use less materials for equal functionality i.e. lightweight materials [System & Services Design] Focus on need not product Reduce the need to consume	DESIGN FOR LONG-LIFE, & MINIMUM IMPACT	5 ways / No Wash Mark Liu Microfibre / Aerogel Inflatable insulation Keep & Share
DIRECT RECOVERY	SALES & DISTRIBUTION	2 / Reuse [REDISTRIBUTION systems]	[DESIGN FOR REUSE] [Durability] Can include physical and emotional strategies. Quality of materials, long lasting, non-fashion, luxury. [Multifunction] Design in multiple uses to prolong life	DESIGN FOR LONG-LIFE & REPAIR	Howies Hand-me-down Benjamine Shine
PROCESS RECOVERY	PRODUCT CONSTRUCTIO N & FINISHING	3 / Recycling [AT PRODUCT LEVEL]	[DESIGN FOR REMANUFACTURE] [design for Disassembly]	DESIGN FOR DISASSEMBLY & MONOMATERIALITY	MultiSheers Uniforms /BREW Nike Considered
	TEXTILE CONSTRUCTIO N & YARN PRODUCTION	3 / Recycling [AT MATERIAL LEVEL]	[DESIGN FOR RECYCLING] [design for Material Reclamation]		FoC, Fabrican INTEXTER Interface VauDe / Ecolog
	RAW MATERIAL	3 / Recycling [AT CHEMICAL LEVEL]	[DESIGN FOR C2C] [Design for biodegradability] Design products which are safe to return to the earth after use as a biological nutrient. [Design for repolymerisation] Design products which are suitable for returning to the appropriate technical cycle as technical nutrients.		Trigema Wonderland Biocouture Eco Circle / Patagonia MONOFINISHING
	POINT OF DISPOSAL /	4 / Recovery [INCINERATION]	NA		NA
	POINT OF DISPOSAL /	5 / Waste [LANDFILL]	NA		NA

Table 4-1 Design for Recycling Analysis

4.3.2 Designing For Remanufacture (At Product Level)

Monomateriality is the ultimate goal but, if designing with a single material is restrictive, another option is designing products to be dismantled for easier maintenance, repair, recovery, and reuse of components and materials. Increasing numbers of designers are creating products that can be easily disassembled and recycled component by component.

Example: BREW Corporate Clothing Project (DEFRA's Sustainable Clothing Action Plan)[21]

Reuse rates of corporate clothing at end-of-life are currently less than 10%. Despite the valuable physical properties of such garments, straight reuse is impeded partly by the presence of brand identity that is attached to fabrics in the form of insignia: logos, emblems and labels. In common with most durable items of clothing, corporate-wear is not subject to design for disassembly and all garment components including the insignia are extremely time-consuming or practically impossible to remove without extensive mechanical damage to the underlying fabric.

By modifying the engineering design of the joint, methods have been identified that can reduce the time and detachment forces needed to remove insignia from corporatewear fabrics. In so doing, the need for manual intervention is substantially reduced and semi-automated processes for disassembling and detaching fabric components are facilitated. One approach based on polymer dissolution involves modification of sewing and embroidery thread materials and the selection of an appropriate solvent system. Another involves the use of heat-activated blowing agents in the adhesive layer. In addition to increasing opportunities for remanufacture and reuse, the ability rapidly to dismantle garments into component parts has wider implications in terms of whole garment disassembly and the economic value of textile recyclates. Potentially, alternative technologies for insignia assembly and disassembly could be applied to the construction of whole garments.

Example: MultiSheers[22]

This was my first project to explore 'design for disassembly' and 'mono-materiality' as a way to produce 'interim' textile products and began before the PhD study. The project used digital manufacturing techniques and the recycling of PET polymer waste.

This project focuses on emergent technology in both the textiles and plastics fields, suitable for thermoplastic material reconstruction and decoration. The preservation of the materials' recyclability was a key element in the design of these 'interim' products. All decorative elements are removable and made from recycled material discarded from the food packaging industry. The main aim of this project was to explore a new 'technology toolbox' for the application of finishing to recycled thermoplastic materials, specifically recycled PET.

[21] http://archive.defra.gov.uk/ [link]
[22] http://ualresearchonline.arts.ac.uk/154/

Example: Nike Considered[23]
Nike's Considered line of shoes are designed with embedded reuse in mind. They are made without adhesives of any kind, to reduce the toxic effects on workers in factories and the environment. They are designed for total component disassembly for easy recycling, and source materials within 200 miles of factories in order to reduce fuel consumption. The Considered shoe even uses vegetable-tanned leather, to eliminate toxic chromium in the waste pipeline. Nike aims to meet and exceed baseline standards set in their sustainability index by 2011, to include all apparel by 2015 and Nike equipment by 2020.

4.3.3 Designing For Recycling (At Material Level)

Most materials recycling can be classified as 'downcycling', however there are some emerging technologies which point to a future where retaining valuable material resources is part of the production process itself. Much of production may hark back to traditional construction methods, however there are new technologies that are pushing the boundaries of manufacturing as we know it.

Rapid Manufacturing, the making of complete objects by additive or layering processes from digital 3D form data, is beginning to reshape the production landscape. It is poised to change the way products are designed and made, and our relation to them as users and consumers. According to Geoff Hollington, leading designer and consultant, rapid manufacturing is a 'radical and disruptive technology with the potential to transform both the global economy and consumer society' (MaDE, 2007).

Making things in this way immediately changes many of the rules. Because forms are not limited by tooling or traditional processes, anything that you can imagine or model on a computer screen can be made. RM promises 'complexity for free', making it a 'manufacturing nirvana', said Hague. This freedom quickly suggests new product opportunities. The most obvious potential is to create customised one-off products, for example where a close fit to the body is required. But the fact that products are effectively grown rather than carved out or assembled from parts gives new licence to draw design inspiration from nature.

Example: Freedom of Creation (3D Printing)[24]
Freedom of Creation are working at the forefront of this arena, designing a huge portfolio of products from a small menu of mono-materials (see fig 4.4). As well as envisioning the future of recycling, this system offers other benefits. It is now a viable alternative to mass manufacturing, transportation and storage. Information can be stored and transmitted digitally and produced 'on demand'. This has wide implications for environmental impact and sustainability, providing suitable raw materials that can be developed and linked back to an efficient recycling system.

Materials used are varied - Metal, Polyamide, even chocolate! The key though is complexity through structure not material combinations and there lies the potential for

[23] http://nikeinc.com/considered-design
[24] http://www.freedomofcreation.com/

sustainability - i.e. monomateriality. Exciting examples of the kind of objects that can be made already came from the Dutch design company Freedom of Creation. The system offers a viable alternative to mass manufacturing, transportation and storage. Information can be stored and transmitted digitally and produced 'on demand'. This has wide implications for environmental impact and sustainability, providing suitable raw materials can be developed. Very little 'waste' material is produced at any stage of the process (MaDE, 2007).

Example: Fabrican (Spray on Fibre)[25]

A company embracing another novel 'additive' manufacturing process, as a radical new way to construct fabrics, is UK based Fabrican directed by Manel Torres (see fig 4.4). The innovative technology was originally developed for spraying a fine mist of coloured cotton fibres onto hard and soft surfaces, but now includes synthetic fibres. As well as a tool for repair, the future potential of this type of material construction offers a reversible process whereby materials could be re-dissolved after use, again closing the loop on any chosen material cycle.

The company, which has its R&D facilities at Imperial College London, has been investigating novel ways to speed up the process of garment construction. The original concept was to utilise Spray-on Fabric in the fashion industry. However, the technology also offers a new approach to the application of fabrics in many different areas. The fabric is formed by the cross-linking of fibres, adhering to create an instant non-woven fabric, which can be easily sprayed on to any surface. Different types of fibres have been tested, from natural to synthetic, incorporating scents and colours (from primary to fluorescent) that provide great flexibility in design. As a non-woven material, Spray-on Fabric offers possibilities for binding, lining, repairing, layering, covering and moulding in ways previously not imaginable.

Example: vauDe / Ecolog [26]

The German outdoor wear company vauDe has an innovative approach to improving the recyclability of its garments. After much discussion and work with component and fabric suppliers, the Ecolog brand was developed out of 100% polyester. All zips, labels, cords, snap fasteners and fabric is created from polyester, making recycling of the garment far more straightforward.

Textile recycling typically involves the process of removing metals and other contaminants. By removing this stage, costs of recycling are reduced and quality of end product tends to be high. Retailers of vauDe are responsible for the return of the garments, which are granulated by Ecolog GmbH, and turned back into polyester products, including fabric. Whilst not necessarily of the quality required for outdoor apparel, the fabric is suitable for seat covers and office furniture etc (DEFRA, 2009, p22).

Example: INTEXTER Automotive[27]

Car manufacturers are already required to disassemble and recycle their products after use. The materials used for furnishing and upholstery of car seats, presented major disposal problems due to their complex construction of several different polymers. This

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[25] http://www.fabricanltd.com/
[26] http://www.vaude.co.uk/news-articles/item/20-strong-brand-alliance-for-ecology-and-high-performance
[27] http://ec.europa.eu/research/growth/gcc/projects/recycling-textiles.html

problem formed the basis of a project led by INTEXTER in Spain, with the objective of developing new production technology that resulted in a soft and voluminous product called 'knitted non woven' and based on 100% mono-material fibre content (i.e. the whole product is constructed from the same polymer). This approach resulted in a fully recyclable textile product with enhanced wearing properties, and a recycled product that can be reused in further reconstructions.

Example: Interface Carpets[28]
Interface Carpets is one company which has successfully created a complete product-return cycle. It has converted its whole business structure from a 'sales based' business to a 'service based' one. It leases its carpet tiles to the contract carpet market and replaces any damaged or worn tiles as required. This has encouraged a completely new set of requirements for their design department as it is in their interest to produce products that are not only durable but also recyclable at end-of-life.

4.3.4 Designing For C2C (At Chemical Level)

The overarching mantra of C2C is waste equals food; a principle based on natural systems, that eliminates the very concept of waste. All materials are viewed as continuously valuable, circulating in closed loops of production, use, and recycling.

Translating the C2C 'rules' into design strategies (Goldsworthy and Lang, 2010):

- Design products of consumption; designed for safe and complete return to the environment, becoming nutrients for living systems - the 'biological metabolism'

  or

- Design products of service; the manufacturer maintains ownership of valuable material assets for continual reuse while the customer receives the service of the product without assuming its material liability. This type of product is suitable for retention in the 'technical metabolism' and represents processes of human industry that maintain and perpetually reuse valuable synthetic and mineral materials in closed loops.

More specifically there are several design strategies which can be employed to this end:

- Design products with a simple material system; use monomaterials or design for disassembly into single material components to enable recyclability
- Take advantage of the natural characteristics of materials. By selecting materials wisely in this way designers can avoid harmful additives
- Design to avoid downcycling, the practice of recycling a material in such a way that much of its inherent value is lost (for example, recycling plastic into park benches). This could include temporary reformations / upcycling / designing to embed reuse.

[28] http://www.interface.com/

4.3.5 Textile Design For The Biological Cycle (Biodegredation)

Designing with materials that harmlessly biodegrade back into the environment is the most fundamental example of C2C thinking. However, this is not straightforward; all materials derived from living sources (animals and vegetable) are 'biodegradable', but few decompose in an ecologically safe manner if dyed and finished with chemicals. For example, a brochure fixed without glues and printed with vegetable dyes is C2C compliant; the same brochure overlaid with even the smallest spot of gloss or metallic finish is not. Therefore, designers working in this idea are exploring some extraordinary approaches to achieve high design that is environmentally considerate.

Example: BioCouture (Bacterial Culture)[29]
Imagine if we could grow clothing. The BioCouture research project is harnessing nature to propose a radical future fashion vision, by investigating the use of bacterial-cellulose, grown in a laboratory, to produce clothing. The ultimate goal is to literally grow a dress in a vat of liquid (see fig 4.3).

Designer and researcher Suzanne Lee has been collaborating with material scientist Dr. David Hepworth in the use of bacterial-cellulose, which is grown in a laboratory to produce clothing. To make this happen, fibre is formed in a vat of liquid consisting of a mixture of yeast and sweet tea, which, when dried, forms a compact leathery papyrus like substance. Colour is then achieved with simple food substances such as tumeric, port, curry powder and cherries.

The experiment began in 2006 and is still under going tests, with three completed garments, that have been made to this date. The most recent work, Eco Kimono, was shown at the *'Warp Factor 09'* Exhibition at Central Saint Martins, and points toward an ancient Japanese technique for waterproofing paper in order to bring the material one step closer to a wearable solution. The material is water and bug resistant whilst being completely organic and biodegradable.

Example: Trigema (Edible fabrics)[30]
Trigema partnered with Dr. Michael Braungart of the Environmental Research Institute in Hamburg and suppliers, including dye-stuff manufacturer Ciba, to develop a T-shirt which can end its life on the compost heap. Trigema, the largest t-shirt and sports clothing manufacturer in Germany, had long offered clothing meeting the Oeko-tex standards for prevention of substances harmful to humans in textiles. The biodegradable t-shirt went a step further, having only components, which can be fully biodegraded to substances which are part of the known biological cycle. To achieve this, Trigema used 100% cotton, from the USA and Pakistan, which was free of pesticides and fertilizer residues and the yarn was spun with natural paraffin. They also used dyes which were specially developed to be biodegradable and also reported to be longer-lasting and truer than standard dyes in addition to their eco and human-friendly properties.

[29] http://www.biocouture.co.uk/
[30] http://www.treehugger.com/sustainable-fashion/trigema-develops-biodegradable-t-shirt.html

Example: Hyun Jin Jeong (Earth Dyeing)
Ancient and mostly forgotten, the art of earth dyeing uses soil from different geographic regions to create a varied if subtle color palette. Chemicals in the textile-dyeing industry have a troubling legacy, but natural dyes are often seen as niche or impractical. For her master's project at Central Saint Martin's College of Art and Design, Jeong collected 45 different soils across South Korea and the United Kingdom. She was able to categorise them into seven different colour families, creating a range of vivid hues. After some experimentation, Jeong managed to apply soil-based paint directly to fabric, resulting in beautiful designs accented by pale washes of ochre, rust, sienna, and granite (see fig 4.3).

Example: Lenneke Langenhuijsen (Wooden Textiles)
Lenneke Langenhuijsen travelled to the South Pacific island of Tonga to learn and document the ancient craft technique of beating bark fiber into a textile. In Tonga the locals beat the bark of the Paper Muberry tree to make cloth. As part of her 'Wooden Textiles' project she has documented this ancient craft in a short documentary and expanded the basic principle to create a new, flexible fabric. Experimenting with techniques often only applied to textiles, such as dyeing and embroidery,
she created a collection of interior textiles. Engineering the beaten wooden fibers using textile techniques such as sewing, dyeing and embroidery, she creates a new fabric that can be washed at 40 degrees (see fig 4.3).
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4.3.6 Textile Design For The Technical Cycle (Repolymerisation)

Polyester is aligned to the industrial cycle and as such needs to be preserved as a recyclable resource. In a 2003 report, US based furnishing supplier Designtex identified this problem and described their vision of a closed-cycle polyester economy, where all polyester fabrics are recycled perpetually:

> Recycling by itself, only postpones the arrival of the discarded material at the landfill, where it may never biodegrade, may biodegrade very slowly, or may add harmful materials to the environment as it breaks down. A genuinely sustainable future depends on creating closed loops, or cycles, for all industrial commodities, including polyester. In a closed loop, materials would never lose their value and would recycle indefinitely (Livingston, 2003).

At that time, it was possible to create mechanically recycled polyester fabric from packaging waste, but not possible to recycle polyester fabrics. Repolymerisation had been successfully trialled but was not yet commercially available. However, this changed in 2005 when Teijin launched their Eco Circle system in collaboration with pioneering sportswear brand Patagonia and the polyester economy became a viable scenario.

Desigtex had identified that this future vision may be hampered by some commonly used processes. Furniture manufacturers often apply their own specifications for finishing fabrics before they are installed on seating and architectural products. The processes used in finishing the fabrics often include chemical backings, which are contaminants, most of which in use today are incompatible with breaking down polyester and repolymerising it.

This is also true of many finishes used in the garment industries, including trimmings and fixings. But these finishes have been at the core of many innovative textile products during the last decade. For example, coating and lamination offer methods of improving and modifying the physical properties and appearance of fabrics and also the development of entirely new products by combining the benefits of fabrics, polymers and films.

> The finishing of a fabric, the final stage in its making, is fast becoming as important as its construction: it is also where the look, texture and performance can be dramatically altered. Treatments include holographic laminates, silicone coatings and chemical finishes which devour surfaces they come in contacts with (Braddock-Clarke, 1998).

However these treatments, although innovative and effective during the material's useful life, often create barriers at the point when a material needs to be taken back to the melting pot for recycling. This project set out to find an alternative to these processes, which might suggest a way forward for recyclable finishing. As William McDonough writes in C2C (2002), our products should be 'gifts for the future' not materials destined for landfill. Many textile processes, nonwoven constructions, chemical finishing processes, coating, lamination and composite materials render products unsuitable for recycling and destined for landfill (Horrocks and Anand, 2000).

> Most environmentalists agree that recycling must increase, and that there may well come a time when coated and laminated materials will come under scrutiny (Fung, 2002).

B. Gulich (Wang, 2006, p27) suggests 'designers should keep in mind how a product, meant to be sold tomorrow, can be recycled or disposed of the day after tomorrow.' He discusses the advantages of single polymer design or single material systems. Products consisting of only one material are 'pure' and easy to reuse. It is not generally necessary to deconstruct the product prior to reprocessing.

Example: Designtex[31]

Designtex, a contract furnishing fabric manufacturer in the United States has been researching this for the contract textiles market for some time. They have been concentrating on developing products which are suitable for 'forward-recycling', a term they coined in a 2003 paper (Livingston, p1) to differentiate the process of using recycled fibres to make fabrics ('traditional recycling') from the direct recycling of polyester or other synthetic fabric into new fabric. Their vision of the future is 'a closed-cycle polyester economy', where all polyester fabrics are recycled perpetually.

Their work with MBDC (McDonough Braungart Design Consultancy) has produced products such as Eco-intelligent Polyester, a toxin-free polymer designed to be recycled harmlessly, and they are also researching the potential of bio-fibres for future applications.

Example: Eco Circle (Patagonia, Common Threads)[32]

In the autumn of 2005, Patagonia launched a new line of recyclable Capilene (polyester) Performance Base Layer garments, and announced a five-year goal to make all Patagonia products recyclable through the Common Threads Recycling Programme, which invites return of used-up clothes and delivers them back to a fibre manufacturer to make new product. In 2005, they had been using recycled polyester for years but had not yet made a product that – at the end of its useful life – could be collected, chopped up, melted and spun into new (and recycled) polyester. They found that making DMT (dimethyl terephthalate, the precursor material to polyester in Teijin's process) from Patagonia Capilene uses 76% less energy and emits 42% less CO2 than making it from petroleum. The CO2 savings jumps to 77% if the garment is incinerated rather than recycled.

In spring of 2007, Patagonia expanded the programme to accept, in addition to Capilene garments, Patagonia fleece and Polartec fleece from any brand. Because fleece is made of polyester, they were able arrange with Teijin to recycle these garments as well into new fibre. They designed polyester shells specifically to be recyclable through Teijin's Eco Circle[33] system (see fig 4.4).

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[31] http://www.designtex.com/
[32] http://www.patagonia.com/eu/enGB/cmmon-threads
[33] http://www.ecocircle.jp

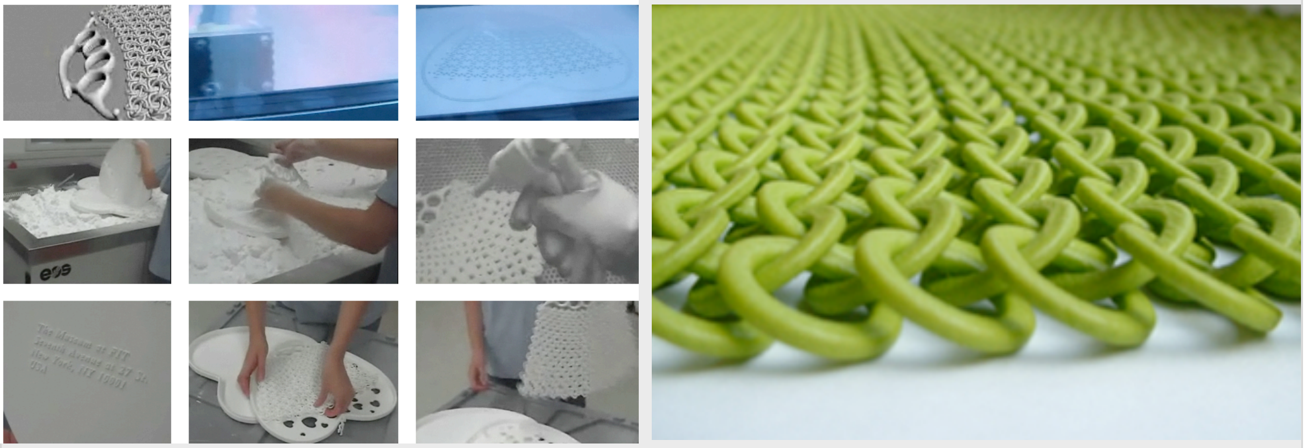
Earth Dyeing, (2011), Hyun Jin Jeong. MA Textile Futures, CSM. A project to rediscover everyday materials from nature. The various kinds of soil from different geographical locations create a varied and subtle colour palette.
Ref: http://www.earthdyeing.com

Wooden Textiles (2011) Lenneke Langenhuijsen Based on an ancient craft technique of beating bark fiber into a textile, textiles have been created using only physical manipulation..
Ref: http://www.llenneke.com/

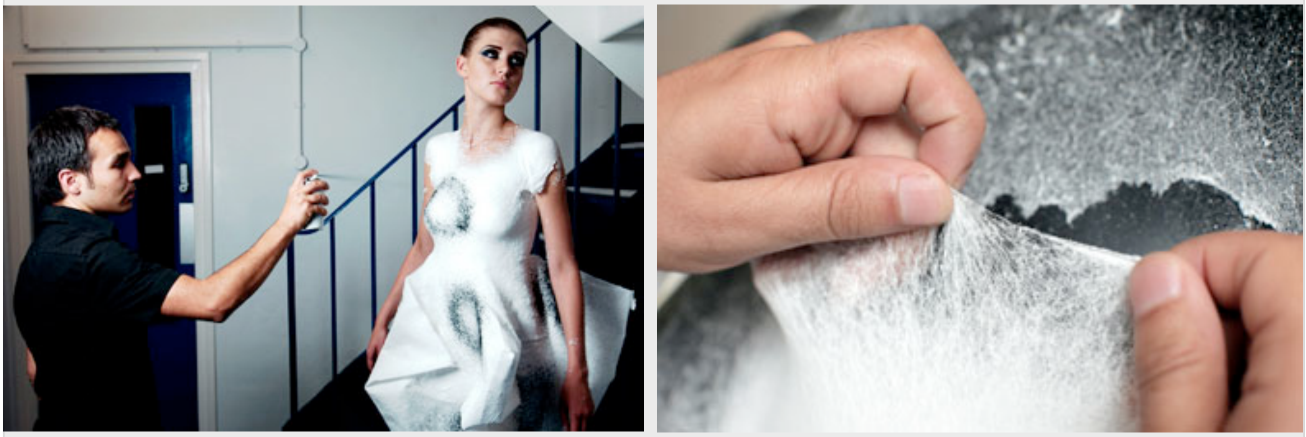
BioCouture, (2005), Suzanne Lee, Textile Futures Research Centre. Biocouture aims to address ecological and sustainability issues around fashion, investigating the use of bacterial-cellulose, to produce clothing.
Ref: http://www.biocouture.co.uk

FIGURE 4-3 EXAMPLES OF DESIGN FOR RECYCLING APPROACHES.

Eco Circle, (2005), Teijin. Unlike mechanical recycling processes for polyester (of the type used to transform PET water bottles into fleece fibre) this system can recycle in perpetuity without any loss in quality.
Ref: http://www.ecocircle.com/



Freedom of Creation (2004) Rapid manufacture techniques such as laser-sintering used by FOC are additive manufacturing techniques, with very little 'waste' material produced at any stage of the process.
Ref: http://www.foc.com/



Fabrican, (2005), Manel Torres, As well as a tool for repair the future potential of this spray-on fibre offers a reversible construction whereby materials could be re-dissolved after use.
Ref: http://fabricanltd.com/

FIGURE 4-4 EXAMPLES OF DESIGN FOR RECYCLING APPROACHES

4.4 SUMMARY

For my design work to be relevant to current polyester recycling practices I needed to look at textile reprocessing in a fresh way, in order to prevent these possible 'barriers' to forward-recycling.

To do this convincingly (without losing quality or desirability) designers need a new 'toolbox' of processes with which to reform and resurface the recovered materials, without the addition of chemicals and additives, which could restrict its future reincarnations.

Many established textile processes involve downcycling or contaminating the material in such a way that it is difficult to recycle further. For example traditional printing and coating processes can restrict a product's disposal options. The key will be to preserve recyclability.

Clean chemical-free polyester could be continually reincarnated as new products, which in their turn would feed the recycling chain repeatedly without degradation of quality. If we believe that oil is running out then this would make plastics a very sought-after commodity and the ability to do this would be invaluable.

From this point in the project the focus for the practice became 'design for C2C'. This changed the brief from an end-of-life solution to one which became embedded in the design process at the outset. This new brief is described more fully in chapter 6.

5 REVIEW OF POLYESTER RECYCLING

5.1 INTRODUCTION

Concentrating my research into the synthetic materials area, due to their suitability for recycling, I further refined my material to polyester, which is the largest growing fibre group in the global textiles industry (see fig 5.4).

The main research question explored here is:

- How is polyester currently recovered and reprocessed?

World Fibre production has been steadily increasing in the last few decades. In 2004 it exceeded 64 million tonnes (International Fibre Journal, 2004). Over the last 15 years demand for natural fibres has remained constant but man-made fibres have doubled (Allwood et al, 2006, p13). This has been driven by demand for polyester, which, now accounts for as much as 45% of global fibres industry (see appendix) and therefore arguably 45% of landfill.

These figures include polyester in both fibre and plastic form. As well as textiles, polyester also accounts for around 6% of the global plastics market and according to figures from the Environment Agency (2001, p6) this represents around 180,000 tonnes of discarded material in the UK.

As a material present in large quantities, both in plastic and textile waste forms, polyester is a key material impacting landfill figures. Recent research suggests that both fibre and plastic waste streams can be recycled to produce new fabrics – therefore we do not necessarily need to differentiate between and plastic and textile waste.

So polyester became the focus very early on in the project. In the conclusion of a report by the Institute of Manufacturing in Cambridge the benefits of recycling polyester were outlined;

> For products in which production dominates impacts, (which is true of synthetic materials such as polyester) process efficiencies should be pursued and the impact will be reduced by extending the life of the product by re-using materials by some form of recycling (Allwood et al, 2006).

The demand for natural fibres has been almost constant for the last 15 years, whereas the demand for synthetic fibres has nearly doubled, with polyester driving this demand. Approximately two-thirds of the UK imports of basic textile materials (fibres, yarns and fabrics) by mass to the industry are synthetic. The remaining portion is of natural origin, with cotton and wool accounting for 15% and 10% respectively (DEFRA, 2007).

5.2 THE RECOVERY & RE-PROCESSING OF POLYESTER

There are several established processes for recycling polyester (shown in fig 5.2), both mechanical and chemical. The polyester recycling industry has developed over the last 30 years from a downcycling activity into a sophisticated resource-preserving process which can be repeated in perpetuity.

The following section unpacks the progress made in this field.

	Mechanical	**Chemical (to Oligomer)**	**Chemical (to Monomer)**
Process	Thermal decomposition through melting process	Decomposition into intermediary by chemical reaction	Decomposition into molecules by chemical reaction
Waste stream	Limited: Transparent bottles and greigetextiles	Limited: Transparent bottles and greigetextiles	Wider: Colouredgoods
Input	Labour Water Energy	Labour Water, Energy Chemicals	Labour Water, Energy Chemicals
Environmental Impact	Low	Medium	High
Impurities	Yes	Yes but limited	No
FibreQuality	low quality / colour limitations	Possible colour limitations	Same as virginpolymer
Close Loop	Materials'life extension	Materials'life extension	Close loop opportunity

Table 5-1 Processes for recycling synthetics (Ducas, 2012)

5.2.1 The Recycling Of Polyester: Mechanical

The mechanical recycling of polyester is a 'life-extention' or 'downcycling' process with thermal decomposition achieved through a melting process. The waste stream it can process is limited to transparent bottles and 'greige' (mixed fibre) textiles. Labour, water and energy are used in the recycling process and the resulting materials are less refined than the original and have colour limitations and unevenness of surface.

In early 1992, Europe's first recycling plant for plastics was opened in the UK, for the recycling of mainly food packaging PET plastic waste (TWI, 2005).

Polyester recycling was first established in the mid 1990's. (Livingston, 2003, p1) Early on a system for recycling PET (Polyethylene terephthalate) packaging waste into textile fibre was initiated. As the world's largest plastics recycler, Wellman, Inc. was the first to reprocess PET containers and producer wastes into usable flake and pellets. They established the first closed-loop recycling chain for a new generation of PET packaging and polyester fibres.

In 1993, they introduced the first polyester textile fibre made from post-consumer PET packaging: Fortrel EcoSpun. A new generation of fibre used in the apparel and interior textile areas.

> Since the decline of the shoddy trade almost no fibre recycling occurs in the UK and there has been virtually no technology innovation in this area for 200 years (Allwood et al, 2006, p69).
>
> Even without these external factors………. The key here is the availability of better technologies, that are cleaner, more energy efficient, and less expensive. Considering the diversity of fibrous waste and structures, many technologies must work in concert in an integrated industry in order to have any noticeable impact on fibrous waste recovery (Wang, 2006).

Although this may be true of natural fibre reclamation, if we look at synthetic textiles recycling as part of the plastics recycling industry then notable progress has been made. This is explained in the following sections.

So what makes polyester suitable for recycling?

> For products in which production dominates impacts, process efficiencies should be pursued and the impact will be reduced by extending the life of the product by re-using materials by some form of recycling (Allwood et al, 2006).

Their suitability for recycling as part of the technical cycle is due to their thermoplastic qualities. A thermoplastic material is a solid, which softens and ultimately becomes liquid at a particular heat and therefore becomes malleable enough to reform, before resetting the form by cooling. Polyester fabrics as well as some polyester plastics share this quality and therefore both types of polymer can be recycled with the same process. As a 'thermoplastic,' polyester is suited to many re-manufacturing techniques, which are not considered standard textile practice.

There are several benefits to be gained from the recycling of thermoplastic materials including:

- the conservation of non-renewable fossil fuels – plastic production uses 8% of the world's oil production, 4% as feedstock and 4% during production,
- reduced energy consumption when compared to manufacturing virgin polymer materials,
- reduced amounts of solid waste going to landfill,
- reduced emissions of carbon-dioxide (CO2), nitrogen-oxide (NO) and sulphur-dioxide (SO2).

Wellman International Limited (WIL) has been making first-grade fibre products, both nylon and polyester, from recycled raw materials for 35 years, and for the last 21 years from post-consumer materials.

PET is a high grade polymer that is ideal for converting into fibre - even after being used once as a bottle - though it first needs to be washed and decontaminated. In recent years the collection of post-consumer waste PET bottles has grown steeply in the EU, as a result of regulations requiring recovery and recycling. Half of all the polyester staple fibre made in the EU is now made from recycled materials. Making polyester fibre from recycled PET has the distinct advantage of using less energy than the chemical process. The energy required to bring post-consumer materials to our processing sites, clean and decontaminate the bottles and grind them into the flakes, together with the power we use in our fibre process, is considerably less than the energy it takes to make virgin intermediate chemicals from oil and convert them to fibre. So polyester fibres made from recycled materials have lower associated emissions than polyester from virgin materials; less even than either cotton or PLA.

Calamai uses another method of mechanical recycling. The materials are not broken down to the chemical level; they only change physically. In this case, the fabric is chopped and shredded down to fibre in a process called garneting. Then it's spun into yarn again. (Mechanical recycling also describes the process of melting synthetics back into resins, then extruding fibre and spinning yarn).

Mechanical recycling, can handle a wider variety of material as input. But the output yarn will be a mix of fibre types and colours. If the garments can be sorted before going into the recycler, then the yarn can be made in specific fibre percentages and colours. Because the fibres are chopped into short lengths during the recycling process, their strength and quality is reduced. This recycled yarn is most appropriate for sweatshirts or canvas fabrics. These shorter fibres need to be blended with longer fibres of virgin cotton or a synthetic, to increase the strength. Thus, while the input variety can be greater, the variety of products we can make with the recycled natural fibre is more limited (Common Threads, 2005).

5.2.2 The Recycling Of Polyester: Chemical (to Oligomer)

The chemical recycling of polyester into oligomers is also a 'life-extension' or 'downcycling' process but with a higher quality resulting material. It is achieved through decomposition into an intermediary raw material through a chemical reaction. The waste stream it can process is limited to transparent bottles and 'greige' textiles. Labour, water, energy and chemicals are used in the recycling process and the resulting material is less refined than the original (but more refined than a mechanically recycled material) and has colour limitations.

5.2.3 The Recycling Of Polyester: Chemical (to Monomer)

The chemical recycling of polyester into monomers is the only truly 'C2C' system (see fig 5.3). It is achieved through decomposition into molecular raw material through a chemical reaction. The waste stream it can process is wider and includes coloured textiles. Labour, water, energy and chemicals are used in the recycling process but the resulting material is the same as the virgin polymer.

In November 2005 the recycling paradigm shifted through the development of a process, Eco Circle by Teijin Ltd (Patagonia, 2007). This is an endless re-cycling system for used garments and other polyester products using chemical processing. This repolymerises polyester fibre back into virgin quality fibre and can be repeated again and again commercially (the process had been piloted some 10-15 years previously). This changed the whole perspective for the recycling of textiles. It was now possible to recycle polyester fibre effectively (DEFRA, 2009).

In this system, polyester is chemically decomposed and recycled with other fibres to make new fabrics. The reason Teijin embarked on the project was to reduce the vast amounts of petroleum and other resources used in fibre manufacturing. Teijin set a 20 percent reduction target from 1990 to 2020, with the aim for all their clothing to be made from recycled and recyclable products. Polyester accounts for some 40 percent of their fibre usage and currently most of that is incinerated after use or ends up in landfill, so the loop process is not energy expensive. Teijin has a PET recycling plant at Matsuyama in Japan that can purify used materials and process them into textured and split yarns and blends such as polyester/wool. They can also recycle polyester/cotton, polyester/rayon, polyester/nylon and polyester/TENCEL so long as the blend contains 80 or 90 percent polyester by weight.

Teijin can also re-process recycled polyester into hollow fibres and performance qualities. Endless recycling is achievable. Purity is the key and Teijin is actively promoting the reuse of polyester, particularly in sportswear and leisurewear (Merchant, 2009).

A recent white paper from Patagonia (Common Threads, 2005) described a detailed environmental analysis and compared the impacts of manufacturing virgin and recycled polyester with quantitative research including detailed analysis of transport of materials between stages. Their research concluded that there is an energy use reduction ratio of 84% in using recycled versus virgin PET, even if incinerated at end-of-life to reclaim some energy. There are 77% fewer CO2 emissions. Their conclusions added that the best scenario was achieved when garment returns were sent by post back to the recycler and when the recycling plants were located close to the final customer.

The garment recycling processes at TEIJIN and Toray entail chemical recycling, in which materials are chemically dissolved to their precursor chemicals. Polyester and nylon are polymers, made by linking identical molecules in a long chain. Polyester is broken down into DMT and EG (ethylene glycol). Nylon 6 is broken down into caprolactam. These precursor chemicals are then purified and used to make new polyester and nylon fibre.

The advantage of chemical recycling is that colour and small impurities can be removed and the resulting recycled fibre is almost the same as virgin fibre. None of the material characteristics of the old garments are apparent in the recycled fibre, so it can be used in many applications. The disadvantage is that there are limitations on what can go into the recycler.

> Many coatings and fibre blends will contaminate this chemical process and inhibit the separation of the precursor chemicals. Therefore design guidelines and careful sorting of the garments are critical for successful chemical recycling. Because of its closed-loop nature, chemical recycling is the highest form of recycling we try to achieve for synthetic materials (Patagonia, 2009).

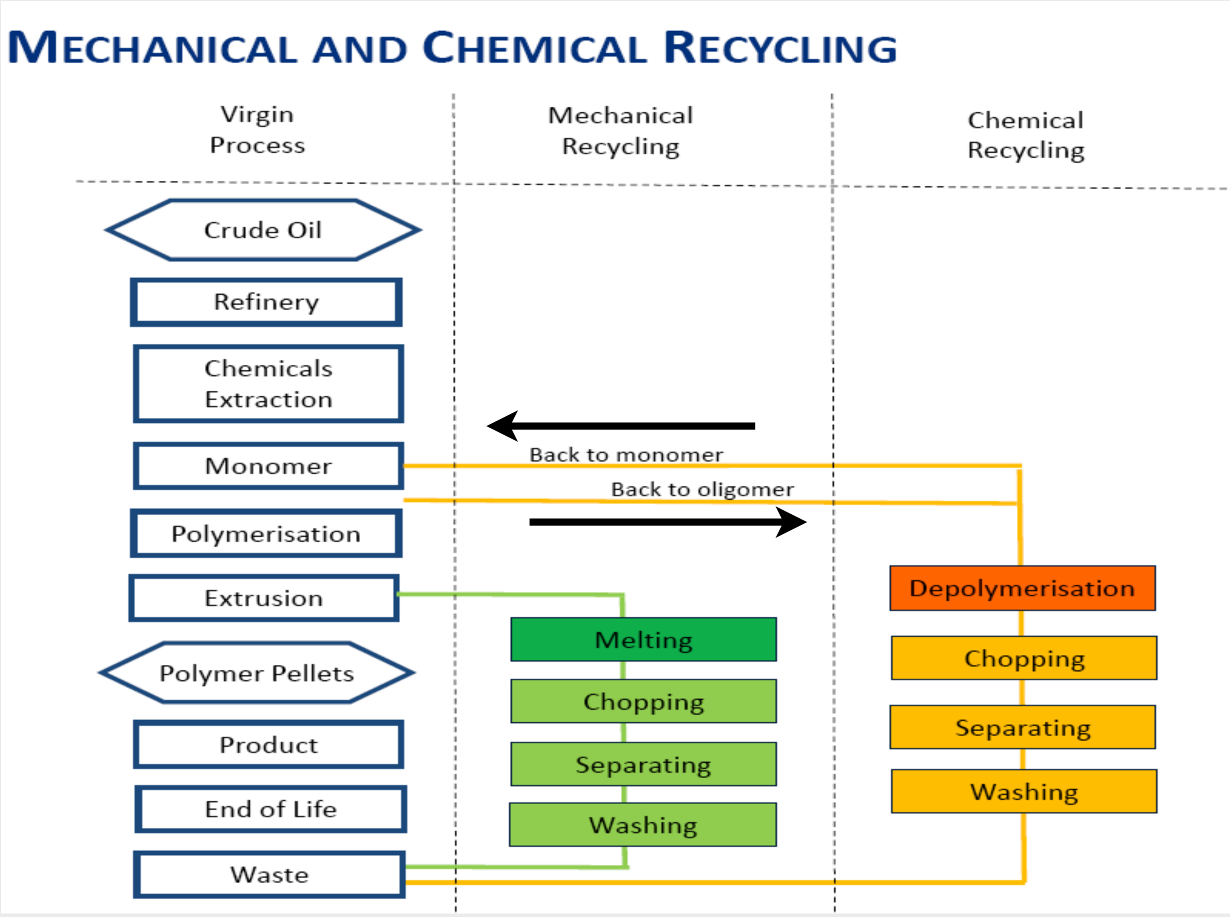


FIGURE 5-1 PROCESSES FOR RECYCLING SYNTHETICS (DUCAS, 2012)

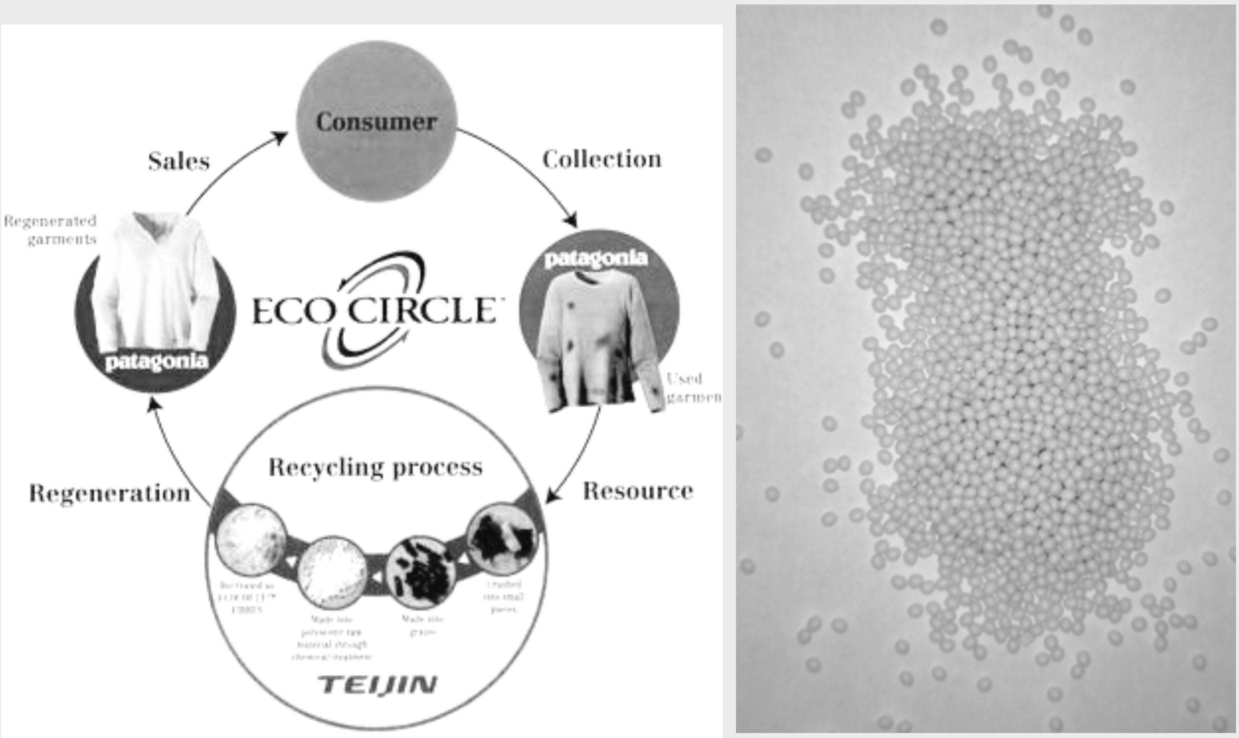


FIGURE 5-2 ECO CIRCLE BY TEJIN. REPLOYMERISATION PROCESS

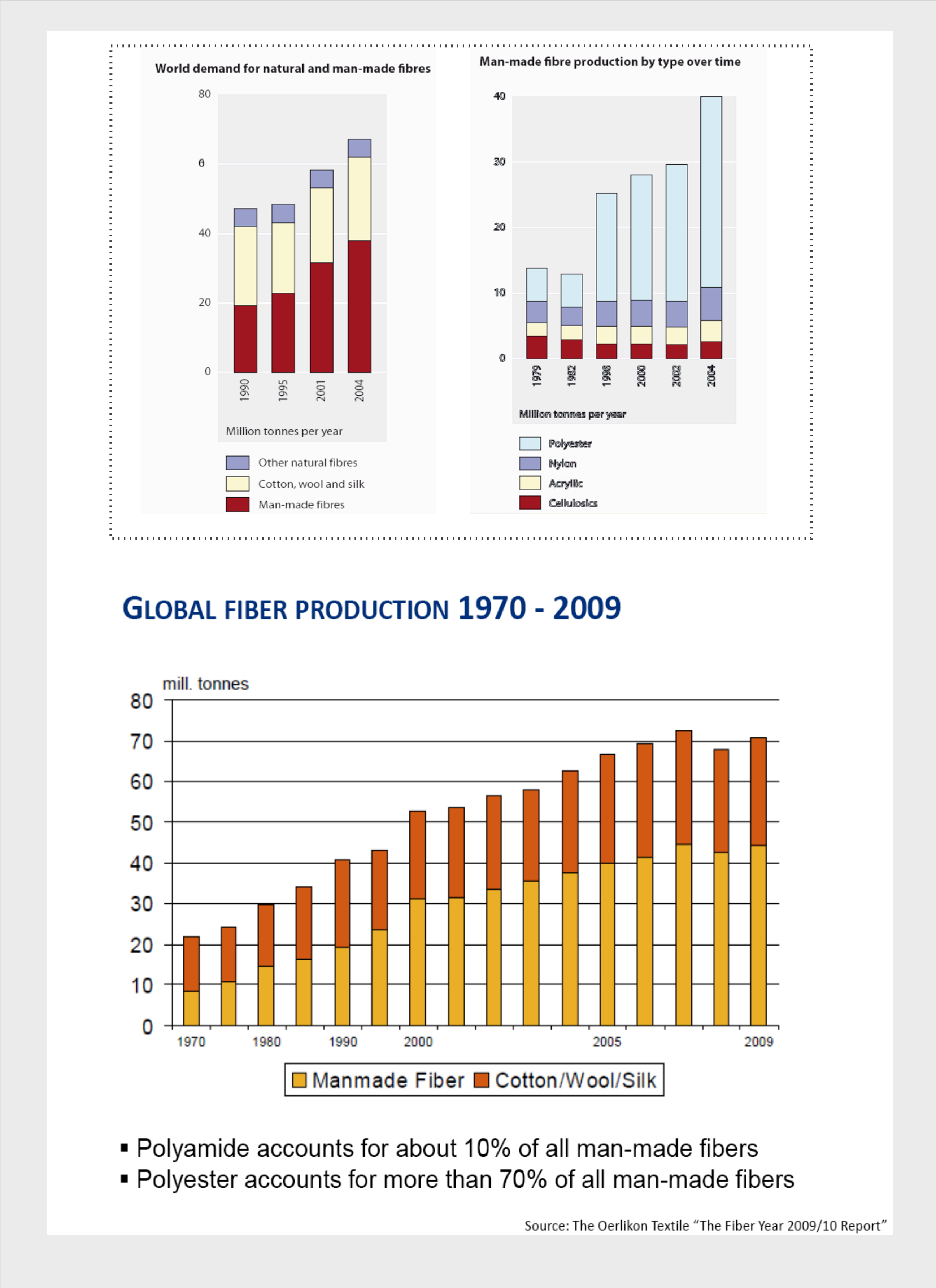


FIGURE 5-3 GLOBAL FIBRE MARKET STATISTICS, 2010.

5.3 WASTE HANDLING AND SORTING TECHNOLOGY

Most of the systems previously outlined depend on a reliable source of identifiable source material for recycling. With sheet plastics this can be achieved with existing sorting technologies. However, textiles present a greater challenge which has been a key factor in the lack of synthetic fibre recycling solutions.

Textile products tend to be complex in structure and material combination, with very few products being 100% one material. Buttons, fastenings and stitching are often non-compatible, with permanent finishing processes preventing forward-recycling.

The European Commission has been tackling this issue with funding for a wide range of projects covering both design for reuse and increased use of recycled content in new products. A CRAFT project co-ordinated by Tricoop, a Belgian specialist in the sorting and distribution of second hand clothing, investigated the production of felts and similar products from textile waste. The most important areas of investigation in this project concerned the classification of waste and the identification of their fibres and any hazardous components in either the dye or the textile. Three technologies were used for the identification of fibrous raw material and dye/finish: near infrared, thermal impulse response and laser induced breakdown spectroscopy. Combinations of these techniques now make it possible to identify the raw materials in textiles with 90% accuracy.

This is a crucial breakthrough if the recycling of polyester fabrics is to become widely introduced as the sorting and redirection of usable waste streams has been a stumbling block to commercial viability for some time. If large amounts of unsorted textile waste can be identified mechanically and accurately, then reprocessing would be more economically viable and more attractive to industry.

5.4 ECONOMIC DRIVERS FOR RECYCLING

The widespread use of recycled polyester is a benefit to the environment because it conserves non-renewable resources and reduces the release of harmful emissions into the biosphere. This is primarily accomplished by reductions in the amount of energy and oil needed to make virgin polyester, along with reductions in the accompanying releases of greenhouse gases into the atmosphere. Recycling, as long as the original value of the material involved is preserved, is economically viable.

In times of textile raw material scarcity, (and rising population) the recycling of end-of-life textiles has become a necessity, and craftsmen and industry are viewing textile waste as a valuable resource. Legislation around disposal and producer responsibility, or 'take-back' schemes, make it increasingly important to develop processes to design textiles that are easy to recycle.

> Generally it is the designer who decides on the structure of a product and the best materials to use, taking function and budget into consideration. The materials chosen have an influence on the process of manufacturing as well as on the process of recycling and disposing the product at end-of-life. Indeed they predetermine all these processes. Designers should keep in mind how a product, meant to be sold tomorrow can be recycled or disposed of the day after tomorrow (Gulich in Wang, 2006).

In recent decades there has been significant development in the use and recycling of polymer based materials in textiles. Within the last few years, in particular, an escalating interaction between textiles, industrial design technology and material science can be observed. In the context of an increasingly aware consumer, especially in the area of sustainability, design needs to embrace its role as mediator between technological innovation and material solutions.

Although the global petroleum reserve may last at least another several hundred years at the current rate of consumption, petroleum and other natural resources are non-renewable in practical terms and as such need to be conserved for future generations.

As oil becomes less available there will inevitably be a premium to pay on synthetic resources.

> As the available supply of oil is depleted, or becomes more difficult to get out of the ground, its price will inevitably climb. At some point, the economic cost of producing new polyester fabric via forward-recycling will equal the economic cost of virgin polyester. And recycling fabric will in itself become a profit-making opportunity (Livingston, 2003, p1).

According to some findings this is arguably beginning to happen already. The limited availability of intermediate ingredients, during 2006, used to make polyester has caused a negative shift in supply / demand with manufacturers, like Colbond, a leading producer of high-quality synthetic nonwovens, having no alternative but to raise prices. Other important factors contributing to this price increase are energy costs and volatile fuel costs that relate directly to transportation.

5.5 A POLYESTER ECONOMY (FORWARD-RECYCLING)

In 2003 (before the final launch of repolymerisation processing – although after a successful pilot scheme) US company Designtex were already beginning to consider how the design of textiles needed to change in order to fit in with a successful 'closed loop polyester economy' (Livingston, 2003)[34] wrote;

> For nearly a decade, fabrics have been woven from recycled polyester fibre. Recycled fibre is made from polyester waste that has been through one useful life in the form of packaging or other consumer products (discarded soft drink bottles are the best-known example of post-consumer waste) or produced as the by-product of a manufacturing process (such as x-ray film trimmings, an example of post-industrial waste).

Over time, the quality of recycled polyester fabrics has steadily improved. This has occurred largely because market demand for environmentally responsible products has justified investment by the supply chain of companies who produce contract fabrics.

We have arrived at a point where recycled content fabrics are commonplace. In most respects, recycled polyester fabrics perform aesthetically and technically as well as virgin polyester fabrics. Virtually every fabric distributor, or jobber, now offers products advertised as 'green' or 'sustainable'. With the exception of Climatex Lifecycle products offered by The Designtex Group and Carnegie, the majority of products promoted in the North American marketplace as sustainable are conventional polyester fabrics woven with yarn made from recycled polyester. This however, only postpones the arrival of the discarded material at the landfill. A genuinely sustainable future depends on creating closed loops, or cycles, for all industrial commodities, including polyester. In a closed loop, materials would never lose their value and would recycle indefinitely.

> Our vision of the future is a closed-cycle polyester economy; a future where all polyester fabrics are recycled perpetually. We have coined the term 'forward-recycling' to differentiate the process of using recycled fibre to make fabrics (traditional recycling) from the direct recycling of polyester or other synthetic fabric to make new fabric (Livingstone, 2003).

5.6 SUMMARY

This was the first piece of research undertaken at the start of the project, in conjunction with a polymer engineering short-course at London Metropolitan University, in order to gain a better understanding of the chemistry and processes required in the recycling of polyester fibre. It was the basis for my understanding when creating my design briefs. This led initially to the practice elements described in Chapter 3, which were responding to an end-of-life strategy for recycling waste using mechanical recycling, however later practice (described in Chapter 2) related more directly to the chemical recycling (repolymerisation) described in this chapter.

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[34] Livingston (2003)

6 A NEW BRIEF: DESIGN FOR REPOLYMERISATION

6.1 INTRODUCTION

This chapter focuses on unpacking the criteria needed for successful recycling of textiles through repolymerisation. This is the only truly ‘closed-loop’ method of perpetually recycling thermoplastic polymers (polyester) and therefore forms the basis for the design work developed in chapter 7.

The main research question explored here is:

- What are the key attributes of a fully recyclable polyester textile and what are the barriers to recyclability?

6.2 CHARACTERISTICS FOR RECYCLABILITY IN POLYESTER

6.2.1 Replacing Traditional Finishing Processes

Fashion cycles continue to move in ever decreasing cycles, requiring quicker turn around time, and a quicker response to market changes and fluctuations. European fabric and garment producers are all seeking ways to achieve greater operational flexibility, in order to respond to this more demanding market. There is also much talk of individualisation, fragmentation and personalisation within the consumer market. Certainly today's customer has higher expectations from the clothing they purchase. It has to satisfy not only the traditional demands of being fashionable and practical, but must also appeal on a more subjective and emotional level. There is also the very important need to produce a more environmentally acceptable product in a sustainable manner, and to be able to dispose of it or recycle it correctly. Manufacturers are greatly concerned with the effective use of energy and materials, plus the need to shorten capital cycles, factors of interest in all areas of textile and garment production.

These challenges are encouraging investigation into what finishing treatments can offer, how they may be able to assist in meeting these demands, whilst producing a textile or garment that appeals to both the objective and subjective demands of the consumer.

Fabric finishing is a range of processes whereby a desired quality or qualities are imparted to fabric in order to improve the appearance, to affect stiffness, weight, elasticity, or softness, to facilitate care, or to protect the wearer. The finishing of a fabric is now equal, or in some cases more important than the fibre or the construction, and can often be a quicker and cheaper method of introducing different design features and functions into a textile. Through finishing techniques, fabrics can now take on new aesthetics and functions. They can be manipulated to be hard, soft, shiny or matt, they can be moulded, they can protect, and they can now also be bio-active and interactive. New ways of combining textile layers are introducing performance composites capable of a wide range of functions and responses.

6.2.2 Properties Of Thermoplastics

Thermoplastic materials have the following qualities:

- Have shape memory properties activated by the application of heat
- Can be coloured permanently through heat-transfer printing processes
- Can be laser cut without fraying due to the melting of cut edges
- Can be transparent or opaque according to treatment applied
- Can be bonded using heat to melt adjoining layers.

These properties made the material particularly suitable for many hi-tech processes, which are aimed mainly towards the plastics market but could easily be adapted for textiles. Most of these processes involve the application of heat to transform the material in a way which would not be possible for other fibres.

Clean chemical-free polyester could be continually reincarnated as new products, which in their turn would feed the recycling chain repeatedly without degradation of quality.

I have discovered many technologies, which are suitable for this purpose but are not yet standard practice. Much of this technology is cleaner, low energy driven, closed-loop, and importantly locally available and my studio practice has developed accordingly into an experimental and material driven process.

A primary outcome of the research is a large resource of fabric samples that documents the material's behaviour and suitability for each technique. Successful samples will be further explored in the creation of prototype designs for development.

> To combine innovation and creativity with new materials and processes is a way for designers to create products that are a pleasure to the senses; meeting the functional requirements needed in a changing world; are economical and environmentally friendly in production; and enhance emotional and intellectual pleasure……..a designer's abilty to exploit [technical] knowledge will often be dependent on how well the designer is able to communicate with technologists (Kavanagh, 2004).

Research into available technologies has led me into the realm of polymer engineering and plastics technology. In order to contribute to the recycling of polyester, I would need to work with the specific properties of the material without damaging its recyclability. This requires a full understanding of the material properties, which are key to its manipulation and recycling.

The following processes described in this chapter can be used with 100% polyester materials (and are available for experimentation in the UK).

Technology has been divided into three types: forming, cutting, joining and surface decoration techniques. A range of new or unusual technologies from these types were selected for experimentation. Because of the nature of polyester (PET), which is a thermoplastic material sensitive to the application of heat, a wide range of technologies could be applied to create effects without adding chemicals to the material. By utilising available digital manufacturing processes there is an opportunity to shortcut these loops further with thoughtful design. Techniques for forming, cutting and marking synthetic materials can be used to extend the life of a discarded textile or create something new.

Potential for this type of production technology forms part of a digital manufacturing revolution – a revolution that has the potential to enable mass customisation and highly responsive localised production, perhaps even in the home.

6.2.3 Overview Of Finishing Techniques For Textiles

This project focused on the impacts or barriers to recycling caused during the finishing process of fabric production. In order to evaluate the potential of the techniques developed during this project they are reviewed and compared to traditional processes and associated environmental considerations, as these processes are prevalent in both the commercial textile industry and also at a smaller scale in studios across the UK as part of a designer maker's toolbox. I have called upon my experience with both sectors during the practice stages of experimentation and analysis.

Finishing is a set of processes applied to a fabric after weaving (or other textile construction methods) to improve the qualities (aesthetic and functional) of the treated material. This can range from improving the handle (touch) of the fabric to adding decoration or preparing it for further processing. Although finishing can be used for a broad spectrum of purposes, this project has focused on the aesthetic or design-oriented processes. Each of these individual finishing techniques are delivered by a vast range of industry partners and crafts people, including textile converters, manufacturers or craft makers.

Finishing processes can be classified as one of two groups; wet (chemical) processes or dry (mechanical) processes.

> Chemical finishing can be defined as the use of chemicals to achieve a desired fabric property. Chemical finishing, also referred to as 'wet finishing', typically takes place after colouration (dyeing or printing) but before fabrics are made into garments or other textile products. However many chemical finishes can also be successfully applied to yarns or garments. The actual method of finish application depends on the particular chemicals and fabrics involved and the machinery available. After application of the chemical finish, the fabric must be dried and if necessary, the finish must be fixed to the fibre surface, usually by additional heating in a 'curing' step' (Fung, 2002, p368). The chemicals involved can include adhesives, polymer coating and 'burn-out chemicals' and acids.

Mechanical finishing is considered a dry operation even though moisture and chemicals are often needed to successfully process the fabric. Most of the mechanical processes explored use heat and pressure to impart the desired effects, which are both energy intensive.

Mechanical devices are used in both categories and the major distinction between the two is what caused the desired change – the chemical or the machine?

6.2.4 Sustainability Issues Of Finishing Processes

The biggest environmental issue relevant to the textile industry is the amount of water discharged and the chemical load it carries. Other important issues include energy consumptions, air emissions, solid wastes and odours. In general terms, it can be said that pollution prevention techniques are employed to improve efficiency and increase profits while at the same time minimising environmental impacts. This can be done in many ways such as reducing material inputs, re-engineering processes to reuse by-products, improving management practices and employing substitution of problematic chemicals.

Recyclability

Recycling of coated and laminated fabrics is generally not easy, because by definition they are frequently made from at least two different types of polymers or materials and separation is likely to be a difficult if not an impossible process for certain articles (see chapter 4). Even standard articles of clothing such as shirts are likely to be made from polyester and cotton – two very different fibres (synthetic and organic). Coatings sometimes contain FR agents such as bromine compounds and antimony, and metallic additives and stabilisers such as those found in PVC and some rubbers (Fung, 2002). This factor causes complications in recycling because these chemicals are often harmful and would not be considered safe to reprocess.

The recycling process itself begins with the logistics of collection, disassembly if required, identification and separation of the various fibre types, and then cleaning and disinfecting in the case of clothing. Material of the same fibre and quality has to be gathered together to make any recycling process economically feasible. Because of central government pressure on local authorities, far more determined attempts are now being made to reduce the amount of waste which goes to landfill and to increase the proportion recycled and composted. Increased landfill charges will change the economic feasibility of recycling and waste disposal processes.

The Climate Change Levy on energy is also likely eventually to have an effect on the economics of recycling. Reusing and certainly reducing are generally agreed to be the best procedures but not applicable to everything at present. As more and more articles are recycled, the issue of coated and laminated textiles may well come under scrutiny and manufacturers of these articles could be affected under producer responsibility considerations. The joining of two or more dissimilar materials may eventually be discouraged as not being environmentally friendly. Consideration is being given to reduced VAT on products bearing eco-labels, and this may well put certain coated and laminated materials at a disadvantage. Probably the long-term future lies in producing laminates from materials of a similar chemical type (for example replacing the lamination of polyester with a polyurethane foam with a 100% polyester version).

Some materials, such as PTFE can be coated with a liquid form of the same polymer to facilitate easier recycling (such as W L Gore's self coated PTFE fabric plus others from Avantex 2011). However this is less common with PET due to its characteristics when melted,[35] i.e. it is difficult to process and would require a highly energy hungry process to do so.

Energy Use

Measures for sustainable environmental protection can only be considered as part of an overall system. Extensive case studies of rational energy use concepts, i.e. regenerative heat recovery for waste water, power heat coupling and thermal insulation of buildings, must be considered for production impacts. Many of the processes explored use high-energy inputs for heat or pressure based functions.

Solid Wastes

In textile finishing industries, many different solid and liquid wastes are created that have to be disposed of. For example, solid waste from yarn production includes dust, seed and packaging waste. Solid waste from knitting and weaving consists of yarn remnants, cutting, faulty products and yarn spools. Solid waste, from the wet treatment of textiles, includes sludge from external works, dirt, grease and vegetable matter as well as waste chemicals and packaging. Some of these solid wastes can be recycled or reused, others are incinerated or put to secured landfill; there are also some wastes which (in some cases) are treated in anaerobic digesters. Many of these wastes are not specific for the textile industry.

Polution & Chemical Use / Water

Chemicals used in the process are dissolved in water or other 'carriers' and must go through an additional cleaning process to avoid contaminating water systems.

Transportation

Energy use related to moving materials to different geographical locations for different stages of processing can be substantial.

Inflexibility Of Process / Large Volumes Committed

The need for 'hardware' in many processes, make batch production or flexibility of design impractical. Digitally driven techniques are preferable and lighter-touch.

[35] This property was witnessed first-hand as part of a Polymer Engineering course undertaken at London Met 2006.

6.2.5 Improving the Sustainability of Finishing

Several recent reports have commented on the need for improvement in these areas. More streamline and digital technologies could enable a lower impact industry with many of the impacts previously described removed or mitigated.

Shifting the location of production nearer to the place of consumption becomes economically more viable if new production technologies are able to reduce labour content of production. 'Whole garment technologies' in particular, which can be used to produce a finished product or garment from a single material are particularly beneficial (Allwood, 2006, p30).

Potentially such technologies may change the cost structure of production, in particular improving the viability of small batches, 'made to order', and reducing the need for stock-holding and unsold product waste due to over-production and associated transport costs.

In the way that digital printing has revolutionised the responsiveness and affordability of the printing industry, could digital production also be relevant in the finishing sector?

There is a need to replace chemical treatments with nonchemical ones, combine and simplify materials and processes, reduce water use and minimise transport in order to reduce the impact of the finishing industry (Lacasse and Baumann, 2004).

I hope to show through the following analysis that the laser finishing techniques I have developed can address these sustainable improvements in all areas listed above.

6.3 CLASSIFYING RECYCLABILITY OF TEXTILE COMPOSITES

A textile can be a complex combination of different resources and life-cycle stories before it ever becomes a garment or a product.

Analysing these structures gave insights into the potential barriers, which might block the return journeys and resulted in the creation of a recyclability matrix. This matrix was used both to clarify the brief for recyclability at the design stage and again to assess the success of the sample outcomes.

The classification of recyclable materials in model 3: The Recyclability Matrix (fig 6.1)was developed from Gulich, (in Wang 2006) and is used to identify levels of recyclability in different textile constructions common in the textile industry.

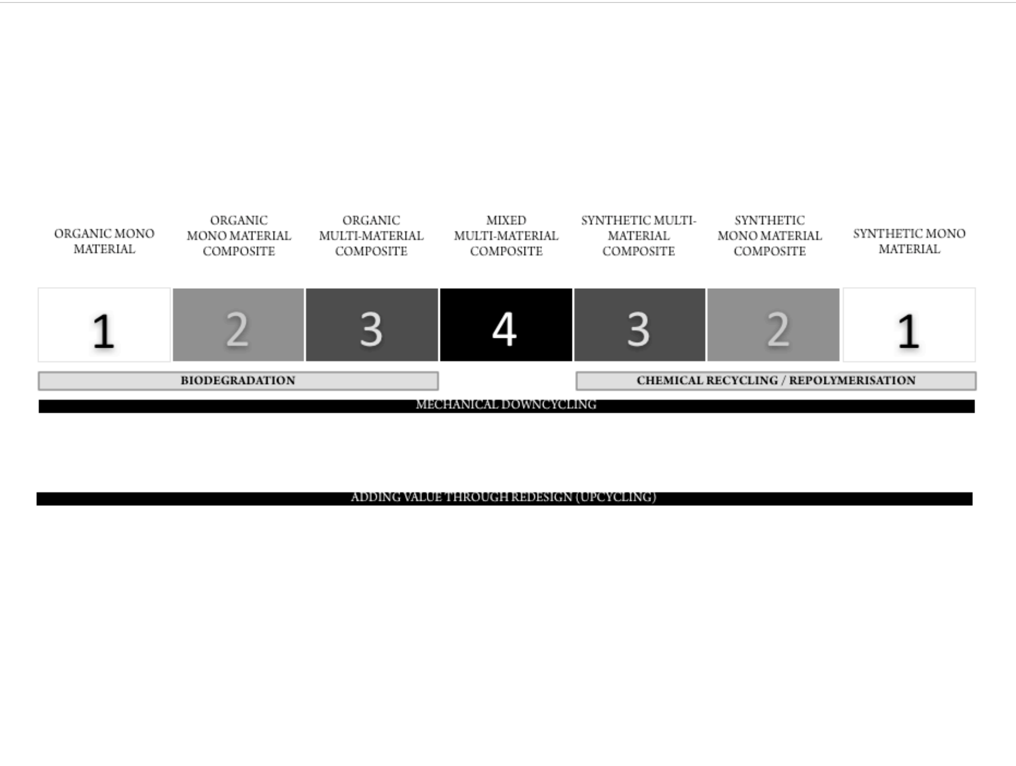


Figure 6-1 MODEL No3 / THE RECYCLABILITY MATRIX

6.3.1 Level 1: Mono Material

Products consisting of only one material in a single system (non-composite) are easy and pure to reuse. With them, it is not generally necessary to separate the product structure prior to processing. This is why single-material systems are preferable when it comes to the design of products easy to recycle.

6.3.2 Level 2: Mono Material Composite

Combinations of different kinds of textile made from the same polymer (e.g. PP fibre material and PP film or coating) are single-material composite systems, which are also easy to recycle.

6.3.3 Level 3: Compatible Multi Material Composite / Temporary Bond

If the required characteristics of a product are not achievable using only a single material, multi-material composite systems are necessary. Systems containing separable composites need to be disassembled prior to recycling, which can be done manually or by machine. This is what happens, for example, to non-textile functional elements used within garments, and to technical textiles.

6.3.4 Level 4: Compatible Multi Material Composite / Permanent Bond

Level Processes such as glueing, laminating or stitching result in composites which cannot be separated. With regard to complete reuse, the materials chosen should go well together so they can be processed together.

6.3.5 Level 5: Mixed Multi Material Composite

Currently, processing makes sense as long as the secondary raw material produced can be well marketed. If the materials used in a multi-material composite system do not go together and if they are not separable from one another, they may serve as a fuel or as a raw material (for the generation of energy or of synthesis gas).

6.4 SUMMARY

Following this initial research I have identified the boundaries and systematic criteria for exploration in the practice experiments.

The insight gained from the above is that textiles, designed to be easy to recycle, need to fall within Level 1 for optimum recyclability, and are characterised by:

- the potential to be disassembled (where necessary) and
- the potential to be recycled in either technical or biological systems

If a closed-cycle polyester economy is to come any closer to fruition then designers must design polyester products with more of an understanding of the material itself and not create products which prevent forward-recycling.

Categorising material constructions as I have done in this chapter has been pivotal in informing my understanding of how to categorise recyclability and therefore design in recyclability at the outset.

7 MONO FINISHING: DESIGN FOR RECYCLING

7.1 INTRODUCTION

This chapter explores the final practice stages of experimentation and development of monomaterial finishing techniques using the technology of 'laser welding'. The conundrum of recyclability versus aesthetic freedom and creativity is approached through a practice-led process and discussed as a comparison with traditional finishes. Recyclability (building on the C2C closed loop system) and aesthetic value (building on techniques developed for upcycling) are explored through novel surface manipulation and bonding techniques with clear environmental advantages over traditional methods.

The main research question explored here is:

- What new finishing techniques might be enabled through the use of laser technology?

Insights gained during the previous research stages provided a set of objectives for the final practice element of the project. The main aim was to develop finishing techniques for recycled polyester which would enable the resulting textile products to be fully recycled (true recycling) in perpetuity through repolymerisation. I had been searching for ways of manipulating the surface of polyester, a thermoplastic material, which could dramatically alter the surface aesthetic without the need for toxic chemicals or adhesives, thus maintaining recyclability.

A technology to provide potential for cutting, joining, forming and decorating textiles is needed, in order to be able to replicate the numerous finishes required. A period of research into potential technologies led to the selection of the laser as the focus. There was existing research (see appendix 9.1) which used the laser as a tool for textile manipulation (Stoyel, Kane, Bartlett, Smith) as documented through a recent conference at Loughborough University (Cutting Edge, 2009).

This research had explored ways of joining textiles and had presented the method of 'laser welding' as a potential area of innovation (Jones and Wise, 2005). Further research into laser technology uncovered a new and emerging laser-welding process which had been trialled for joining fabrics (Altex, 2007 and Leapfrog, 2006) and later through an educational project (Coleg Sir Gar, 2007).

Initial tests showed promising results and funding was obtained from the Materials KTN and The Welding Institute (TWI) in Cambridge to set up a series of experiments to develop 'proof of concept' sampling. During the experiments, many more finishes were replicated than originally expected and the results are presented in this chapter.

Because of the nature of polyester, which is thermoplastic, a wide range of technologies can be applied to create effects without adding chemicals to the material. By utilising available digital manufacturing processes there is an opportunity to shortcut these loops further with thoughtful design. Techniques for forming, cutting and marking synthetic materials can be used to extend the life of a discarded textile or create something new.

7.2 BRIEF: MONOMATERIAL FINISHING FOR SYNTHETIC TEXTILES

This project was developed to explore a novel application of a patented laser welding process, and was funded through a SPARK award from the Materials KTN. The potential benefits of this research were focussed in a number of sectors;

> …a key opportunity lay in the Automotive industry where potential volumes are large and there is always interest for innovations in interior trim techniques. Additionally, the industry has to respond to the '95% recyclability in 2016' ELV initiative; currently required levels around 80% are reasonably cost-effective to achieve, but far greater recovery of currently challenging 'fluff' (largely upholstery and trim materials, including PU) will be necessary.[36]

Similar issues are pressing in other textile-based industries such as contract furnishing, domestic interiors, architecture and garment manufacture.

7.3 TECHNOLOGY: WELDING TEXTILES WITH LASERS

Laser welding was selected as the technology to explore for the final practice phase. As for many digital processes there are some established advantages of replacing traditional processes with a digital one: (Bartlett, 2006, p13)

- Replacing a traditional process (i.e. laser as a 'non contact' alternative process)
- Eliminating restraints of repetition (not limited by tooling costs / repeat patterns)
- High Speed Process (freedom to transfer designs directly from computer to cloth)
- Permanence of mark
- Removal of additional agents (i.e. devore chemicals / bleach etc)
- Economy of process (cost savings due to flexibility of process)

Laser welding also seemed to have further advantages for the purpose of this project:

- Low energy compared to the CO_2 laser
- Ability to control patterning more accurately during lasering

7.3.1 Transmission Laser Welding (Clearweld)

A less widely used laser process in the textile industry is that of laser welding. This emerging technology was successfully patented in 2002 but as yet has not been fully commercialised in the textiles industry.

TWI and Gentex Corporation (UK) patented a successful process in 2002 called Clear Weld. This process uses a Nd:YAG laser of 50-100 watt output and 500-1000 mm/min beam scanning speed to heat a colourless infrared-absorbing ink, sprayed or printed onto the synthetic fabrics to be joined. Unlike the CO_2 method the fusing process is confined within the joint interface and does not disturb the surfaces of either joined textile.

[36] extract from application for SPARK funding, 2006

Most of the current developments in textile finishing with lasers have been conducted with CO2 lasers. Although the laser welding process explored was first patented in 2002, the focus of subsequent exploration has been as an alternative to traditional stitch and seaming techniques, for product constructions. The main aim for this research was to explore this technology as a tool for textile 'finishing', concentrating the study on the surface manipulation of textile substrates. This was explored through a collaborative investigation with TWI, the engineering research facility based in Cambridge, who hold the patent for the technology.

The process uses lasers and infrared absorbing materials for precise joining of coloured or clear synthetics. It offers superior engineering advantages compared to today's adhesive and solvent bonding, and ultrasonic, vibration and hot-plate welding methods. They explored the potential for this technology to be used as a stitch and seaming replacement system during the Altex (2007) & Leapfrog (2006) projects.

7.3.2 Benefits

The attractions of laser welded textiles are manifold; the external texture and appearance is retained, strong air and water proof seams can be made quickly and effectively, production is fast and almost fume free and the colour of the parent material is unaffected by welding. There is also great flexibility for automation, and multiple layers can be welded in one pass.

- External appearance is retained - the melting occurs at the interface only
- Multiple layers can be welded selectively using a flat construction - internal structures can be generated by welding only where absorbing material is placed, so closed products with internal welded structures are possible
- Good seam strength - 40-100% of the parent material strength in a tensile test. Laser welded joints resist high mechanical loads, they are gas tight and often achieve the same strength as the base material
- Leak tight seams are feasible
- With lasers, almost any kind of seam weld contour can be realised and there is a solution for nearly every work piece geometry
- Minimal thermal and mechanical stress input is applied: what you weld is what you see. The welding is so precisely localised that even sensitive components very close to the weld remain unaffected
- The results are surfaces with perfect quality, no micro particles, glue or roughness
- Automation potential - especially with flat bed and robotic systems
- Low reject rates and constantly high reproducibility
- No additional mechanical load due to contact-free welding
- Cost-efficiency with excellent precision and optical quality
- The process is clean (no toxic agents required)
- Fast - welding speeds of over 20m/min have been demonstrated
- Wide range of synthetic materials processable - nylon, polyester and polypropylene fabrics and coated or laminated fabrics with foam or membrane layers
- Control of melt volume and hence seam flexibility
- A novel appearance to the seam - new design opportunities

7.3.3 Limitations

- One part must be transparent to the infrared laser (not limited to visually transparent materials) - some textiles cannot be processed due to the presence of certain colourants or additives
- Variable heating in some patterned fabrics - also due to differential absorption in certain colourants
- Investment in new equipment and training, capital equipment and infrastructure
- Natural materials to be studied - these cannot be processed by melting, but laser initiated bonding may be possible with interlayer films

7.4 PRACTICE: (MONO-FINISHING) LASER-FINISHING FOR REPOLYMERISATION

7.4.1 Designing The Study: A Craft Approach

The approach was based on combining the design process with a methodical testing of materials and settings. The design work was studio-based and testing was carried out with technical assistance from TWI at their premises in Cambridge. The practice led research was designed very much as a ‘design’ process. Working closely with a technical specialist, enabled smooth communication and translation of ideas, with experimentation based on action and reflection throughout the study (see fig 7.1).

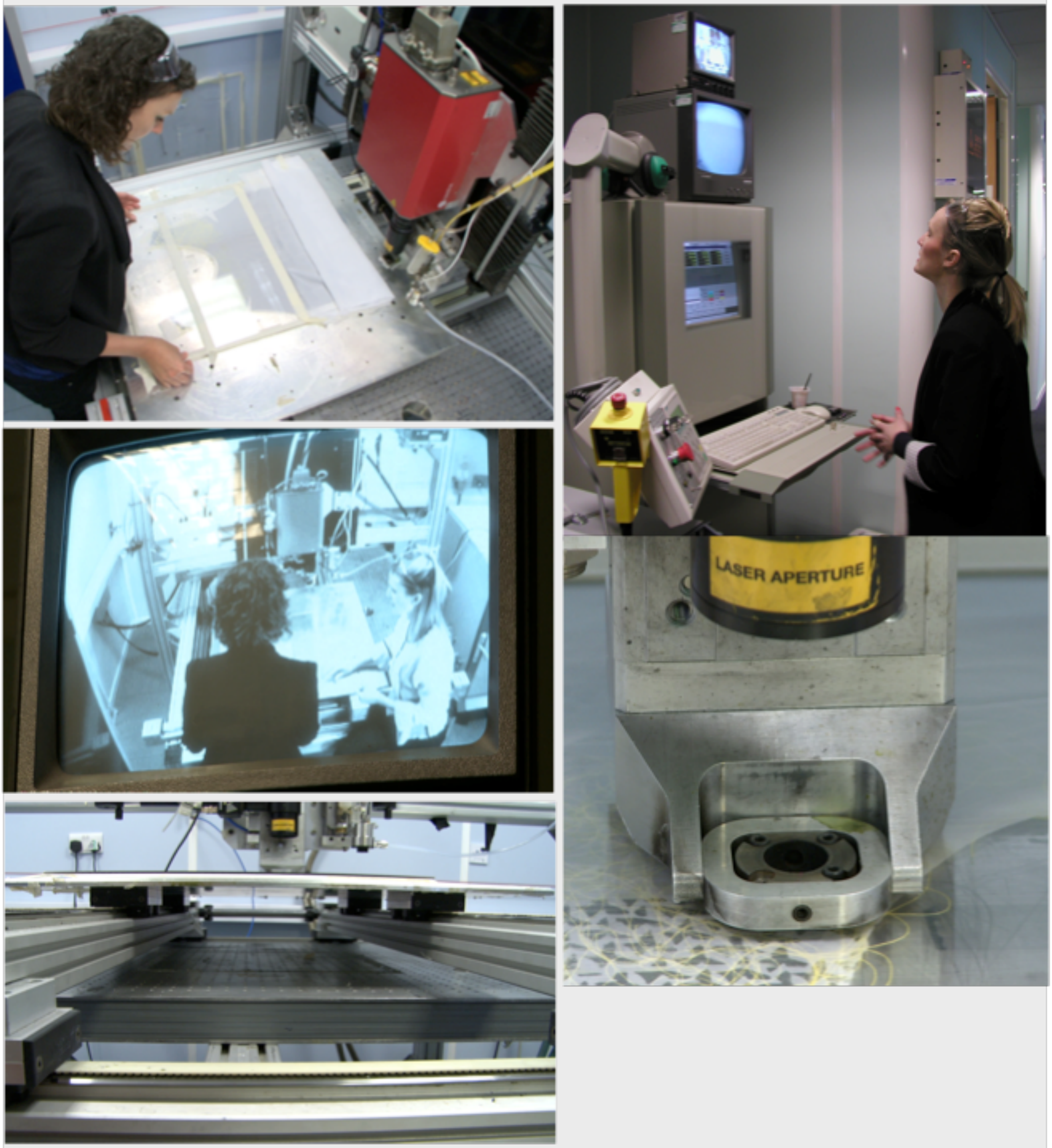
Methodologically, the approach for this study is practice-led, within a ‘craft approach’ to new technologies, as expressed below;

> Traditional makers develop an in depth understanding of the materials and tools that they work with, through various combinations of hands on experience, and technical/scientific understanding. Through this dialogue with materials and processes they are able to develop an individual aesthetic, a personal visual vocabulary. (Masterton, 2004)

This emphasises ‘hands on interaction’ with materials and processes and the importance of personal creative goals and design narratives, which may relate to materials, imagery, processes and the end location/use of the work. Due to the technical nature of the processes explored through the practice elements, collaboration and discourse with textile engineers, chemists and technology specialists has been a key aspect of this approach. There were several stages to the experiments:

- Finding ways to overcome the limitations of the available equipment
- Optimising settings for mark making and welding with the chosen materials
- Identifying and exploring finishing techniques

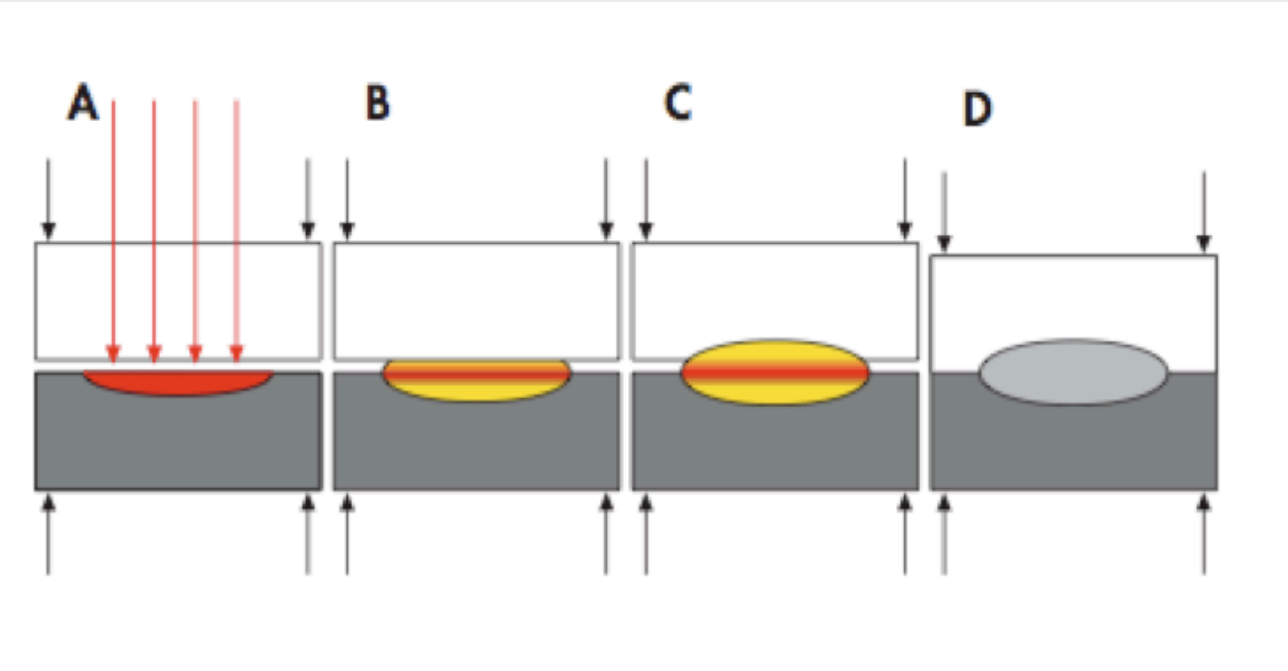
Because the material, polyester, was a familiar material, I spent very little time testing the parameters of power and speed for the material I was exploring. I did look closely at the type of effect or mark that could be achieved with various fabric constructions and weight. These ranged from a single layer transparency effect to a much more complex construction on multiple layers bonded without any surface marks – and a variety of effects between the two.



MonoFinishing project experimentation at TWI (The Welding Institute), Cambridge, 2010

Photography: The Science Museum, 2010

FIGURE 7-1 LASER-WELDING TECHNOLOGY IN USE, 2008-2009



Laser Welding process diagram, courtesy of TWI (The Welding Institute), Cambridge, 2010

Laser light penetrates the upper layer and is absorbed by the lower material (A). The melting of the latter transfers (B) the heat to the upper layer (C). The mutual melting pool solidifies under external pressure to a high-quality weld (D).

FIGURE 7-2 LASER-WELDING CONCEPT DIAGRAM, COURTESY OF TWI

7.4.2 The Laser Welding Process

The laser welding process consists of three stages, which can be merged into two processes if the absorber material is incorporated in advance of welding:

- Application of the laser absorber material system to the textile
- Assembly of the seam and application of clamping pressure
- Irradiation of the seam with a near infrared laser to melt the material where the absorber has been applied and create a permanent weld

7.4.3 Application Of Absorber Material System

The absorber may be applied in the form of a low-viscosity liquid, which dries rapidly to leave a very thin deposit on the surface of the textile. It may also be deposited on the surface of an interleaving film that is compatible with the textiles to be joined. A third option is to incorporate the absorber into the fibres of the textiles. In all cases, the fabric can be prepared in advance of welding.

7.4.4 Assembly Of The Seam

The seam, including any interleaving film, is assembled and held in place such that the interface between the textiles can be irradiated through one of the textiles. The assembly also applies a clamping pressure to the joint during welding without hindering access of the laser.

Low heat conductivity and viscosity of polymers means that the most practical welding geometry is overlap welding. Here, the laser beam penetrates the upper material and is absorbed by the lower material. The heating of the latter leads to plastification which bridges the gap between materials and melts the upper material by heat transfer. Therefore, having a small gap is an important success factor. This is achieved by applying pressure to the materials to be joined during welding and is illustrated in the following diagram.

7.4.5 Irradiation

A near infrared laser, such as a diode laser, is used to irradiate the seam. The absorber material system absorbs the laser radiation, concentrating the heat at the interface between the textiles. A thin film of polymer is melted in each textile and the application of clamping pressure brings these films into contact. The pressure is maintained, as the films cool and solidify, to produce a permanent weld.

Laser light penetrates the upper layer and is absorbed by the lower material (A). The melting of the latter transfers (B) the heat to the upper layer (C). The mutual melting pool solidifies under external pressure to a high-quality weld (D) (see fig 7.2).

7.4.6 Equipment & Process Specification

The trials were made with an Nd:YAG laser at the infrared wavelength (1064 nm). The parameters which were changed between one test and another were the energy or the pulse width or the number of shots. The laser was used out of focus with a spot size of approximately 2mm diameter.

The laser can be used in three configurations: the flat-bed system with a laser mounted on a moving gantry, a robotically moved laser source working over a shaped support and a 'sewing machine' type system where the textile is moved through the equipment manually.

The set up used for the purposes of these experiments was the flat bed system. This allowed maximum flexibility in terms of laser control through XY axes while being a fairly simple set up.

The laser was mounted on a moving gantry above a fixed flat bed. The textiles were positioned on the flat bed, with absorber already applied. The laser was manipulated around the joint line, and pressure applied at the same time using either a slider or a roller. The textiles were covered with a transparent cover sheet for this operation. This equipment is suitable for seams with no 3-dimensional shape and may be used for welding very large items. To date this has been used with manual placement of the textiles followed by automated welding, rather like laser cutting systems.

The maximum size of the working bed was 600mm square, however samples were restricted to a much smaller scale in order to maximise the variation of testing within a limited time frame.

7.4.7 Materials (& Selection Criteria)

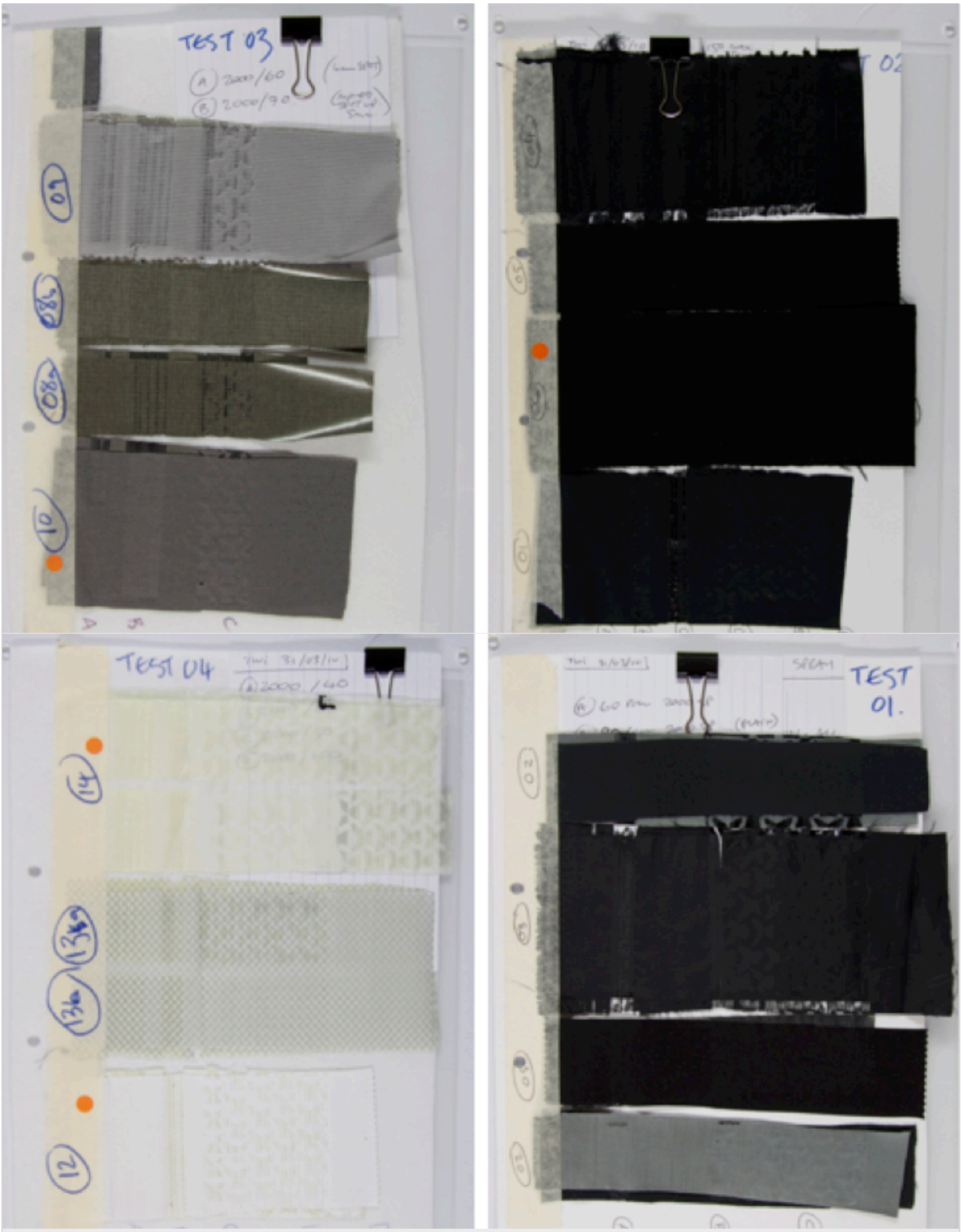
Only 100% polyester substrates were used for experimentation (see figs 7.3 – 7.17) although in many different constructions; knitted (fleece), woven, nonwoven (wadding, felt, paper), yarn, monofilament, plastic sheet, foil and chopped flock fibre. This variation of materials was essential in order to maximise the number of effects achievable.

Following an initial 'desk based' survey of available recycled polyester, three subsequent trips [PV Sep 05, Heimtextil Jan 07 and Avantex Jun 07] were undertaken to complete a database of available material suppliers.

Wherever possible recycled polyester was used, although some virgin qualities were also tested. The key factor was that only 100% monomaterial polyester was used without added agents (adhesives or coatings).

7.4.8 Image Management [Input / File Creation]

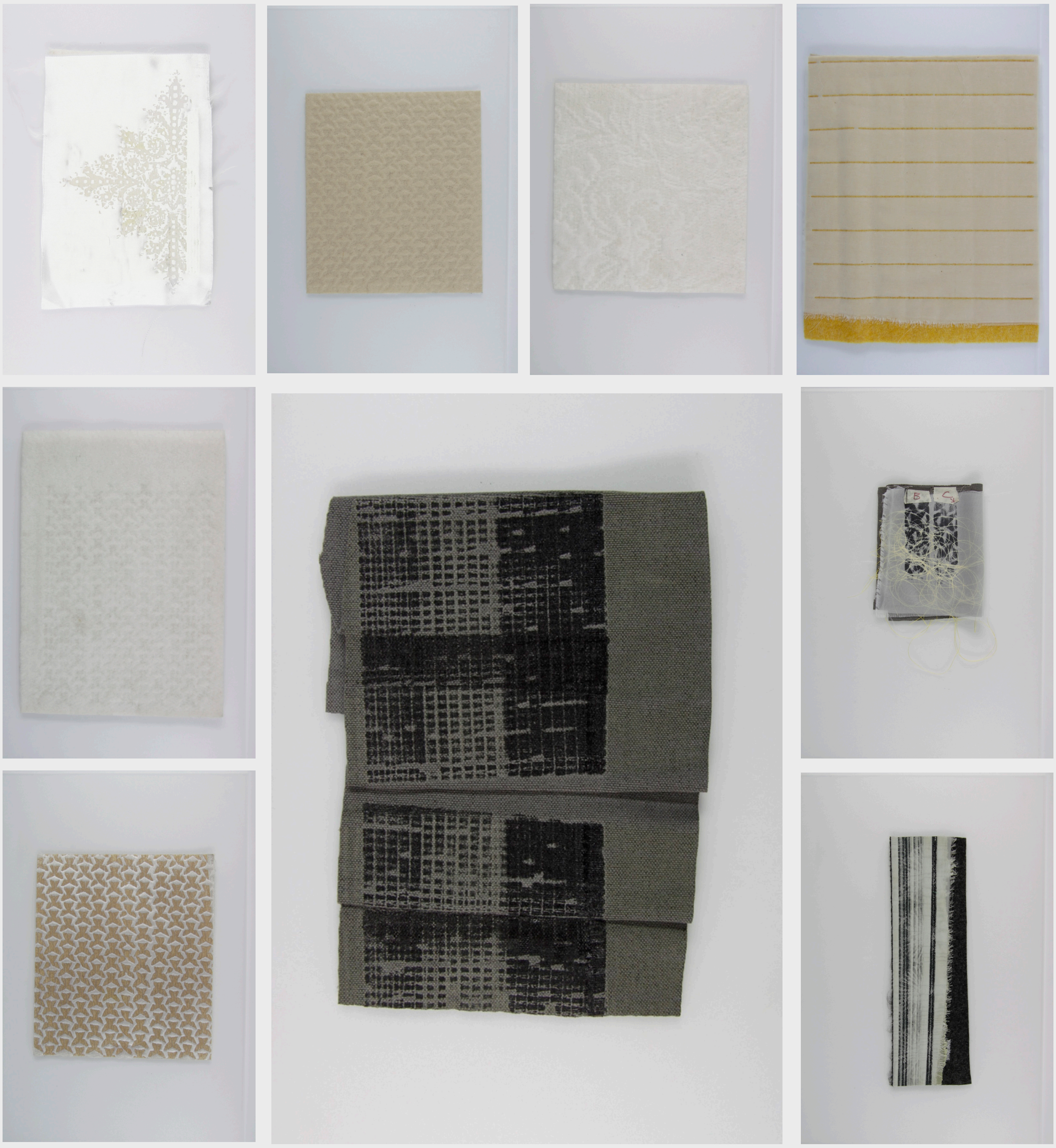
Minimal design software was utilised for this experimentation. Adobe illustrator and Photoshop were used to create laser-cut stencils for the application of the IR absorber but the laser welding equipment was not able to run directly from these files so more 'low tech' solutions had to be found.



Materials testing conducted at TWI (The Welding Institute), Cambridge, 2010
Work produced for 'Trash Fashion: Designing Out Waste', Antenna Gallery, Science Museum, London, 2010

Photography: Goldsworthy, 2010

FIGURE 7-3 MATERIALS TESTING CONDUCTED AT TWI, CAMBRIDGE, 2008-2009



MonoFinishing samples produced at TWI (The Welding Institute), Cambridge, 2008

Photography: Goldsworthy, 2009

FIGURE 7-4 MONOFINISHING SAMPLE DEVELOPMENT, 2008-2009

MonoFinishing samples produced at TWI (The Welding Institute), Cambridge, 2008

Photography: Goldsworthy, 2009

FIGURE 7-5 MONOFINISHING SAMPLE DEVELOPMENT, 2008-2009

7.5 RESULTS & ANALYSIS OF MONO FINISHES & IMPACTS

The finishes I explored came about throughout the experimentation stages in direct response to knowledge acquired through making and in response to the knowledge I gained from the materials.

Originally I was looking at laminating as a way to resurface waste material and 'upcycle' it. However this became much broader as soon as the experiments were underway and the flexibility of this process became apparent.

The following pages provide an analysis of the finishes achieved through the experimentation stages. A comparison of impacts for each process is given along with a summary of key impact reductions with laser techniques.

I looked at five key finishing processes. Each process was achieved with a combination of 'melt effect' and 'material construction' as visualised in tables 2.1 and 2.2. All 'added materials' used were also 100% monomaterial polyester in order to preserve recyclability and combination melt techniques were also used for more complex embellishments during experimentation.

This section will present the results of the practical experiments conducted at TWI, Cambridge during the final stage of development and categorise the effects achieved in relation to finishing processes. After initial testing I designed the study to investigate combinations of three key effects and three material approaches.

It was found that by combining these approaches, traditional finishing techniques could be replicated with the laser process. A collection of existing textile processes were emulated and explored successfully, resulting in materials not only created from recycled polyester materials, but also suitable for full chemical recycling into high value polymer of virgin quality.

The following images show samples produced during the early stages of experimentation.

7.5.1 Single Layer Manipulation & Embellishment

When the laser was applied to single layer materials two main characteristics could be achieved. Transparency was the result in certain material substrates, such as fine satin weaves, and emulated a devore finish. This surface effect has been explored previously by other designers using the CO2 laser. However, the use of the laser welder gave more easily controlled results with less destruction to the surface of the material treated.

More dense textile constructions and materials resulted in a melted surface effect akin to spot lamination or coatings.

This led to a further group of experiments which explored surface embellishments such as beading, sequins, embroidery, flocking and foiling – all achieved by adding decorative elements to the surface of the materials without the use of adhesives or stitch.

	Surface melt	Total melt	Internal melt	Single layer manipulations	Single layer embellishments	Multi layer composites	
Finish Replicated	Effect			Construction			Added Material?
Coating [Spot Laminating]	X			X			NA
Devore [Transparency]		X		X			NA
Flocking & Foiling			X		X		Plus PET Flock / Foil

Table 7-1 Single-layer Embellishment analysis

7.5.2 Multi Layer Manipulation (Composites)

Layering, laminating and composite multi-layered techniques are used to improve the performance of a textile, to add additional functions through the application of layers or surface treatments to either the face (front) or the back of a textile. (Hibbert, 2000)

In my own previous work for the 'Ever and Again' exhibition I used these techniques for their aesthetic potential and used the CO2 laser as a tool to resurface low grade recycled felts in order to 'upcycle' them to a higher value material product. The CO2 technique had not always produced controllable or successful results and I wanted to test this new technology as an alternative. I quickly discovered that laser welding could produce much more stable bonds, joining layers together with minimum disruption to the surface of the materials joined.

As this technology had been previously employed mainly as a stitch substitute, that is to create seam bonds for garment construction, I began by experimenting with multi-layer composites. Sampling explored stitch replacement techniques (e.g. quilting, sashiko, 3D constructions), dimensional surfacing techniques (e.g. embossing) and bonding techniques (e.g. double faced laminations). At certain power settings I observed that the top surface was affected (melted). In the exploration of seaming this would be considered undesirable, however, in the exploration of finishing techniques this opened up a new area for investigation.

	Surface melt	Total melt	Internal melt	Single layer manipulations	Single layer embellishments	Multi layer composites	
Finish Replicated	Effect			Construction			Added Material?
Stitch Bonding			X			X	NA
Laminating [Composites & 3D]			X			X	NA

Table 7-2 Multi-layer Composite analysis

7.5.3 Flocking

Outline

Flocking is a surface modification used for imparting a velvet, chamois or other special appearance to a smooth textile substrate through the application of fine fibre particles (flock) to adhesive coated surfaces (Vigo, 1994).

The flocking process is used on items ranging from retail consumer goods to products with high technology military applications. Cut polyester is used for industrial applications such as automobile window seals, glove compartments, and roofing (Swissflock).

Flocking of an article can be performed for the purpose of increasing its value in terms of the tactile sensation, aesthetics, colour and appearance. It can also be performed for functional reasons including insulation, slip-or-grip friction, and low reflectivity.

DESIGN INPUT	SUBSTRATE PREPARATION	FINISH APPLICATION	FIXATION	CLEANING	RECYCLABILITY OF FINAL PRODUCT?
Traditional Process Stencil creation through flat bed screen or rotary system	application of adhesive to surface of substrate	application of flock to adhesive by various means - loose fibre application by electrostatic charge - pneumatic system - transfer method	Drying and curing of substrate to fix adhesion of flock	wash off of final material to remove loode fibres cleaning of excess adhesive from equipment	final products often mixed fibre (if flock and substrate not from the same material group) recycling score **4**
Traditional impacts hardware / equipment cost of preparation for initial run	chemical adhesiveswet print process	danger of inhaling loose fibre	energy use in drying and curing	wet process wash off into water system / wasted adhesive & fibre	additives: adhesive & flock fibre wasted fibre
LASER Impacts hardware / equipment cost of preparation no screens or plates required to input design	no adhesives needed	energy use low (30W power source) no loose fibre	fixation occurs during application – no heating or curing required	no wet process or cleaning required	no additivesresulting in 100% monomaterial product recycling score **1**

Table 7-3 Comparison Table: Flocking & Foiling

The Process & Associated Impacts

Flock can be made from natural or synthetic materials such as cotton, rayon, nylon and polyester. There are two types of flock - milled and cut. Milled flock is produced from cotton or synthetic textile waste material. Because of the manufacturing process, milled flock is not uniform in length. Cut flock is produced only from monofilament synthetic materials. The cutting process produces a very uniform length of flock (Swissflock).

The basic process consists of affixing these short fibres to a fibrous substrate that has been previously coated with an adhesive.

The earliest flocking techniques employed mechanical or electrostatic methods, however, other techniques such as pneumatic and transfer flocking or combinations of mechanical/electrostatic or pneumatic/electrostatic are also currently practised.

The adhesive may be applied to the full surface or partially applied to produce a surface pattern. The adhesive is usually set by hot air drying, then unbound fibres removed to clean the surface. The flocked fabric can then be further finished, dyed or printed (Vigo, 1994).

The electrostatic method requires the application of a high-voltage electric field. In a 'Flocking Machine' the flock is given a negative charge whilst the substrate is earthed. Flock material flies vertically onto the substrate attaching to previously applied glue.

The transfer method involves a pre-flocked sheet which is then transferred to the substrate again through the use of glue and application of heat and pressure to fix the fibres (Swissflock).

Comparison with Laser Process

The technique I explored through laser welding (fig 7.6 – 7.7) negated the need for adhesive as the flock fibres were bonded directly from flock paper to fabric substrate using only the application of heat from the laser. Therefore there was no need for hardware (screens) or the wet process associated with printing the adhesive onto the substrate. The transfer process is much cleaner as there is no loose fibre and fixation happens when the design is applied so does not need an additional process.

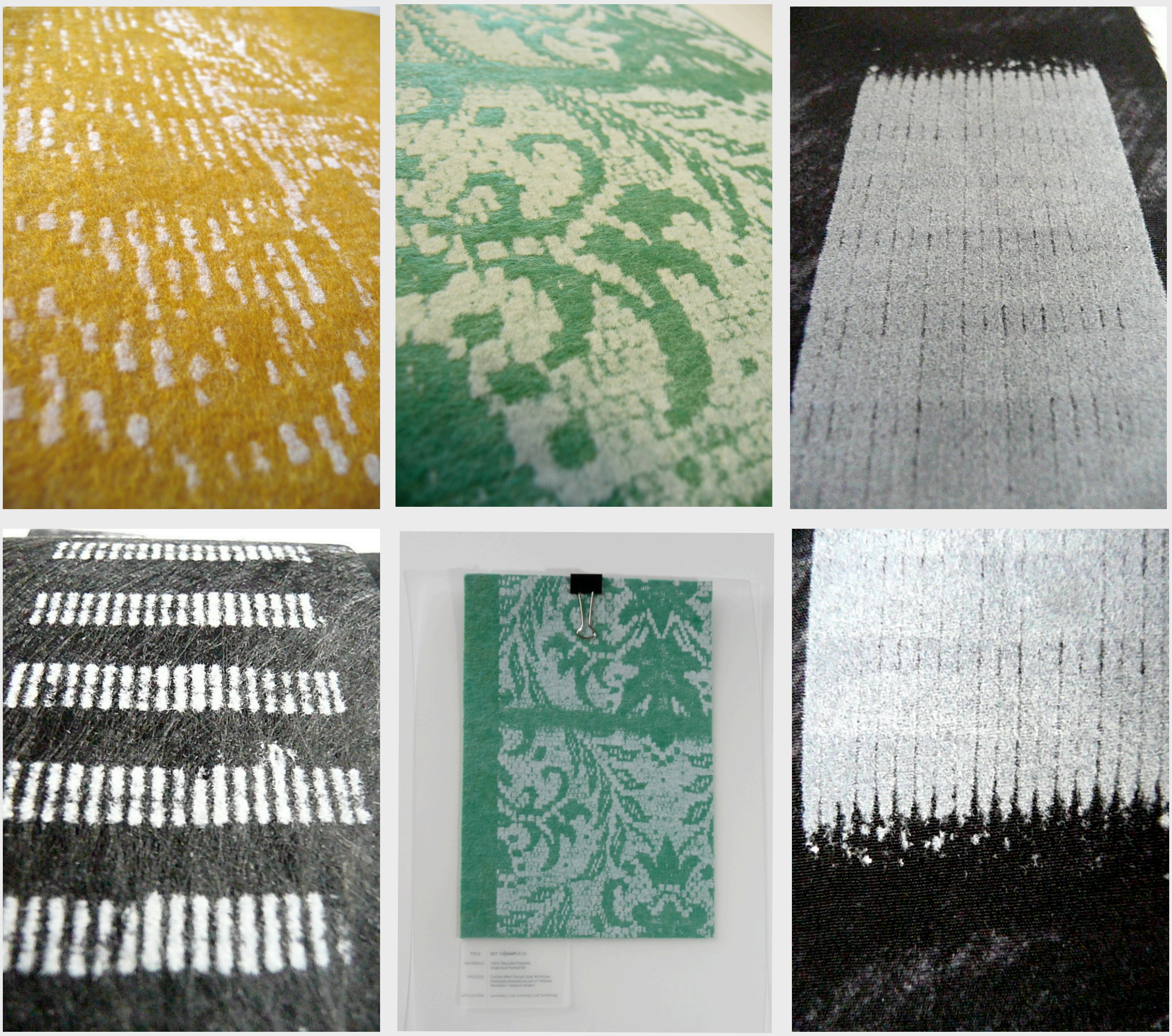
The recyclability score rises from [4] to [1] (the most easily recyclable).

NB Foiling is a very similar process but uses a thin sheet of polymer which adheres to the adhesive areas rather than fibre.

Flocking, MonoFinished samples, 2008

Photography: Goldsworthy, 2009

FIGURE 7-6 FLOCKING, MONOFINISHING SAMPLES, 2008



Flocking, MonoFinished samples, 2008

Photography: Goldsworthy, 2009

FIGURE 7-7 FLOCKING, MONOFINISHING SAMPLES, 2008

7.5.4 Coating (Spot Laminating)

Outline

A coated fabric is a construction that combines the beneficial properties of a textile and a polymer. The textile (fabric) provides tensile strength, tear strength and elongation control. The coating is chosen to provide protection against the environment in the intended use. Fabric coating, a physicochemical technique, has evolved from a relatively crude and minor method using drying oils, natural rubber and cellulose derivatives as coating materials to a versatile and important method to improve functional textile properties by employing a variety of synthetic and natural elastomers and thermoplastics as coating materials (Vigo, 1994).

A variety of useful products are produced by coating and laminating. for automotive air bags, footwear, interlinings, upholstery, hats, labels, umbrellas, adhesive tapes, rainwear, protective clothing, artificial leather articles, window blinds, tents, sleeping bags, curtains, floor coverings, luggage, sails, mattresses, filter fabrics, geotextiles and many others. The entire market sector of technical textiles benefits from coated and laminated products (Schindler and Hauser, 2004).

DESIGN INPUT	SUBSTRATE PREPARATION	FINISH APPLICATION	FIXATION	CLEANING	RECYCLABILITY OF FINAL PRODUCT?
Traditional Process Stencil creation through flat bed screen or rotary system (or plain?)	pretreatment of substrate	polymer coating (thermoplastic) - knife method - roller method	drying and curing of substrate to fix coating	cleaning of excess polymer from equipment	final products often mixed fibre (if polymer coating and substrate not from the same material group) recycling score **4**
Traditional Impacts hardware / equipment cost of preparation for initial run	chemical preparation often required	includes solvent or water carrier plasticisers often used long list of chemicals	energy use	wet process wash off into water system / wasted adhesive & fibre	polymer coating
LASER Impacts hardware / equipment cost of preparation no screens or plates required to input design	na	energy use low (30W power source) no loose fibre	no heating or curing required	no wet process or cleaning required	no additivesresulting in 100% monomaterial product recycling score **1**

Table 7-4 Comparison Table: Coating (Spot Laminating)

The Process & Associated Impacts

Fabrics are often 'coated' with a polymer in liquid form in order to impart functionality such as waterproofing. This is a very widely used finishing technique, offering a range of properties. The surface can be texturised for additional design features, and it can provide weatherproofing qualities, but this is not breathable. Decorative elements, such as threads, can be trapped under the coating (Hibbert, 2000).

Coating requires a textile substrate to be treated. The substrate plays a major role in establishing the final properties of the finished article. Yarns made from staple fibres provide rough surfaces that enhance adhesion to chemical coatings. Filament yarns generally need to be pretreated with chemicals to generate a more reactive surface (Schindler and Hauser, 2004).

The chemicals used for coating are polymeric materials, either naturally occurring or produced synthetically. These include natural and synthetic rubbers, polyvinyl chloride (PVC), polyvinyl alcohol (PVA), acrylic, phenolic resins, polyurethanes, silicons, fluorochemicals, epoxy resins and polyesters. Coating formulations also typically include auxiliaries such as plasticisers, adhesion promoters, viscosity regulators, pigments, fillers, flame retardants and catalysts. Generally the textile component provides strength and/or flexibility, the polymer coating delivers thermal insulation and barrier functions against liquids. Both components contribute to various aesthetic requirements.

The most common coating application method is the knife-over-roll system (Schindler and Hauser, 2004). The shape and angle of the coating blade, the gap between the blade and the fabric and the viscocity of the coating all effect the amount of coating applied and the penetration into the fabric. Usually a direct coating consists of two or three layers. The first base coat or tie coat delivers adhesion to the fabric, the main layer (top or cover coat) consists of the dominating type of polymer with all the additives necessary for the required properties, and often there is a final or finish coat for protective and aesthetic demands.

Reverse or transfer coating follows a contrasting order of the layers. It is used when the textile component does not have enough dimensional stability or has a structure which is too open for the direct coating process. Therefore a support foil called release paper is used, first coated with the finish layer, then with the main layer, followed by the tie coat and at last the textile, for example a knit-wear or a thin non-woven. Every coat step needs a short pre-gelation. After the final heating and end-gelation the release paper is separated. After the coating is applied, the fabric can be heated to evaporate water and other solvents and cured if required by the polymer system. Some coated fabrics are embossed or printed, depending on the fabric's end use.

Comparison with Laser Process

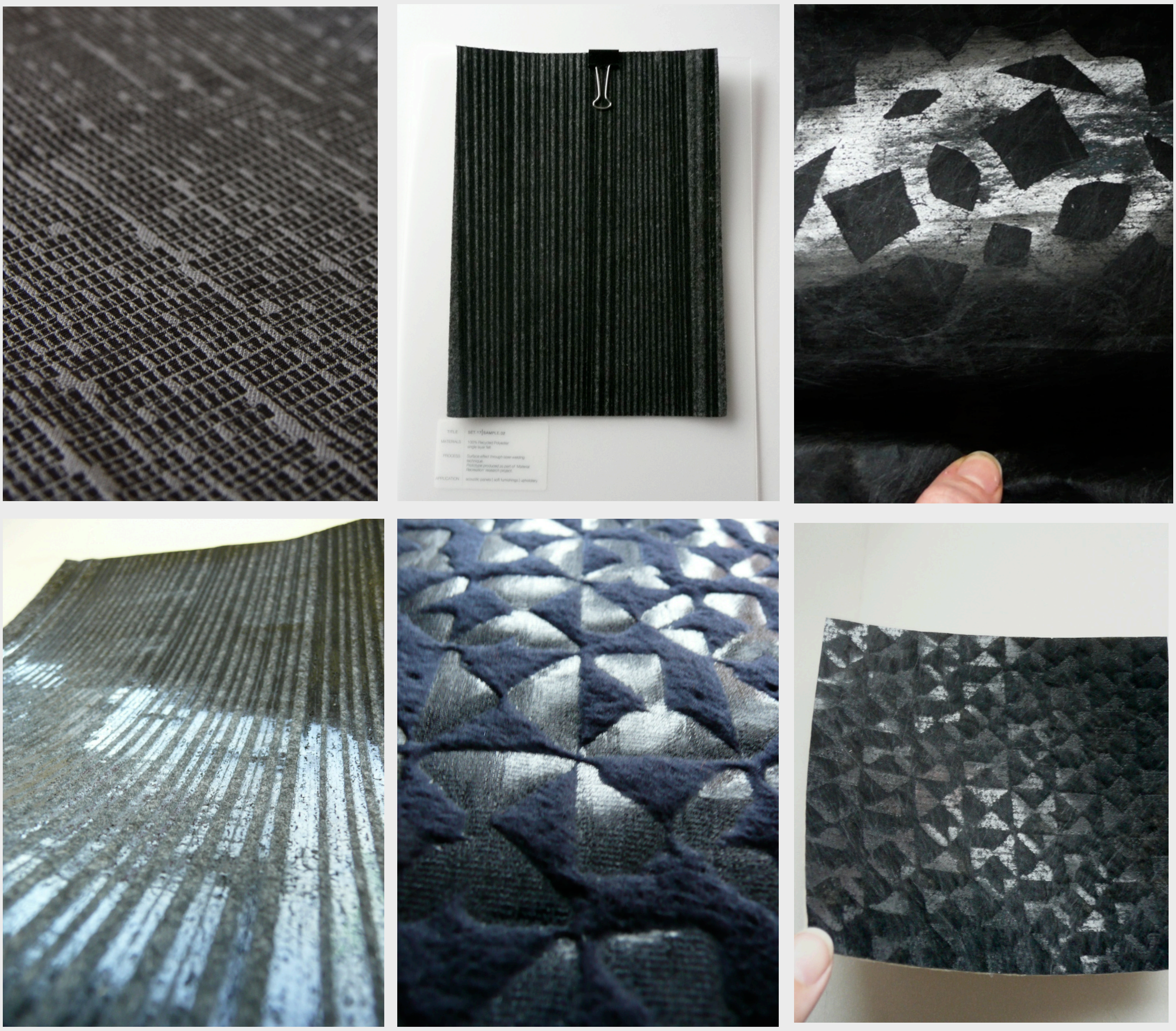
By controlling and limiting the melt to the surface of the material a 'coated' finish can be achieved without the addition of a liquid coating (fig 7.8 – 7.9). Therefore there was no need for hardware (screens) or the wet process associated with printing the adhesive onto the substrate.

The recyclability score rises from [4] to [1] (the most easily recyclable).

Coating, MonoFinished samples, 2008

Photography: Goldsworthy, 2009

FIGURE 7-8 COATING, MONOFINISHING SAMPLES, 2008



Coating, MonoFinished samples, 2008

Photography: Goldsworthy, 2009

FIGURE 7-9 COATING, MONOFINISHING SAMPLES, 2008

7.5.5 Devore (Transparency)

Outline

Devore is the production of a pattern on fabric by printing with a substance that destroys one or more of the fibre types present. This process has been used traditionally to create a transparent section to an otherwise opaque woven fabric for the main purpose of decoration.

DESIGN INPUT	SUBSTRATE PREPARATION	FINISH APPLICATION	FIXATION	CLEANING	RECYCLABILITY OF FINAL PRODUCT?
Traditional Process Stencil creation through flat bed screen or rotary system	na	application of 'burn out' chemicals by printing	heat curing	wash off devore chemicals and burned off fibres	basis for devore is mixed fibre material therefore the most complex material construction possible. recycling score **4**
Traditional Impacts hardware / equipment cost of preparation	na	devore chemicals	energy use	wet process wash off chemicals & loose fibres into water system /	mixed fibre material
LASER Impacts hardware / equipment cost of preparation no screens or plates required to input design	na	energy use low (30W power source) no devore chemicals	fixation occurs during application – no heating or curing required	no wet process or cleaning required	no additivesresulting in 100% monomaterial product recycling score **1**

Table 7-5 Comparison Table: Devore (Transparency)

The Process & Associated Impacts

The process involves printing a chemical onto a viscose content fabric. This burns away the cellulosic fibre and creates an opaque area to the design. Similarly, coatings can be removed to show transparent sections. Variations on this technique are used on fabrics which are woven from a blend of cotton and polypropylene, such as denim. By burning away the cotton warp with chlorine, the polypropylene weft fibres are exposed. Similarly, the same blend of fibres can be treated with a roller to burn and melt the fabric's surface in a moiré pattern (Hibbert, 2000).

The environmental implications of this process are well documented and include the use of a mixed fibre substrate (negating recyclability) and the use of toxic chemicals to burn out the required fibres. Also a large amount of water is needed for this process.

Depending on the nature of the fibres that have to be destroyed, several treatments and chemicals are possible. A fabric made of silk and cotton, or polyamide and viscose, can be broken by destroying the cellulose fibres during carbonising with aluminium sulphate or boiling with caustic soda. Benzoylperoxide is the substance which is printed on acetate fibres to destroy them and produce devore (Lacasse and Bauman, 2004).

Comparison with Laser Process

Selective transparency can be digitally programmed and achieved without chemicals on a monomaterial (polyester) substrate. Further work is needed to optimise the power needed for transparency to occur without unnecessary stiffening of the substrate in order to preserve handle (fig 7.10 – 7.11).

The recyclability score improves from the least easy to recycle [5] to the most easy [1].

Devore, MonoFinished samples, 2008

Photography: Goldsworthy, 2009

FIGURE 7-10 DEVORE, MONOFINISHING SAMPLES, 2008

Devore, MonoFinished samples, 2008

Photography: Goldsworthy, 2009

FIGURE 7-11 DEVORE, MONOFINISHING SAMPLES, 2008

7.5.6 Stitch Replacement (Ultrasound Bonding & Quilting)

Outline

Stitch-free welding involves the fusing together of layers of fabric by ultrasonic heating, high frequency radiation or bonded films. These processes can reduce fabric waste, energy use and noise pollution. Sonic 'stitching' is already used as a replacement to traditional stitch methods and so I have compared the proposed process to the sonic alternative.

DESIGN INPUT	SUBSTRATE PREPARATION	FINISH APPLICATION	FIXATION	CLEANING	RECYCLABILITY OF FINAL PRODUCT?
Traditional Process Stencil creation through creation of a metal plate or roller	na	Bonding occurs through application of heat created by sound wave vibration	fixation occurs during application – no heating or curing required	na	no additives resulting in 100% monomaterial product recycling score **1**
Traditional Impacts hardware / equipment cost of preparation	na	energy use	na	na	na
LASER Impacts hardware / equipment cost of preparation no screens or plates required to input design *	na	energy use low (30W power source)	fixation occurs during application – no heating or curing required	no wet process or cleaning required	no additives resulting in 100% monomaterial product recycling score **1**

Table 7-6 Comparison Table: Ultrasound Bonding & Quilting

The Process & Associated Impacts

Through the application of high frequency sound waves, changes can be effected to the molecular structure of a man-made material, producing heat, which in turn modifies the textile's appearance. Ultrasound can be used for processes such as quilting, web bonding, laminating, embossing, patterning, cutting and seaming. No glues or thread are needed, and materials suitable for ultrasonic applications are thermoplastic polymers such as polypropylene and polyester (Hibbert, 2000).

Comparison with Laser Process

The developers (TWI) of laser welding claim that it might save energy through removal of thermal taping in sealed seams, some material (no thread used) and lead to simpler production chains. Although 10% more expensive to produce compared to stitch methods, the resulting products are 15% lighter and therefore there will be cost and energy savings in the transportation of products (Allwood et al, 2006).

* The advantages of the laser process I am suggesting come in the 'environmental improvements' of the process (as the recyclability of both processes is high). With a digitally inputted design process the need for costly hardware is removed and energy costs during the process are also less.
TWI developed the 'laser sewing machine' with Prolas GmbH and Pfaff which won the 2005 Techtextil Innovation prize (however this development also required a metal 'die' as the sonic system does and therefore does not have the digital advantages of the proposed method).

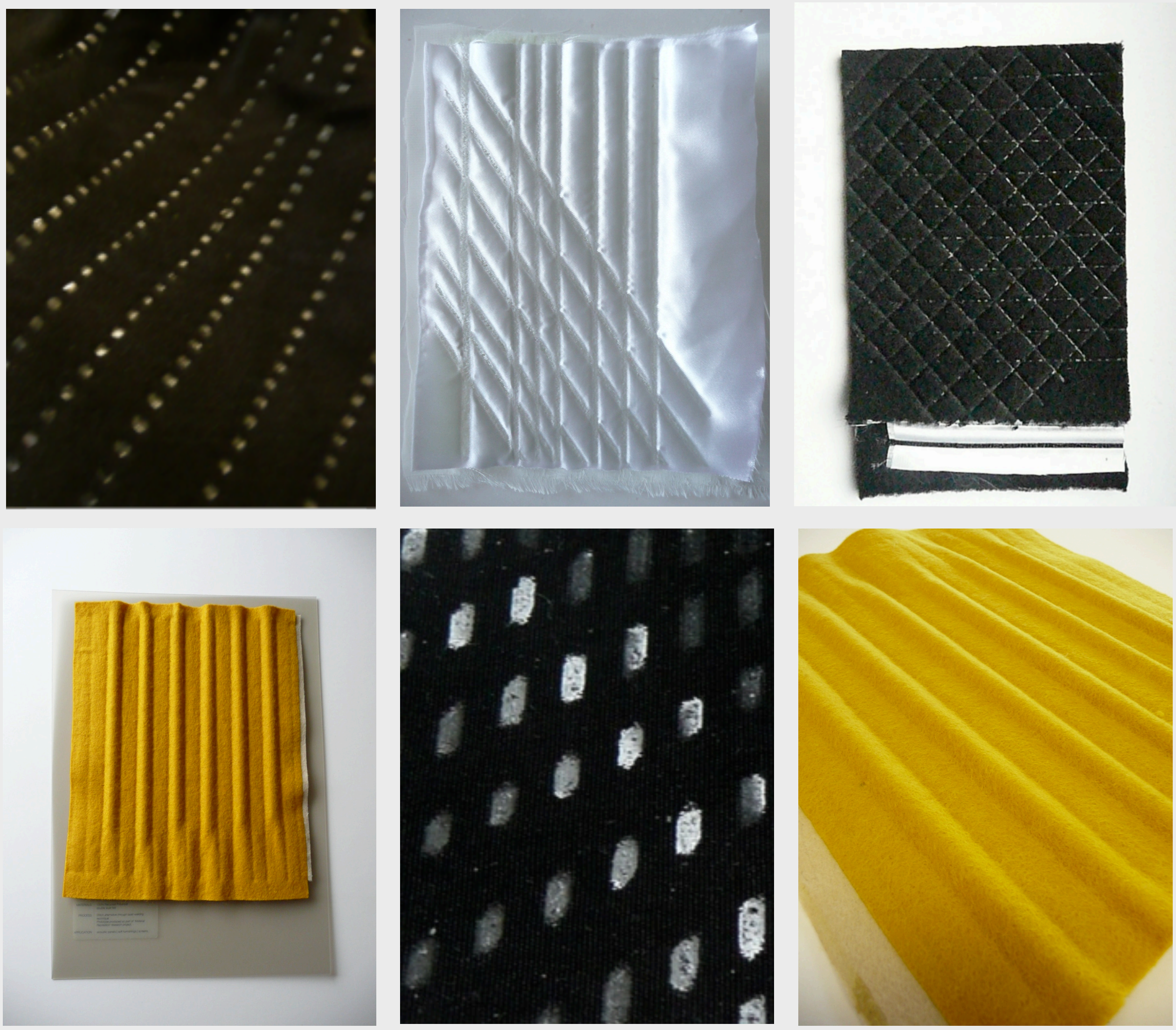
The advantage of this process over the sonic method is the controllability of the process and the flexibility of alternative finishing techniques within the same technology (fig 7.12 – 7.13).

The recyclability score remains at the most easy [1].

Stitch Replacement, MonoFinished samples, 2008

Photography: Goldsworthy, 2009

FIGURE 7-12 STITCH REPLACEMENT, MONOFINISHING SAMPLES, 2008



Stitch Replacement, MonoFinished samples, 2008

Photography: Goldsworthy, 2009

FIGURE 7-13 STITCH REPLACEMENT, MONOFINISHING SAMPLES, 2008

7.5.7 Laminating (Composites & Layered Effects)

Outline

The laminating process involves applying an adhesive coating to the surface of the primary substrate, bringing the second substrate together with the adhesive layer, thereby making a three component composite, and finally, with heat and pressure, forming the final laminate. The adhesive can be applied by a variety of techniques including the knife over roll method, scatter coating of thermoplastic polymers and rotary screen printing of adhesive emulsions or solutions.

Consonant with the immense market importance of coatings and related fibre composite products, there are many special processes and products, including front, back and double-face coatings, water vapour permeable coatings, foam and spray coating, flame laminating, bonding, flocking, hot-melt and paste-dot coating for fusible interlinings and other textile composite materials for wide technical usage (Schindler and Hauser, 2004).

DESIGN INPUT	SUBSTRATE PREPARATION	FINISH APPLICATION	FIXATION	CLEANING	RECYCLABILITY OF FINAL PRODUCT?
Traditional Process stencil creation (for adhesive methods) or die creation (for heat methods) through flat bed screen or rotary system	application of adhesive to surface of substrate	addition of second layer substrate	heat & pressure used to fix laminate layers	Cleaning of excess adhesives from equipment	basis for laminates is often mixed fibre material with the addition of adhesives, therefore the most complex material construction possible. recycling score **4**
Traditional Impacts hardware / equipment cost of preparation for initial run	chemical adhesives / wet print process	energy use for heat process	energy use in drying and curing	wet process wash off into water system / wasted adhesive	additives: adhesive
LASER Impacts hardware / equipment cost of preparation no screens or plates required to input design	no adhesives needed	energy use low (30W power source)	fixation occurs during application – no heating or curing required	no wet process or cleaning required	no additivesresulting in 100% monomaterial product recycling score **1**

NB This was the most complex set of results with effects produced comparable to multiple finishing treatments:

Table 7-7 Comparison Table: Laminates (Composites)

The Process & Associated Impacts

Lamination is used for a variety of functional and decorative effects which have been explored through the sampling stage. However for the purposes of this analysis the comparison has been drawn with Elastomeric Membranes and Sandwich Layers, which are common industry processes.

ELASTOMERIC MEMBRANES

These are elastic polyurethane or polyester membranes which are applied to the reverse of woven and knitted fabrics, or sandwiched between two layers . They allow for some movement and ease in use. Functional properties can also be added such as wind and water-proofing and they can be very light weight as in Gore-tex Paclite for active sports.

An elastomeric membrane applied to the back of a fabric will allow the fabric to recover if it is scratched or pierced, making it an ideal application for luggage, durable seating, and rugged outerwear.

SANDWICH LAYERS

Through bonding techniques it is possible to add multi functional features and design variation by layering textile structures. Woven fabrics can be bonded to both warp and weft knits, and thin weatherproof membranes can be sandwiched between layers for additional comfort and function.

Dimensional thermal layers can be trapped between two fabric surfaces incorporating space to trap air. 3D knitted and woven structures are used to create dimensional textiles providing sound proofing, insulation, and shock absorption.

Comparison with Laser Process

By controlling and limiting the melt between the layered materials, a 'laminated' finish can be achieved without the addition of an adhesive (see fig 7.14 – 7.17). Therefore there is no need for hardware (screens) or the wet process associated with printing the adhesive onto the substrate.

The recyclability score rises from [4] to [1] (the most easily recyclable).

Laminating, MonoFinished samples, 2008

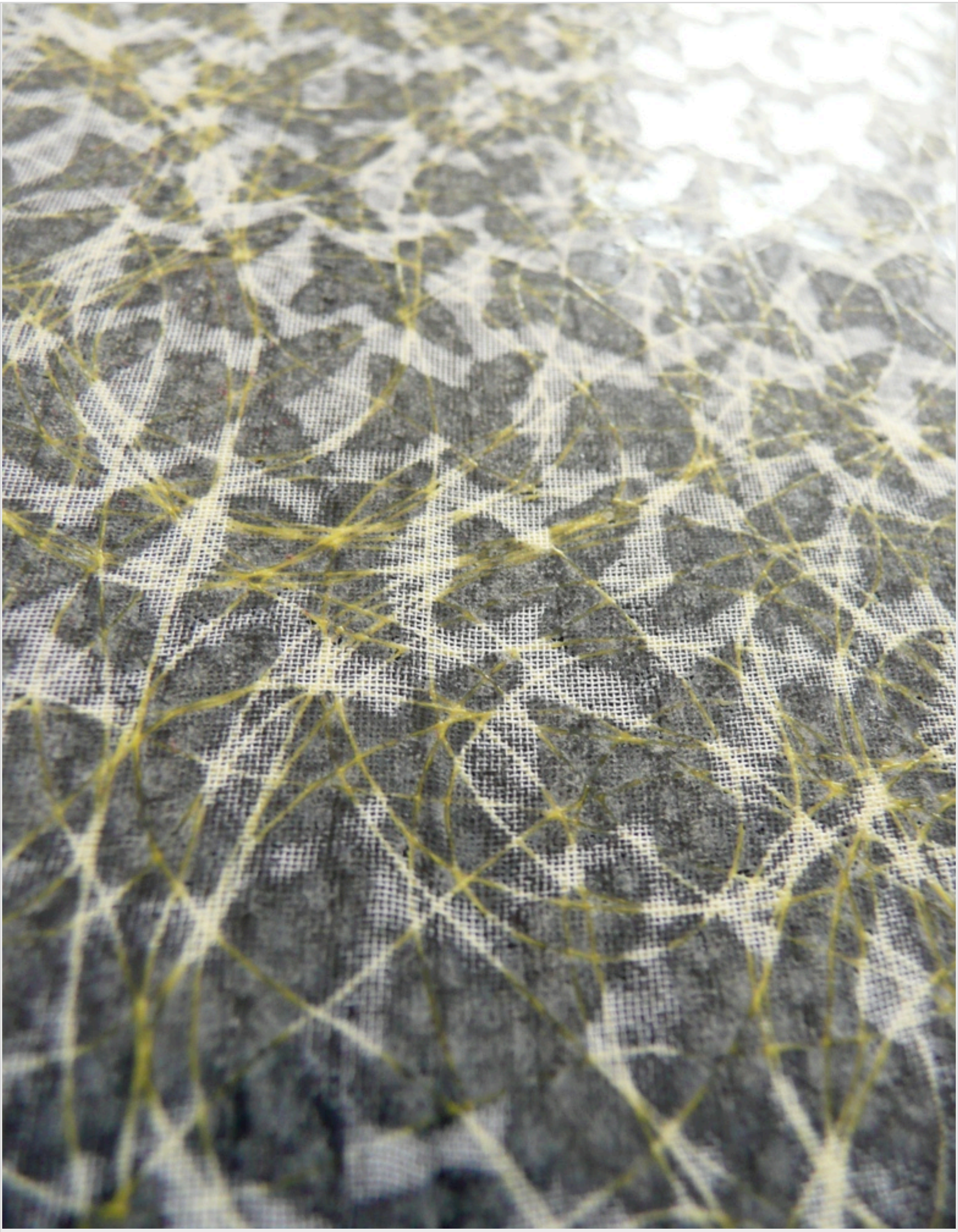
Photography: Goldsworthy, 2009

FIGURE 7-14 LAMINATING, MONOFINISHING SAMPLES, 2008

Laminating, MonoFinished samples, 2008

Photography: Goldsworthy, 2009

FIGURE 7-15 LAMINATING, MONOFINISHING SAMPLES, 2008



Laminating, MonoFinished samples, 2008

Photography: Goldsworthy, 2009

FIGURE 7-16 LAMINATING, MONOFINISHING SAMPLES, 2008

Laminating, MonoFinished samples, 2008

Photography: Goldsworthy, 2009

FIGURE 7-17 LAMINATING, MONOFINISHING SAMPLES, 2008

7.6 SUMMARY

This chapter contains a description of the key practice which contributed to the final thesis. An argument for the appropriateness of laser-welding for the project is outlined as well as an examination of previous research.

The laser welding technique was selected for use in this set of experiments (which make up the key practice element of the thesis) in order to answer the research questions stated at the start of this chapter:

- Which technologies might offer new ways to manipulate this recyclable material (Polyester)?
- How might new techniques be developed utilising the laser-welding process to enable complex, monomaterial structures suitable for 'forward-recycling?

The intention for the final practice work was to develop the idea of 'resurfacing' – using laser welding for bonding textile layers. However the experiments resulted in a much broader range of effects that thought possible (these were presented in Part 1). The resulting material samples illustrated many new finishing and resurfacing techniques, some being replacements for traditional methods and others completely new processes, which would be unattainable with conventional tools. Recyclability is preserved in all materials, while aesthetics, function and innovation retain priority in the design process.

The following key benefits of the technology were explored and include the following:

- Control of melt volume and hence seam flexibility
- A novel appearance to the seam providing new design opportunities
- Minimal thermal and mechanical stress input is applied: what you weld is what you see. The welding is so precisely localised, that even sensitive components very close to the weld remain unaffected
- Multiple layers can be welded selectively using a flat construction and internal structures can be generated by welding only where absorbing material is placed, so that closed products with internal welded structures are possible

One of the key advantages of this technology over the more commonly used CO2 lasers is that they work with a much lower energy consumption and are more controllable which enables complex effects to be designed into a single process. The potential for the use of laser welding to increase the productivity and quality of welded seaming of fabrics for garment production has been previously explored, but my focus was on the surface finishing of the fabric.

8 CONCLUSIONS

8.1 SUMMARY OF BENEFITS & FURTHER WORK

This research has made contributions to knowledge in the field of 'recycling design for textiles', in the following ways:

Firstly by proposing a new model for designing 'C2C textile products' that can contribute to a future closed-loop material economy. It does this by making a synthesis that has not been made before, whereby theories of 'design for recycling' are synthesised into a model for designing new recyclable textile structures.

Secondly by presenting a new application of laser-welding technology as a tool for the finishing of 100% polyester textiles which can be repolymerised at end-of-life. This can be explained as 'applying a technique in a new area': laser welding (previously explored in textiles only for garment seaming) is applied to the construction of complex monomaterial systems and the surface engineering of recyclable synthetic textiles.

Furthermore the research shows that the recyclability of polyester textile products can be preserved through this new digital finishing process, which is beneficial in the following ways:

- Fabric surface manipulation can be controlled more accurately through digital input.
- Complex 3D constructions can be formed with selective welding through multiple layers.
- Gloss surface patterning can be achieved without any extra materials or coatings.
- New types of nonwoven constructions can be produced through welded web constructions.
- Strong bonded layers can be achieved without the need for adhesives.
- Dimensional / padded materials for upholstery could be produced as a single component, thus enabling easier disassembly and repair.
- The final product retains recyclability through repolymerisation at 'end-of-life'.

Further Insights from research:

- Recycling alone is not a satisfactory solution to the problem of landfill unless a 'long view' is taken. i.e. Materials can be infinitely recycled (as in nature) not merely downcycled.
- In order to design for any particular 'materials system' a designer must understand the rules of that system. This can be difficult to achieve in the usual commercial timeframes and methods.
- Visualisation and mapping are useful tools for understanding this field of research and communicating it for designers.

Specific findings relating to laser process:

During this project laser welding was found to be a potential alternative to many existing finishing processes and some innovative techniques not attributable to existing processes were also identified. The resulting materials retained 100% monomateriality and were successfully preserved as recyclable resources.

In order for this technology to be available for full scale production several developments of the equipment and process are required and it is hoped that collaboration with a suitable industrial partner can be achieved in order fully to resolve the potential for a highly responsive, integrated manufacturing and recycling system which can sit within a vision for a closed loop polyester economy in the future.

The key advantage of this process, when compared to traditional methods is the 'Preservation of recyclability' (resulting materials are fully recyclable), however there are other sustainability advantages:

- Reduction of process steps (all production techniques achieved using only a single fibre and a single process)
- Reduction of transportation between steps
- Dry process / no waste water (no cleaning or washing needed)
- Removal of adhesive or coating chemicals & polymers
- Reduction of energy when compared to processes which use mechanical heat
- Process is controlled digitally and has advantages associated with digital systems (flexibility/short runs/local and global potential/connected systems/accuracy/speed of production/economy)
- The flexibility of this system enables combinations of complex finishes to be achieved in a single run
- Full integration with product construction and recycling systems is possible.

Science and Technology Barriers
There are several key barriers to full commercialisation which are currently being investigated with technology partners:

- Fluid application – the need for precise metering and clean application (no drips, smears or blockages) is paramount and cannot yet be reliably achieved.
- Fabric clamping and handling – existing fabric clamping method distorts the fabric to be seamed or must be used in 'batch-mode', un-clamping and moving between each weld.
- Manipulation and operation of laser – the laser control, both optical and mechanical has not been tackled on any scale yet, meaning that initial estimates of system price are impossible to achieve. Accuracy of the weld path is also an issue which has not been addressed.
- Process development - scientific and technical understanding of the long term potential of the new Laser welding technology to progress the development of new textile products.

The following is a list of suggestions for further exploration;

- Explore more fully the parameters for each technique/process (and potential others – resist dyeing / web formation etc)
- Solve digital deposition of the absorber
- Explore functionality potential of laser formed finishes (e.g. encapsulation) more in depth explorations of technical finishing capability of process.
- Repeat experiments with natural polymers, (e.g. cellulosics & silks)
- Develop network potential with recycling industry
- Combine digital deposition of absorber & colour (inks/dyes), CO2 laser (cutting) and ND:YAG laser (welding) systems into a single / continuous production line for the development of a complete product cycle capability
- Develop technique for ‘web formation’ (this process was explored during experimentation but not included in ‘finishing’ collection) This could provide alternative ways of creating ‘textile constructions’)

8.2 FURTHER WORK: INTEGRATION WITH PRODUCT CONSTRUCTION SYSTEMS

As a continuation of this project I am currently developing the work further into full product-construction capabilities through the development of prototype 'Mono Garments' (see fig 8.1 – 8.3 and 8.5). This is an exploration of laser finishing to produce recyclable polyester textile products with full recyclability designed-in.

In the production of complete garment pieces for the Trash Fashion Exhibition at the Science Museum and ReThink! At the Tilburg Museum (see fig8.4) the aim was to push the technology one step further and use the laser not only to decorate the material's surface but also to cut and weld a garment pattern as part of the same process. The finished piece is therefore 100% recycled polyester and fully recyclable.

Further funding is being sought to continue this work with a consortium of European textile and product manufacturers and TWI. The science and technology barriers outlined previously will be a key focus of this project as well as exploring the above suggestions for further exploration.

Samples and garment pieces produced at TWI, Cambridge. Finishing combined with garment construction in a single process for integrated production capability.

Ref: Work first exhibited at 'Trash Fashion: Designing Out Waste', Antenna Gallery, Science Museum, London, 2010
Photography: Science Museum, London, 2010

FIGURE 8-1 MONOFINISHED GARMENTS, 2010.

Samples and garment pieces produced at TWI, Cambridge. Finishing combined with garment construction in a single process for integrated production capability.

Ref: Work first exhibited at 'Trash Fashion: Designing Out Waste', Antenna Gallery, Science Museum, London, 2010
Photography: Science Museum, London, 2010

FIGURE 8-2 MONOFINISHED GARMENTS, 2010

Samples and garment pieces produced at TWI, Cambridge. Finishing combined with garment construction in a single process for integrated production capability.

Ref: Work first exhibited at 'Trash Fashion: Designing Out Waste', Antenna Gallery, Science Museum, London, 2010
Photography: Science Museum, London, 2010

FIGURE 8-3 MONOFINISHED GARMENTS, 2010

Samples and garment pieces exhibited at 'ReTHINK!', Audax Textile Museum, Tilburg, 2010
Images available at http://www.textielmuseum.nl/en/for-the-press.html

Photography: Audax Textile Museum, Tilburg 2010

Samples and garment pieces exhibited at 'Trash Fashion: Designing Out Waste', Antenna Gallery, Science Museum, London, 2010
Ref: More info at http://antenna.sciencemuseum.org.uk/trashfashion/

Photography: Science Museum, London, 2010

FIGURE 8-4 EXHIBITIONS FEATURING MONOFINISHED GARMENTS, 2010

Film presenting laser-welding process made for 'Trash Fashion: Designing Out Waste', Antenna Gallery, Science Museum, London, 2010

More info at http://antenna.sciencemuseum.org.uk/trashfashion/
Photography: Science Museum, London, 2010

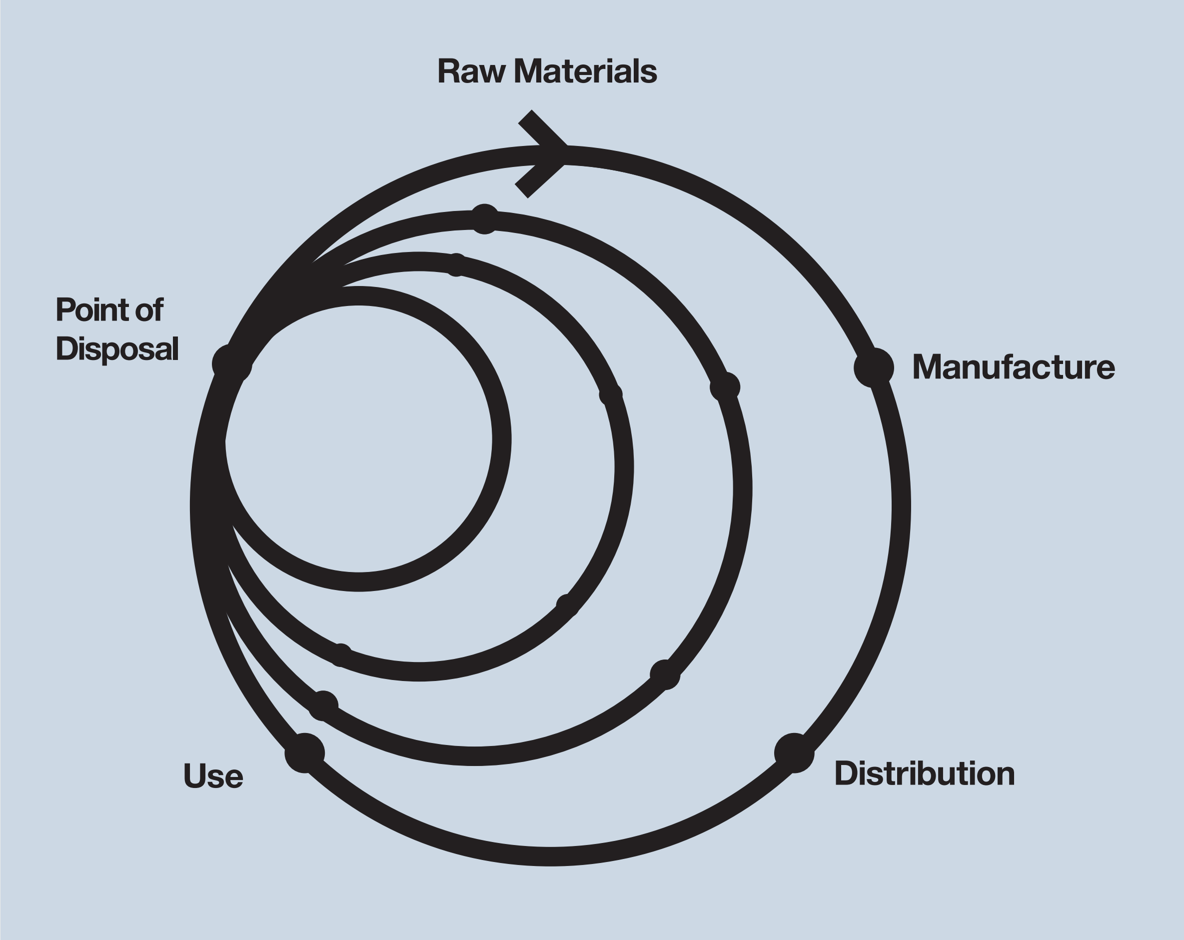
FIGURE 8-5 FILM OF THE MAKING OF MONOFINISHED GARMENTS, SCIENCE MUSEUM, 2010

Design for Material Ecologies

Unlimited materials with unlimited life-cycles.

A genuinely sustainable future depends on creating interconnected loops, or cycles, for all industrial commodities. These cycles would be part of a scaled-up system of material exchange which is open and dynamic, including all material resources in an infinite industrial ecology.

Opening the material network and enabling industrial ecologies.



A vision for the future; unlimited material recycling through an open loop material ecology.

Graphics: Laura Gordon, Franklin Till, 2012

FIGURE 8-6 AN OPEN LOOP MATERIALS ECOLOGY

8.2.1 Visions for the future; unlimited recycling through an open loop material ecology?

A final question considered in this conclusion is;

- How might this project fit within a future vision for manufacturing of local, interconnected, responsive production?

and leads me towards a new thread of inquiry for future work.

> 'The future of industry, the way we make and sell products, is not in the familiar systems of mass-production we currently follow. Digitisation, new methods of distribution and retail offer designers and manufacturers an opportunity to react to the current landscape and better serve the consumer.'[37]

This suggests a move towards a more reactive, responsive, agile and less wasteful system based on market need rather than a speculative approach.

The exciting potential of this kind of system, if it could be linked to appropriate recycling systems (repolymerisation in the case of polyester), is for a move beyond 'closed loop systems' into a more 'open loop' vision. This would mean that like the natural cycles which surround us, technical cycles could also feed systems other than its own: textiles become bottles, become product, become textiles again, which would limit the need for transportation to their source.

Recycling and production 'hubs' could be developed on a local and global scale and work towards a truly 'connected' materials ecology (see fig 8.6).

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[37] Houseley, L. (Ed), (2010) Industry: Tom Dixon, Design Research Publishing Ltd. P7

9 APPENDICES

9.1 TEXTILE DESIGNERS WORKING WITH THE CO2 LASER

The following case studies show a selection of leading designers and companies who have innovated with the use of lasers as a tool for textile finishing. Although all of these designers and companies are pushing the potential of the laser as a tool for more efficient or environmentally responsible production, none of them have been specifically considering the use of the laser with monomaterial specifically to explore its potential for controlling recyclability or future recycling of materials.

(1994) Janet Stoyel

Stoyel was one of the first designers to establish the laser as a finishing tool for textiles with her company 'Cloth Clinic' started in 1994. In particular her work to explore alternatives to the devore process through laser finishing, uses no dyes, no chemicals, no wet finishes and no stitch. Devore is a particularly renowned pollutant, generating chemical and colour waste and also generating large quantities of fibrous sludge. Of her innovative work in textiles Stoyel has written:

> By inventing futuristic processes and harnessing the latent design potential of Photon Laser and Ultrasound technology, I realise permanent effects on materials in an environmentally holistic manner, without dyes, chemicals or wet applications, challenging conventional material concepts through the ultimate marriage of engineered materials and technology. I exploit the characteristics inherent within a material, changing molecular structures, alchemetically transforming surfaces (Stoyel, 2009)

(1998) Anne Smith

Smith's Altered States project (1998-2000) also explored the potential of laser cutting and etching technology, as a method for environmentally low impact methods for producing decorative effects on fabrics. The project focused on the exploration of the aesthetic and commercial viability of the application of laser cutting and marking technologies to interior, furnishing, fashion and accessories materials, and resulted in a patent on the 'application of laser cutting and marking technologies to generic flooring materials'.

(2001) Lauren Moriarty

Moriarty's graduation collection included a range of laser cut and heat formed 'rubber lace' textile and lighting products. The materials she used emphasised the 'melting' effects of the process which could also be heat formed into 3D products.

(2006) Dr. Savithri Bartlett

Bartlett's doctoral research project, completed in 2006, at Loughborough University School of Art and Design (LUSAD), accepted the challenge to archaic fabric printing technology by suggesting an innovative route for dye uptake and surface design of textiles. The use of lasers as a means of controlling dye uptake at the surface of textiles was achieved by changing the quality of the material surface, thereby controlling colour intensity achieved during dyeing. Her research asked 'How might lasers/intense pulsed light radiation be used to increase the uptake of dye at the surface of a fabric weave, while minimising the potential degradation in a particular fibre?'

In the late 1970's, several investigations demonstrated that synthetic as well as natural fibres had improved dyeability and wettability when exposed to laser irradiation…… [38]

> [Savithri Bartlett's] PhD research considered the use of lasers in textile manufacture and to [explore opportunities] in the area of marking a material surface. Laser technology is a 'second wave' technology in as much that it has been around for some time and a substantial body of knowledge is already in the public domain. Nevertheless there remain areas of potential exploitation with respect to textiles that are worthy of investigation by designers…Savithri recognised that it was easy to become completely immersed in the technical process and forget that the prime objective was to produce 'beautiful textiles'. (Kavanagh, 2004) [39]

(2009) Dr. Faith Kane

Kane's doctoral research revolves around the exploration of 'new' textile construction and surface patterning techniques including laser cutting and fabric etching. The need for more sustainable textile processes and products is a central aspect of the work. Her PhD project (Designing nonwovens: industrial and craft perspectives) focused on the construction of novel nonwovens engineered specifically for dévoré printing and laser processing and was framed within the designer/maker mode of production. The resulting fabrics have been shown in national and international exhibitions. This strand of the work continues through a focus on the investigation of environmentally friendly textile processing techniques. [40]

> Kane's research aimed to identify elements within certain nonwoven production processes that offer opportunities to manipulate the visual and tactile qualities of the resulting materials. It aimed to develop a range of samples and prototype products that can be produced on a small scale production level. (Kavanagh, 2004). [41]

(2009) Jakob Schlaepfer[42]

Jakob Schlaepfer Combines laser-cutting, embroidery and embossing to create fabrics that are technically advanced and have a futuristic feel and aesthetic (textile shown was exhibited at Techno Threads, Science Gallery London) [43] The company initially purchased a 100 watt CO2 laser cutting system to re-interpret traditional lace in 1997, when laser technology was commercially viable, though still expensive. With the laser, Schlaepfer designers translated design ideas into digital, vector format files to drive the cutting. Due to the cost of the process these exclusive fabrics are a luxury commodity of high value. They expanded their production in 2006 when they set up Emboscan - a laser unit on the embroidery machines creating new technical possibilities.

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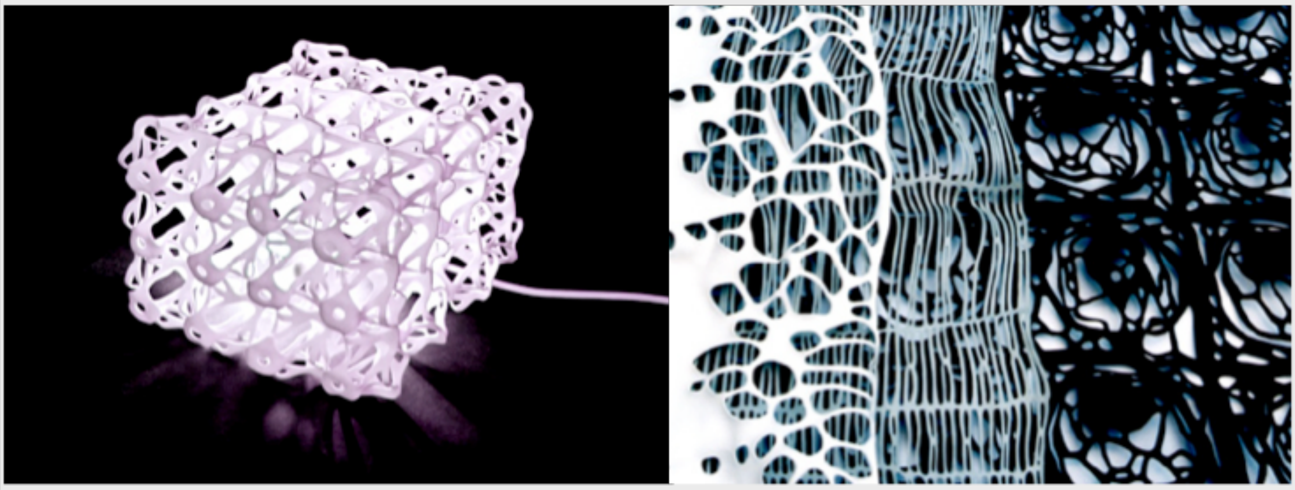
[38] http://www.amazon.co.uk/Textile-Processing-Properties-Preparation-Performance/dp/0444882243/ref=sr_1_5?ie=UTF8&qid=1303473219&sr=8-5#reader_0444882243
[39] Kavanagh, 2004
[40] http://www.lboro.ac.uk/departments/ac/mainpages/Research/staffpages/kane/kane.htm have emailed for refs
[41] Kavanagh, 2004
[42] http://www.jakob-schlaepfer.ch/en/about-us/history/
[43] http://www.flickr.com/photos/sonialuna/2739094151/



Lauren Moriarty

Anne Smith

Dr Janet Stoyel

FIGURE 9-2 EXAMPLES OF TEXTILE DESIGNERS WORKING WITH THE CO2 LASER

Jacob Schlaepfer

Dr Faith Kane

Dr Savithri Bartlett

FIGURE 9-1 EXAMPLES OF TEXTILE DESIGNERS WORKING WITH THE CO2 LASER

9.2 PREVIOUS PROJECTS WITH THE LASER WELDING PROCESS

9.2.1 Altex: Automated Laser Welding For Textiles

In Europe several tens of millions of workers operate in dangerous environments and require protective clothing. Additionally there is a large market for outdoor waterproof sports and leisure wear.

In these applications highly engineered fabrics provide a barrier to particles, liquids or gases. The main limitation however is the joining of these fabrics as sewing penetrates the material and resealing is required in a second taping process. Alternative sealing methods using hot melt adhesive tape are emerging, but these all use an additional layer between the fabrics at the seam. The current procedures are time consuming, highly labour intensive and the use of tape is limited in applications using complex 3D seams. Additionally, because of the limited peel strength of taped seams and the continuous bending of the joints during use as well as maintenance and washing, the sealed seam often delaminates.

Laser welding offers a method of making sealed seams without using additional film at the joint. The process melts a thin layer of the fabrics without affecting the outer surfaces by transmitting the laser energy through the outer fibres. The process is also suitable for automation. This results in a joint that has a greater flexibility and softer feel than is made with other welding methods. The outer texture of the fabric is also retained.

The aims of this project were to develop equipment, textiles and procedures for manufacturing textile products based on recent laser welding process innovations. Laser welding allows sealed seams to be made for applications such as outdoor clothing, with the potential for a reduced number of process steps and improved reliability, consistency and security compared to alternative techniques. The process is also suited to automation and would potentially fit into a fully automated production line for garment or other textile product manufacture such as bed manufacture.

Demonstration garments have been prepared in polyester fabrics of two types; a black fleece jacket including welded zips and a plain woven shirt. The welding was carried out on a flat bed system with manual positioning of the pieces. [44]

In the work described below, the use of laser welding in the fabrication of textile products, specifically protective garments and mattresses was examined. Existing waterproof textiles have been welded, producing seams that meet the industry requirements for strength and water resistance. Textiles more suitable for laser welding have been specified with suitable laser transmission and polymer compatibility properties.

The use of laser welding and the prototype welding station for the manufacture of garments and bed mattresses was successfully demonstrated in the following applications:

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[44] ALTEX

- The body of a waterproof jacket with seams sealed in one welding operation instead of stitching and taping
- The hood of the waterproof jacket, demonstrating the shaping of a 3D shaped seam form using a moulded support
- The border of a mattress allowing the weld to be made in situ on the mattress, and solving the problems of matching the size of the border to the mattress

Further developments are being considered to integrate the automated laser welding station into a garment prototype production line.

9.2.2 Leapfrog

TWI also carried out a project in collaboration with Coleg Sir Gar to develop alternative joining methods for garment manufacture. The project was funded by the Knowledge Exploitation Fund, European Social Fund and the European Regional Development Fund, and involved design, construction and commissioning of a unique textile welding machine which includes three thermal joining techniques: transmission laser welding, direct laser welding, and ultrasonic welding.

Leapfrog was a joint research and innovation initiative of the European textile and clothing industry, led by Euratex, aiming at a technology breakthrough in the clothing industry. It brought together a critical mass of European textile and clothing companies and research centres which will attempt to develop and implement new ways of:

- fabric preparation for clothing production
- automated garment manufacture
- virtual garment prototyping
- supply chain integration and mass customisation.

Original work using Clearweld concentrated on garment joining applications, making traditional stitching in products like gloves, fleeces, jackets and shirts a thing of the past. Since those early days the process has been adopted for making airbags, inflatable buildings and foam-backed upholstery products.

> The future of textiles manufacture may well include automated stitching machines with robots for picking, handling and seaming fabrics for garments-making, as is being developed in the European Leapfrog project. Ultimately automated laser seaming is expected to become important for outerwear and other areas particularly where sealed seams are required.[45]

[45] (Coleg Sir Gar, 2007, p1)

Examples of laser-welding projects, ALTEX and LEAPFROG

Photography: TWI

FIGURE 9-3 EXAMPLES OF LASER WELDING PROJECTS, ALTEX AND LEAPFROG

9.3 SYNTHETIC FIBRE PRODUCTION & CONSUMPTION

Key statistics referenced throughout the thesis relate to research from 'The Fibre Year 2010', Engelhardt. (pp88-89)

Total World Fibre Production in 2009 was 70,526,000 tonnes
Natural fibres represent 37% of this (26,392,000 tonnes)
Of which 25,191,000 tonnes are cotton (36% of total)
Man-made fibres represent 63% of this (44,134,000 tonnes)
Of which 40,338,000 tonnes are synthetic (57% of total)
And 3,796,000 tonnes are cellulosic (5% of total)

Polyester fibre represents 31,867,000 tonnes
(45% of total world fibre production & 79% of world synthetic production).

9.4 EXAMPLE PAPERS & ARTICLES FROM THE THESIS

9.4.1 Without a Trace (see pages 199-206)

Jun 2010 Without a Trace, Commissioned article for Viewpoint Magazine, Issue 26; The New Normal (co-authored with Dara Lang) pp108-115

9.4.2 Borrowed Materials (see pages 207-215)

Oct 2010 Sustainability in design: NOW! Challenges and opportunities for Design Research, Education and Practice in the 21st Century, Proceedings of the LENS Conference, Bangalore, India Greenleaf Publishing, London ISBN-13: 978-1-906093-54-9

Without A Trace

Knowledge about sustainability within the design and fashion industries is now widespread; a growing number of designers are going one step further and embracing Cradle-to-Cradle principles which consider a product's lifespan from beginning to end, report Dara Lang and Kate Goldsworthy

Over the past decade, the fashion, furniture, food and beauty industries have had to evolve to meet the rapidly changing demands of a planet and people newly alert to environmental threats and the human role played in these. Issues that have come to the fore include recycling, reuse, waste, carbon emissions, natural versus synthetic, and organics. Yet products with elements that are non-biodegradable or that cannot be reused are still ending up in landfill.

The Cradle-to-Cradle (C2C) movement, however, is fast gaining ground, as industry seeks to produce goods that leave minimal trace. C2C production is based on natural systems that eliminate the very concept of waste. All materials are viewed as continuously valuable, circulating in closed loops of production, use and recycling. C2C is gathering momentum and promises to become the New Normal in sustainable design.

'We have left an era dominated with overly done, striking and unusual designs,' says Merel Kokhuis, managing editor of Frame magazine. 'Cradle to Cradle is an emerging trend that has surfaced as a result of a recession and global warming. Designers are looking for other ideas and C2C is the natural step forward.'

The term Cradle to Cradle was first coined in the 70s by Swiss architect Walter R Stahel, and the concept was refined at the beginning of the new millennium by German chemist Michael Braungart and architect and designer William McDonough. Braungart and McDonough promised a new way of thinking about 'making things' in their collaborative publication the Hannover Principles, which they followed in 2002 with Cradle to Cradle: Remaking the Way We Make Things; the book has been reprinted many times and is now a cult read.

'C2C is a dialogue that celebrates new design and creativity,' says Braungart. 'Designers want to be key changers for innovation and C2C is the way. It gives designers more self-esteem, it makes us proud to be engineers, and it honours a beautiful shift in design. We don't need luxury any more; that's what we used to want. C2C provides quality, it encourages people to think aesthetically. It means that good design doesn't need to sell cheap. It can be less expensive but still maintain good qualities.'

C2C begins with the initial design process. C2C principles mean ensuring that all materials involved can be re-used or returned to the soil with no toxicity issues. It envisions buildings to be, like trees, net energy exporters that produce more energy than they consume, that accrue and store solar energy and that purify their own waste water. When C2C products have been used, they either return to the industrial cycle, supplying high-quality raw materials for new products or, alternatively, decompose harmlessly in landfill to become food for plants and animals, while replenishing soil.

To help brands meet these conditions, McDonough and Braungart have introduced C2C Certification, a protected term of McDonough Braungart Design Chemistry (MBDC) consultants. This provides brands with the opportunity to be evaluated and certified according to C2C principles. The ranks of those seeking certification are burgeoning, as companies and designers begin to realise the environmental, cost-efficient and marketing potential of C2C. Brands such as Nike, Puma, Philips and Kodak and designers such as Tom Dixon, Yves Béhar and Gwenael Nicolas have already begun to adopt this sustainable approach.

'C2C is one of the success stories – two people who have shown that you can design and manufacture things people want, while doing less damage to the environment and still making a profit,' says Maja Kuzmanovic, founder of FoAM, a Brussels-based multidisciplinary research group consisting of designers, scientists, cooks, artists, engineers and gardeners who aim to integrate sustainable design and eco-technology into new public contexts. 'I think C2C is becoming increasingly popular because McDonough and Braungart have good business sense, good timing and the scientific and design knowledge to back their ideas.'

In early 2009, Aveda became the first beauty company in the world to receive C2C sustainability endorsement from MBDC and its affiliate, the Environmental Protection and Encouragement Agency (EPEA), based in Hamburg, Germany. The certification system covers four standards, Basic, Silver, Gold and Platinum, and seven Aveda products are currently certified at Gold level. These

Key C2C Approaches

ULTRA-BIODEGRADABLE
Designing with materials that biodegrade back into the environment without leaching harmful dyes and chemicals

MONO-MATERIALS
Simple use of one material makes for a cleaner path to recycling

DESIGNED DISASSEMBLY
Clever construction methods that use bindings and fixings rather than glues or metal fasteners ensure easier reuse and recycling

UP-CYCLING
Adding value to materials through redesign

CLOSED-LOOP
Design using materials that can be infinitely recycled without compromising quality

Opposite (from top): Organic Factory by Giles Belley, gillesbelley.fr

'Brindille' (twig)
The 'Brindille' home perfume concept consists of a 'twig' and a plate made of agromaterials. The twig dissolves, releasing aromatic molecules and a light perfume, when it comes into contact with water placed in its dish. 'Brindille' can be cut into pieces; longer pieces diffuse for a longer period of time.

'Colline' (hill)
'Colline' is an organic fertiliser system which models the erosion process and contains seed mixed with agromaterial. Buried in a pot and watered, after several days 'Colline' releases both seeds and nutrients, and the nutrients continue to feed the plant throughout its growth.

'Plaine' (plain)
'Plaine' is an organic fertiliser system placed on the earth in a pot. Water slides over it, gathering nutrients, and seeps down to moisten and enrich the compost in the pot. 'Plaine' is eroded and dissolved by water, further releasing its nutrients.

'C2C gives designers more self-esteem, it makes us proud to be engineers, and it honours a beautiful shift in design'

Michael Braungart, co-developer of Cradle-to-Cradle theory

include its Smooth Infusion shampoo and conditioner, which contain C2C-certified biological nutrient ingredients such as Australian sandalwood oil and Brazilian uruku pigment. Aveda has also achieved Silver designation for its packaging, which is deemed to meet technical nutrient requirements, can be reused, and uses 100% wind energy during manufacturing. 'Aveda has been at the forefront of the environmental movement within the beauty industry since its inception and they continue to innovate by fully embracing Cradle-to-Cradle design,' says Braungart.

Designers and brands interested in following the C2C route can take one or all of various different paths. These could include: creating products made with single materials untarnished by gloss or paint; making packaging and goods which are entirely biodegradable; replacing traditional bindings and fixings such as glue and metal screws with removable, biodegradable or reusable elements; and engaging in considered design that envisions a second life for products once their initial use has been fulfilled.

The following examples are not all C2C certified, but are design approaches which fit C2C's guiding principles.

BACK TO THE ROOTS

Designing with materials that biodegrade harmlessly back into the environment is the most fundamental C2C principle. However, this is not straightforward; all materials derived from living sources, both animal and vegetable, are 'biodegradable', but few decompose in an ecologically safe manner if dyed or finished with chemicals. For example, a brochure fixed without glues and printed with vegetable dyes is C2C compliant; the same brochure overlaid with even the smallest amount of gloss or metallic finish is not. Designers are therefore exploring some extraordinary approaches to achieve high design that's environmentally considerate.

Dutch product designer Bas van der Veer's bioplastic planters use the biodegradable qualities of a renewable biopolymer. When a tree is planted, the planter protects it from falling over and will gradually biodegrade in the soil. Eventually it will return to nature completely, while feeding the tree at the same time. 'The bioplastic planter is a way of replacing [common] plastics with renewable plastics,' says van der Veer.

Designer and researcher Suzanne Lee has been collaborating with materials scientist Dr David Hepworth on the use of laboratory-grown bacterial-cellulose to produce clothing. The fibre is formed in a vat of yeast and sweet tea, and, when dried, forms a compact, leathery, papyrus-like substance. Colour is added using simple food substances such as turmeric, port, curry powder and cherries. Lee's 'Eco Kimono', made from bacterial-cellulose, was shown at the recent Warp Factor 09 exhibition at Central Saint Martins College of Art and Design, where Lee is a senior research fellow. Lee was inspired by an ancient Japanese technique for waterproofing paper to bring the material one step closer to a wearable solution; it is water- and bug-resistant, completely organic and biodegradable.

Wasara is a collection of beautifully designed disposable tableware created by Japanese designer Shinichiro Ogata. Disposable usually implies the opposite of environmentally friendly; however, Wasara is uniquely produced using common waste materials rather than wood pulp. The collection is made from reed pulp, bamboo and bagasse (waste sugarcane fibre) and is fully biodegradable and compostable.

Organic Factory is a series of domestic objects made of agromaterials by French product designer Gilles Belley, the winner of last year's Bource Agora award. Belley's objects, influenced by natural forms, are made from agricultural waste and are biodegradable; agromaterials can replace petroleum-based plastics.

Bio denim jacket (opposite, top) and 'Bio Bomber' (below), by Suzanne Lee, biocouture.co.uk (photography by Gary Wallis)

Opposite, below: 'Ever and Again' shirt by Rebecca Early, beckyearley.com

'Autarchy' by Studio FormaFantasma, formafantasma.com

American company Brooks Sports designs and markets running apparel. Its 'Green Silence' shoe features the company's BioMoGo, the world's first biodegradable running-shoe midsole, is made using 75% post-consumer recycled materials, water-based adhesives and non-toxic dyes, and is packaged using 100% post-consumer recycled materials.

At Milan Design Week 2010, Studio FormaFantasma presented the 'Autarchy' installation, which featured kitchen vessels and lampshades created from a bio-material composed of 70% flour, 20% agricultural waste and 10% natural limestone. The mixture was dried and baked at low temperatures and the items were coloured with natural dyes made from vegetable matter and spices. Each harmlessly biodegradable item featured a unique colour and pattern.

BASIC NEEDS

Design simplicity reduces the need for unnecessary materials, weight and manufacturing processes. Using single or mono-materials to create products is one of the most effective ways to ensure a clear post-use path, for example by making recycling easier. Designers are rediscovering traditional crafts to pursue a simpler way of making, using a simple palette of materials.

Designer Tom Dixon has long explored minimal-impact furniture and homewares. Dixon leads the field with the launch of his biodegradable bamboo fibre dishware and his extrusion machine, which seeks to avoid the waste that is often a by-product of furniture production. Dixon's 'Offcut' series features a newly launched bench made from the irregular wood found just beneath a tree's bark, generally discarded in mainstream wood production. The bench's construction requires no screws or glue and is flat-packed for easy delivery. The natural-finish version of the bench is made from oak treated with soap. A clear example of C2C design simplicity, the 'Offcut' range can return to the environment completely safely.

Swiss designer Florian Hauswirth's latest design is the 'Just Wood Chair 2' ('JWC2'), a stackable dining chair made exclusively from wood using dowel-welding construction and natural colour treatment. German furniture company Oliver Conrad has created a new line of stools and tables that celebrate wood in its natural state. A collection of coffee tables is made from a single piece of solid oak, simply oiled; the wood's cracks and imperfections lend the stools their unique character. Conrad's 'Firewood' stool binds together a bundle of rough-cut logs with natural surfaces free from chemical treatments.

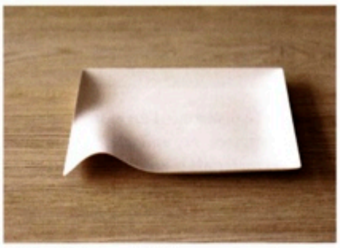
Much of C2C production harks back to traditional construction. At the same time, however, new technologies are pushing the boundaries of manufacturing as we know it. Rapid manufacturing, the making of complete objects by additive or layering processes from digital 3D data, is beginning to reshape the production landscape. Rapid manufacturing is poised to change the way products are designed and made, and our relationship with them as users and consumers. According to Geoff Hollington, leading designer and consultant, rapid manufacturing is a 'radical and disruptive technology with the potential to transform both the global economy and consumer society'.

The Freedom of Creation design and research company is at the forefront of this arena, designing a huge portfolio of products from a small menu of mono-materials. As well as envisioning the future of recycling, this system offers other benefits. It is now a viable alternative to mass manufacturing, transportation and storage. Information can be stored and transmitted digitally and items can be produced on demand. This has wide implications for environmental impact and sustainability, providing suitable raw materials can be developed and linked back to an efficient recycling system.

UK-based Fabrican, directed by Manel Torres, is embracing another novel additive-based manufacturing process: spray-on fabric. The innovative technology was originally developed for spraying a fine mist of coloured cotton fibres onto hard and soft surfaces and now includes synthetic fibres. As well as a tool for repair, the future potential of this type of construction offers a reversible process that could allow materials to be dissolved after use, again closing the production loop.

DESIGN FOR DISASSEMBLY

If designing with a single material proves too restrictive, designing products that



Disposable tableware by Wasara, wasara.jp

Bioplastic planter by Bas van der Veer, basvanderveer.nl

can be dismantled for easier maintenance, repair, recovery and reuse of components and materials is another option. Increasing numbers of designers are creating products that can be easily disassembled and recycled piece by piece.

Swedish designer Ake Axelsson's 'Wood' is an elegant, lightweight chair made from local red beech sourced from sustainable forests, for the Gärsnäs furniture company. 'Wood' is not 100% mono-material, as some fixings and screws are used in construction. However, the chair is packed disassembled, to reduce shipping costs; volume accounts for 80% to 90% of these for a normal chair. Reducing shipping volume also reduces carbon footprint. Surface finishing is optional but, if desired, the chair can be treated with wax or an eco-labelled stain.

Swedish design duo Mattias Karlsson and Erik Björk of Karlsson & Björk also create beautiful pieces using simple, elegant construction techniques. Their 'Hella' chair features leather fabric woven onto wooden poles, which make up the backrest of the chairs; the two materials are easily separable or updatable.

Gearoid Muldowney's Dublin-based Superfolk studio uses locally sourced Irish woods in a furniture series that can be refashioned according to the user's needs. Superfolk's stools, made from sustainably managed oak and ash, are laced together and can be combined in various arrangements to create benches, tables and foot rests. In a similar vein, Japanese designer Yukari Hotta's 'KILE' shelving system is assembled using wooden wedges, with no need for metal fasteners.

UP-CYCLING

Down-cycling is recycling a material in such a way that much of its inherent value is lost. An example is recycling plastic bottles into lower-grade plastic used to make park benches. Eventually quality is lost to such a degree that landfill is the only option. For this reason, 'up-cycling' (adding value through redesign) has become the new goal, as designers find novel ways to embed products with reuse potential and extend the life of existing products without degrading quality.

Polyester is an ultra-recyclable material choice. A polymer, it can be designed into truly closed loops and taken back to its chemical components repeatedly without losing value. To achieve this, polyester products are first broken down into small pellets, which are then chemically 'decomposed' and returned to the raw material. This system of recovery, EcoCircle, was developed by Japanese chemical and pharmaceutical company Teijin. Teijin claims that, unlike mechanical polyester recycling processes of the type used to transform water bottles into fleece fibre, EcoCircle can recycle infinitely without any loss in quality. This remanufacturing process consumes 84% less energy and emits 77% less carbon dioxide than the processing of virgin fibre, even taking into account transportation to Japan for recycling.

Fashion and textile designers such as Rebecca Earley, reader in sustainable design at Chelsea College of Art and Design's Textile Environment Design research cluster, have been working with such techniques. Earley's Top 100 project is a collection of reclaimed, reworked and reprinted polyester shirts that can be fully recycled. The potential for this recycling technology in creating true closed loops for non-renewable resources is invaluable and points towards the potential of a truly self-sustaining polyester economy. Many global companies are now working with this system, including Patagonia, which collects redundant garments in-store for its Common Threads recycling programme. Howies and Finisterre have introduced similar initiatives

Nike's Considered shoe line was designed with embedded reuse in mind. The shoes are made without adhesives of any kind, to reduce toxic effects not only on the environment but also on factory workers. They are made from materials sourced within 200 miles of factories to reduce fuel consumption, and are designed to disassemble totally for easy recycling. The Considered shoe even uses vegetable-tanned leather, to eliminate toxic chromium waste. Nike aims to meet and exceed the baseline standards set in its sustainability index by 2011, to include all apparel by 2015 and Nike equipment by 2020.

With major brands such as Nike and Aveda embracing C2C production methods such as re-use, disassembly and biodegradability, it seems certain that this growing design ethos will be one of the key influences and trends of the coming decade. Yet there is a note of warning to be sounded. Kuzmanovic suggests that viewing C2C as a 'rising trend' could be dangerous. 'Trends are fashions, they come and go,' she points out. 'In the 1990s there was a passing trend in eco-fashion which may have done more damage than good in making the public and the industry environmentally conscious.' As Kuzmanovic notes, people easily become bored with fashions and start looking for the 'next big thing'. 'Some of the ideas and techniques that C2C subscribes to should not go out of fashion if we are to adapt to environmental and economic turbulences of the coming decades and beyond,' she says. 'These concepts should become the core of the design process.'

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c2ccertified.com
basvanderveer.nl
biocouture.co.uk
wasara.jp
gillesbelley.fr
brooksrunning.com
formafantasma.com
tomdixon.net
florianhauswirth.ch
oc-moebel.de
freedomofcreation.com
fabricanltd.com
akeaxelsson.com
karlssonbjork.se
superfolk.com
yukarihotta.com
teijin.co.jp
upcyclingtextiles.net

'JWC2' chair by Florian Hauswirth, florianhauswirth.ch (photography by Philipp Hänger)

Borrowed materials

Laser-finished textiles for a closed-loop polyester economy

Kate Goldsworthy
Central St Martins College of Art & Design, London, UK

In order to design for closed-loop (cradle to cradle) systems where waste materials can become inputs for new production, the textile industry needs new tools and processes with which to create fully or truly recyclable products.

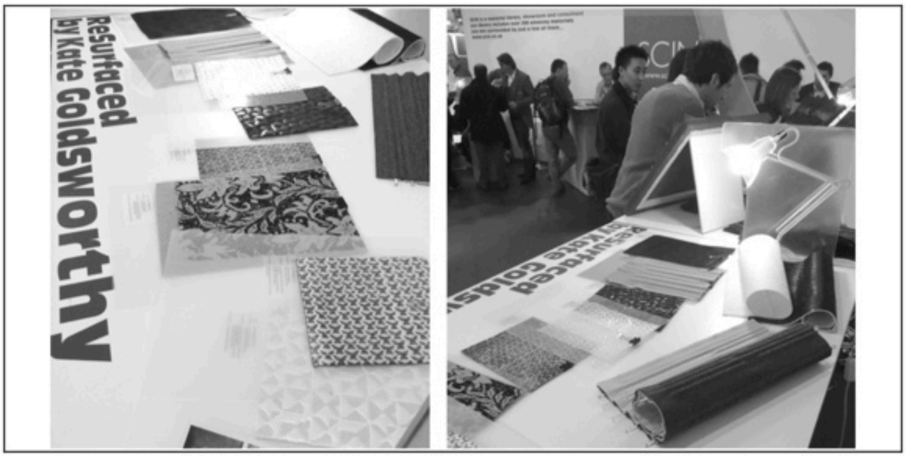
However, rather than being cyclical and self-perpetuating, the current means of textile production are linear and one-way. Finishing processes often mix materials from different 'metabolisms' creating complex hybrids that are irreversible. With this ever-increasing demand for performance and functionality, it is the design of these products that prevents them from being effectively recycled and leaves us with a legacy of waste (Allwood et al, 2006).

This practice based research project set out to explore innovative technologies that afford new opportunities for textile finishing, with a particular focus on the recyclability of synthetic thermoplastics. Polyester, the most common textile synthetic fibre, represents as much as 60% of global fibre production (Morley, 2009) and can be recycled repeatedly without loss of quality if kept 'pure'.

The research concluded that there is potential for 'design for recycling', enabled through a new set of technological processes, specifically 'laser-welding.' This new technique facilitates the production of complex and functional products that maintain their monomaterial credentials, which are essential if they are to be fully recyclable.

Figure 1: Samples shown at Green Scin, the materials experiment, March 2009

Source: author



Applying Cradle to Cradle (C2C) Design Principles to Textiles

Current textile Recycling

Over the course of the last decade, the fashion and textile design industry has been evolving to meet the fast-changing demands of consumers newly alert to the environmental impacts of their purchases. Recycling, once a niche, craft activity has become more common and sits alongside other corporate initiatives that attempt to reduce waste, carbon emissions or toxic chemicals from a products lifecycle.

> In times of textile raw material scarcity, (and rising population) the recycling of end-of-life textiles has become a necessity, and craftsmen and industry are viewing textile waste as a valuable resource. Legislation around disposal and producer responsibility (take-back) make it increasingly important to develop processes to design textiles that are easy to recycle. (Gulich, 2006)

However the eventual result, no matter the intention, are products that can no longer be reused and so end-up in landfill.

> Recycling by itself, only postpones the arrival of the discarded material at the landfill, where it may never biodegrade, may biodegrade very slowly, or may add harmful materials to the environment as it breaks down. A genuinely sustainable future depends on creating closed loops, or cycles, for all industrial commodities, including polyester. In a closed loop, materials would never lose their value and would recycle indefinitely. (Livingston, 2003)

A Cradle to Cradle Approach

Designers have been addressing this problem and seeking to produce better, more sustainable ways of working, using Cradle-to-Cradle (C2C) design principles based on natural systems that eliminate the very concept of waste. All materials are viewed as continuously valuable, circulating in closed loops of production, use and recycling. It is a movement that has the potential to move recycling systems from a limited 'extended life technique' to that of truly perpetual material flows which retain value through each reincarnation.

First coined in the 1970's by Swiss Architect Walter R. Sahel, the term C2C was refined at the beginning of the new millennium by German chemist Michael Braungart and architect and designer Michael McDonough, who promised a new way of thinking about "making things" in their collaborative publication the Hannover Principles, which they followed up with Cradle to Cradle: Remaking the Way We Make Things in 2002. A book that has undergone many reprints and is now a cult read.

Designers working to this end can adopt many different approaches, but the central theory involves diving all materials into two main systems, biological or technical.

1. Biological materials can be returned to **biological cycles** (the earth) where they harmlessly decompose and become food for plants and animals while rebuilding nutrients in the soil.

2. Technical materials can be returned to **industrial cycles** (manufacture) when no longer useful, thereby supplying high quality raw materials for new products.

Box 1: Principles of cradle to cradle design

Source: Developed from McDonough & Braungart 2002

> The overarching mantra of C2C is waste equals food; a principle, based on natural systems, that eliminates the very concept of waste. All materials are viewed as continuously valuable, circulating in closed loops of production, use, and recycling. To adopt these principles designers need to acknowledge two defined material metabolisms within our material landscape and design intentionally for one or the other.

The Designers Role in Facilitating Recycling

C2C is a dialogue that celebrates new design and creativity. It is a methodology which, rather than focussing on logistics and technology to solve our resource problems, places the designer at the centre of the solution (Goldsworthy & Lang, 2010).

> Generally it is the designer who decides on the structure of a product and the best materials to use, taking function and budget into consideration. The materials chosen have an influence on the process of manufacturing as well as on the process of recycling and disposing the product at end of life. Indeed they predetermine all these processes. (Gulich, 2006)

For textile designers this means two very different approaches for working with either natural or synthetic materials at all stages of the production cycle. In the case of biological (natural) fibres the key concern is to prevent use of any chemicals, which would cause harm if they were leached into natural systems as material is returned to the earth through biodegredation. For synthetic materials the priority is to design products, which can be effectively recycled in perpetuity without loss of quality.

There are several approaches, which can be used to complement this overarching design strategy:

Box 2: Complementary Approaches to cradle to cradle design

Source: Developed from McDonough & Braungart 2002

Design products which are:

- ULTRA-BIODEGRADABLE: Designing with materials that biodegrade back into the environment, without leaching harmful dyes and chemicals.
- MONO-MATERIAL: Simple use of one material makes for a cleaner path to recycling.
- DESIGNED FOR DISASSEMBLY: Clever construction methods that use bindings and fixings without the need for glues or metal fasteners ensure easier reuse and recycling.
- UP-CYCLED: Adding value to materials through redesign.
- CLOSED-LOOP: Design with materials that can be infinitely recycled without losing quality.
- USE APPROPRIATE MATERIALS: Take advantage of the natural characteristics of materials. By selecting materials wisely in this way designers can avoid harmful additives.
- DESIGN TO AVOID DOWNCYCLING: The practice of recycling a material in such a way that much of its inherent value is lost (for example, recycling plastic into park benches). This could include temporary reformations / upcycling / designing to embed reuse.

B. Gulich (Wang, 2006, p27) suggests 'designers should keep in mind how a product, meant to be sold tomorrow, can be recycled or disposed of the day after tomorrow', suggesting that a designer has the power to 'design in' recyclability at the beginning of the creative process. He goes on to suggest that one way of doing this may be the development of single polymer design or single material systems. Products consisting of only one material are 'pure' and easy to re-use. It is not generally necessary to deconstruct the product prior to reprocessing.

However, this suggests a paring down and simplification of design and construction not always appealing to the designer or indeed the consumer. Is it possible to create textile products pure enough in construction to enable recycling yet complex enough to vary in function and aesthetic?

Opportunities & Barriers for a Closed-loop Polyester Economy

Repolymerisation of polyester

Polyester is a common textile material, from the technical cycle, representing as much as 60% of global fibre production (Morley, 2009) and as such needs to be preserved as a recyclable resource. In a 2003 report, US based furnishing supplier Designtex described their vision of a closed-cycle polyester economy, where all polyester fabrics are recycled perpertually.

At this time, repolymerisation of polyester fabrics had been successfully trialled but was not yet commercially available. However, this changed in 2005 when Teijin launched their EcoCircle system in collaboration with pioneering sportswear brand Patagonia and the polyester economy became a viable scenario.

The process works by reclaiming the valuable chemicals embodied in the waste polymer, which is then used to make new virgin-quality materials. Unlike other material recycling, this breakthrough technology represented a measurable reduction in CO2 emissions and energy use, when compared with production using virgin resources, and could be repeated without loss of material quality.

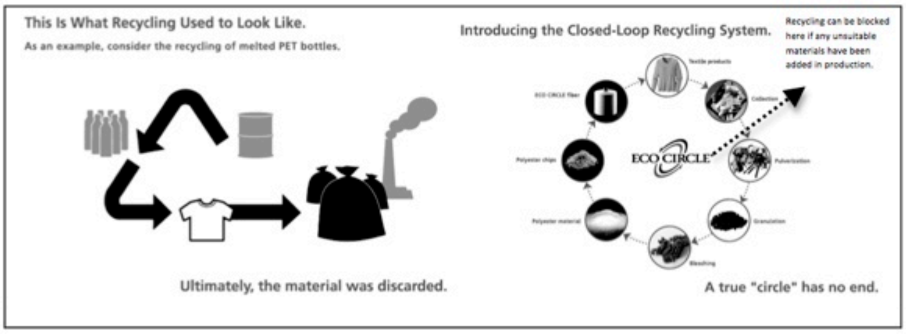
If polyester textile products were kept 'pure' and preserved as monomaterials during their production they could be returned, thus avoiding landfill or downcycling, as often was the case.

The environmental argument for recycling polyester

> The widespread use of recycled polyester is a benefit to the environment because it conserves non-renewable resources and reduces the release of harmful emissions into the biosphere. This is primarily accomplished by reductions in the amount of energy and oil needed to make virgin polyester, along with reductions in the accompanying releases of greenhouse gases into the atmosphere. (Livingston, 2003

Figure 2: EcoCircle polyester recycling process

Source: Diagrams courtesy of Teijin Fibres Ltd, www.ecocircle.co.jp



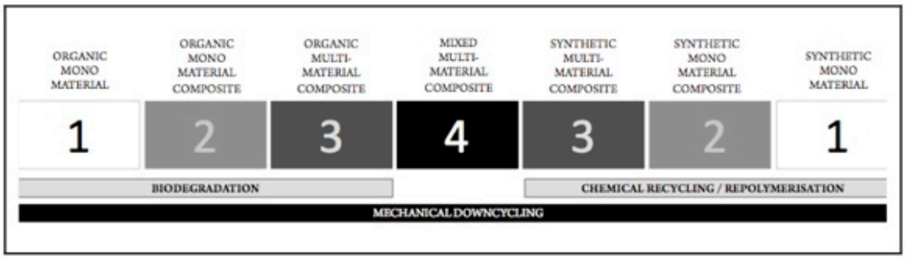
Barriers to the closed-loop recycling of polyester

Many textile processes, nonwoven constructions, chemical finishing processes, coating, lamination and composite materials render products unsuitable for recycling and destined for landfill (Horrocks and Anand, 2000). For example furniture manufacturers often apply their own specifications for finishing fabrics before they are installed on seating and architectural products. The processes used in finishing the fabrics often include chemical backings, which are contaminants, most of which in use today are incompatible with breaking down polyester and repolymerising it.

This is also true of many finishes used in the garment industries, including trimmings and fixings. But we cannot simply remove these finishes from use. They are an essential part of the textile industry and have been at the core of many innovative textile products during the last decade. For example, coating and lamination offer methods of improving and modifying the physical properties and appearance of fabrics and also the development of entirely new products by combining the benefits of fabrics, polymers and films. However these finishes also move a material from its most easily recyclable construction (a monomaterial) to a multi-material composite, which is impossible to recycle with current technologies.

Figure 3: Recyclability of material constructions based on Wang, 2006

Source: author



Fashion cycles continue to move in ever decreasing cycles, requiring quicker turn around time, and a quicker response to market changes and fluctuations. European fabric and garment producers are all seeking ways to achieve greater operational flexibility, in order to respond to this more demanding market. There is also much talk of individualisation, fragmentation and personalisation within the consumer market. It has to satisfy not only the traditional demands, of being fashionable, and practical, but must also appeal on a more subjective and emotional level. There is also the very important need to produce a more environmentally acceptable product in a sustainable manner, and to be able to dispose of it or recycle it correctly. Manufacturers are greatly concerned with the effective use of energy and materials, plus the need to shorten capital cycles, factors of interest in all areas of textile and garment production.

These challenges are encouraging investigation into what finishing treatments can offer, how they may be able to assist in meeting these demands, whilst producing a textile or garment that appeals to both the objective and subjective demands of the consumer.

The finishing of a fabric is now equal, or in some cases more important than the fibre or the construction, and can often be a quicker and cheaper method of introducing different design features and functions into a textile. Through finishing techniques, fabrics can now take on new aesthetics and functions. They can be manipulated to be hard, soft, shiny or matt, they can be moulded, they can protect, and they can now also be bio-active and interactive. New ways of combining textile layers are introducing performance composites capable of a wide range of functions and responses.

> The finishing of a fabric, the final stage in it's making, is fast becoming as important as it's construction: it is also where the look, texture and performance can be dramatically altered. Treatments include holographic laminates, silicone coatings and chemical finishes which devour surfaces they come in contacts with. (Braddock-Clarke, 1998)

So there is a paradox between keeping a textile 'monomaterial' and recyclable and the need for innovative finishing to add aesthetic and functionality to fabrics. This project set out to find an alternative way to impart these finishes to polyester textiles without making the resulting materials incompatible with repolymerisation.

The Laser as a Tool for Clean Textile Processing Techniques

The challenge was to find ways of manipulating the surface of polyester, a thermoplastic material, which could dramatically alter the surface aesthetic without the need for toxic chemicals or adhesives, thus preserving recyclability.

Lasers create heat and when used with thermoplastic materials cause melting. This creates the potential for various surface effects to be achieved without the adding of any other materials – simply by controlling the way the laser interacts with the material. During this project I explored the potential for a new series of finishing techniques using the laser with 100% recycled polyester.

The Use of CO2 Lasers for Environmental Benefit

Lasers are certainly not new in the textile industry: Other designers have explored the potential of innovative laser finishing with regards to environmental benefit.

Janet Stoyel was one of the first designers to establish the laser as a finishing tool for textiles with her company 'Cloth Clinic' started in 1994. In particular her work to explore the devore process through laser finishing, uses no dyes, no chemicals, no wet finishes and no stitch. Devore is a particularly renowned pollutant, generating chemical and colour waste and also generating large quantities of fibrous sludge. Of her innovative work in textiles Janet has written:

> By inventing futuristic processes and harnessing the latent design potential of Photon Laser and Ultrasound technology, I realise permanent effects on materials in an environmentally holistic manner, without dyes, chemicals or wet applications, challenging conventional material concepts through the ultimate marriage of engineered materials and technology. I exploit the characteristics inherent within a material, changing molecular structures, alchemically transforming surfaces (Stoyel, 2009)

Anne Smith's Altered States project (1998-2000) also explored the potential of laser cutting and etching technology, as a method for environmentally low impact methods for producing decorative effects on fabrics. The project focused on the exploration of the aesthetic and commercial viability of the application of laser cutting and marking technologies to interior, furnishing, fashion and accessories materials, and resulted in a patent on the 'application of laser cutting and marking technologies to generic flooring materials'.

Savithri Bartlett's doctoral research project, completed in 2006, at Loughborough University School of Art and Design (LUSAD), accepted the challenge to archaic fabric printing technology by suggesting an innovative route of dye uptake and surface design of textiles. The use of lasers as a means of controlling dye uptake at the surface of textiles was achieved by changing the quality of the material surface, thereby controlling colour intensity achieved during dyeing.

Adapting Laser Welding as an Innovative Finishing Tool

For my own doctoral research I have been concentrating on the area of 'laser welding' as a process for investigation. Laser welding was identified as an area of potential innovation for textile finishing and explored through a collaborative investigation with TWI, an engineering research facility based in Cambridge. The resulting material samples illustrated many new finishing and resurfacing techniques. Some were replacements for traditional methods and others, were completely new processes, which would be unattainable with conventional tools. Recyclability is preserved, while aesthetic, function and innovation retain priority in the design process.

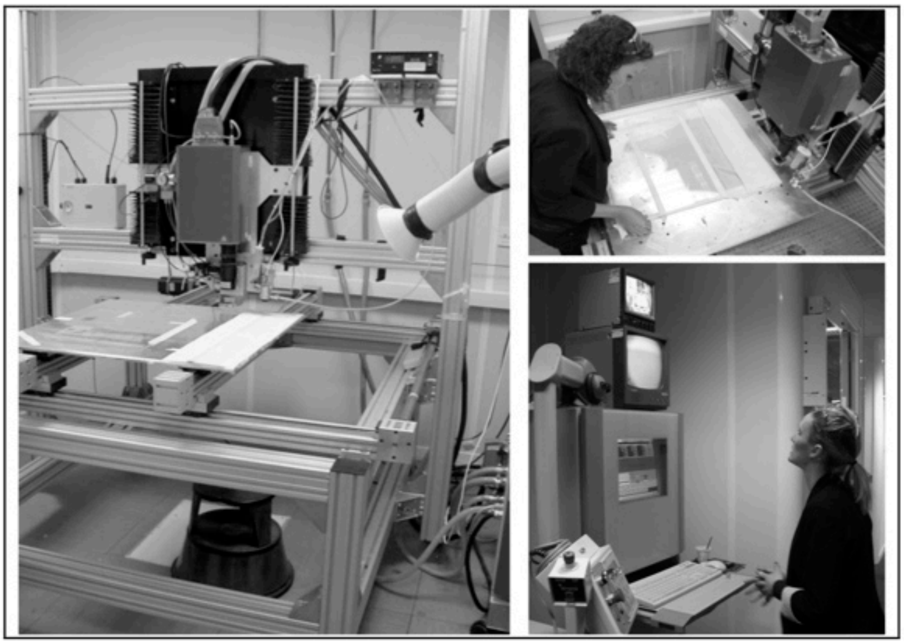
One of the key advantages of this technology over the more commonly used CO2 lasers is that they work with a much lower energy consumption and are more controllable which enables complex effects to be designed into a single process. The potential for the use of laser welding to increase the productivity and quality of welded seaming of fabrics for garment production has been previously explored, but my focus was on the surface finishing of the fabric.

Experiments: Exploring Technology with a Craft Approach

The practice based research was designed very much as a 'design' process. Working closely with a technical specialist, also trained as a designer, enabled a hands-on, craft approach to be used with experimentation based on action and reflection throughout the study.

Figure 4: Working at TWI during PhD project, 2009

Source: Images courtesy of The Science Museum, London



Materials were sampled and further tests designed according to the results, which were often unexpected.

> Traditional makers form an in depth understanding of the materials and tools that they work with, through various combinations of hands on experience, and technical/scientific understanding. Through this dialogue with materials and processes they are able to develop an individual aesthetic, a personal visual vocabulary. (Masterton, 2005)

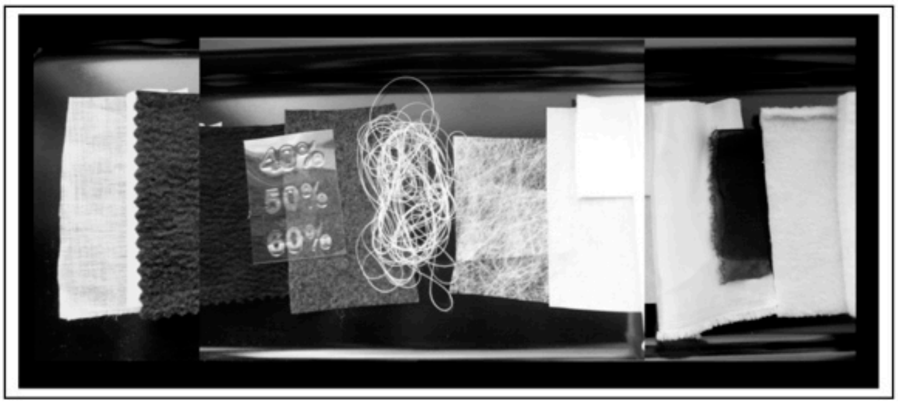
There were several stages to the experiments:

- finding ways to overcome the limitations of the available equipment
- optimising settings for mark making and welding with the chosen materials
- identifying and exploring finishing techniques which could be achieved through this process

I used many different constructions of polyester materials in the tests; knitted, woven, nonwoven, yarn, monofilament, sheet and fibre. This enabled maximum variation of results whilst still retaining 100% monomateriality.

Figure 5: Various polyester substrates used during experimentation

Source: author



The various fabric constructions and weights varied the type of effect or mark that could be achieved through the application of the laser. These ranged from a single layer transparency effect to a much more complex construction on multiple layers bonded without any surface marks – and a variety of effects between the two.

Results of Experimentation

After initial testing I designed the study to investigate 3 main approaches:

- Multi Layer Composites
- Single Layer Embellishments
- Nonwoven Constructions

As this technology had been previously employed mainly as a stitch substitute, that is to create seam bonds for garment construction, I began by experimenting with multi-layer composites. A previous body of work for the 'Ever and Again' project (Earley, 2007), had looked into the use of CO2 laser welding as a tool to resurface low grade recycled felts in order to 'upcycle' them to a higher value material product. The CO2 technique had not always produced controllable or successful results but I quickly discovered that laser welding could produce much more sophisticated and subtle effects, bonding layers together with minimum disruption to the surface of the materials joined.

Sampling explored stitch replacement (for quilting, sashiko, 3D constructions), and resurfacing techniques (emulating embossing, double faced laminations, jaquard effects). In some cases at certain power settings I observed that the top surface was affected. Where in the exploration of seaming this would be considered undesirable, in the exploration of finishing techniques this opened up a new area for investigation.

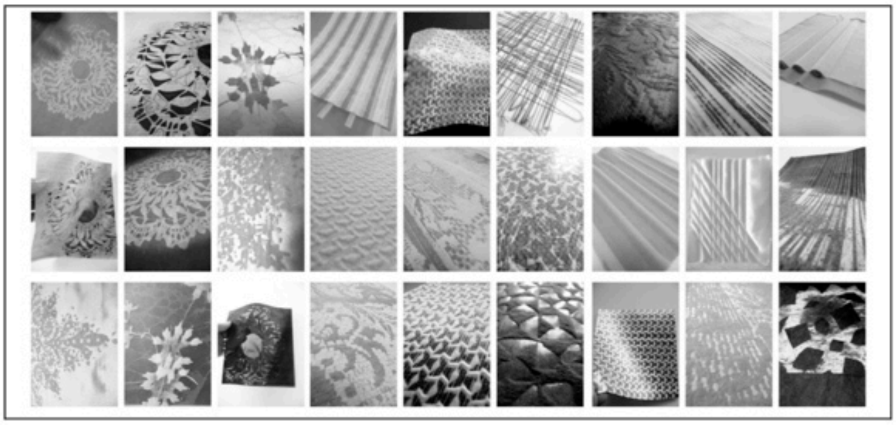
When the laser was applied to single layer materials two main characteristics could be achieved. Transparency was the result in certain material substrates, such as fine satin weaves, and emulated a devore finish. This surface effect has been explored previously by designers using the CO2 laser. However, the use of the laser welder gave more easily controlled results with less destruction to the surface of the material treated.

More dense textile constructions and materials resulted in a melted surface effect akin to spot lamination or coatings. This led to a further group of experiments which explored surface embellishments beading, sequins, embroidery, flocking and foiling – all achieved without the use of adhesives or stitch.

The final experiments leading on from observation of the bonds created between yarns in the experiments to emulate embroidery, were based on the replication of web formation, perhaps alternatives to lace or nonwoven constructions.

Figure 6: Selection of final samples developed during PhD project 2009

Source: author



In all over 20 existing textile processes were emulated and explored successfully resulting in materials not only created from recycled polyester materials, but also suitable for full chemical recycling into high value polymer of virgin quality.

Conclusions and future work

Current processing and finishing methods such as chemical coatings or lamination, commonly used in the textile industry's ever growing desire for performance and functionality, create barriers closed-loop recycling, by mixing materials with different reprocessing needs into an irreversible state. These complex hybrid materials designed in the ever-increasing drive for performance and functionality, leave a legacy of waste and prevent inclusion in future fabrications.

The research set out to find alternatives to these traditional finishing techniques, which could be employed to preserve monomateriality in polyester materials in order to work within this system. Working within the boundaries of the technological metabolism, the aim was to find new technological tools for creating monomaterial textile products. These tools enable aesthetic and functional features as well as recyclability. This was not intended as a search for a replacement to all traditional and low-tech processes, but as a complementary set of techniques.

Through a practice based and design-led project, I explored many techniques using laser-welding to produce varied finishing effects, which worked on the principle of controlled manipulation of synthetic surfaces without the contamination of additional materials.

The resulting prototypes showed that several effects, which would normally need chemical coatings or adhesives, could be achieved without any added agents. Colour could still be achieved through the usual dyes as they can be 'burned off' as part of the recycling process. The result was a collection of textile prototypes demonstrating techniques, which could be used to create products 'designed for recycling' within a future polyester economy.

Notes

The Clearweld ® process was invented and patented by TWI. It is being commercialised by Gentex Corporation. The process uses lasers and infrared absorbing materials for precise joining of coloured or clear synthetics. It offers superior engineering advantages compared to today's adhesive and solvent bonding, and ultrasonic, vibration and hot-plate welding methods.

The practice element of the project was supported by the Textile Environment Design (TED) cluster at Chelsea College of Art & Design, with technology access from The Welding Institute (TWI). The project was funded with a SPARK Award from the Materials KTN. With special thanks to Jo Lewis (TWI) for her technical expertise and help throughout the project.
Recycled polyester materials were provided by Teijin Fibres Ltd.

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10.2 PROJECT OUTPUTS AND DISSEMINATION

The practice outputs and research have been disseminated throughout the course of the project (2006-2012). Key exhibitions, international conferences and events, workshops and publications are listed below in reverse chronological order.

10.2.1 Exhibitions

MonoFinishing

Mar 2012	FutureWear VF Corp Summit, New work (Laser Line Garment & Samples) commissioned by the VF Corporation (through TFRC) for their internal summit event in North Carolina (currently unpublished)
Jan 2012	No More Waste, Experiment Gallery, Museum of Science and Industry (MoSI), Manchester
Sep 2010	ReTHINK!, New work (Mono Garments & Samples) commissioned by the Audax Textile Museum, Tilburg (until Jan 2011)
Jun 2010	Trash Fashion: Designing Out Waste, New work (Mono Garments) commissioned by the Science Museum, London (until Aug 2011)
Oct 2009	Warp Factor 09; Textiles Research at CSM, Japan, China, London
Mar 2009	Green SCin: the materials experiment, EcoBuild 2009, Earls Court, London

ReSurfaced

Jan 2012	Everything Must Go, Exhibition for The Waste of The World Project, The Bargehouse, London
Dec 2007	Hidden Art Annual Awards Exhibition, Rich Mix, London
Oct 2007	Ever & Again: Experimental Recycled Textiles, Triangle Gallery, Chelsea College of Art and Design, Millbank, London (15 – 27 October 2007) [available at http://www.everandagain.info]

Twice Upcycled

Oct 2009	Taking Time: Craft and the Slow Revolution, Collaborative work with R Earley shown in Craftspace touring exhibition, Birmingham Museum and Art Gallery then on tour in the UK (until July 2011)
Aug 2008	Imaginative Qualities of Actual Things, 3-logy Triennial 2008, Price Tower Arts Centre, Oklahoma, USA (until Jan 2009)
Apr 2008	TechnoThreads, curated by Professor Marie O'Mahoney for The Science Gallery, Trinity College Dublin (until Jul 2008)

10.2.2 Public Presentations

Feb 2012 Perspectives on Future Sustainable Design, TFRC Symposium with Keynote from Dr. Jonathan Chapman. LVMH Lecture Theatre, CSM, London

Jan 2012 Everything Must Go: Talking Rubbish, Seminar Presentation & Panel, The Bargehouse, London

Apr 2011 Novel Laser Surface Finishing of Textiles for Recyclability, Presentation at Industrial Laser Applications Symposium (ISLAS) 2011, Warrington

Oct 2010 Sustainability in design: NOW! Challenges and opportunities for Design Research, Education and Practice in the 21st Century, Bangalore, India [available at http://www.lensconference.polimi.it]

Sep 2010 Interlace: thinking on textiles through social and cross-disciplinary dialogues, Nottingham Castle Museum & Art Gallery, Nottingham

Nov 2009 Cutting Edge: lasers and creativity, Loughborough University, School of Art and Design

Nov 2009 Futurescan: mapping the territory, Association of Fashion and Textiles Courses Conference, Foresight Centre, University of Liverpool

Oct 2009 IMPACT: Design for Recycling, guest lecture, with TED (CCW), HAW, Hamburg

May 2009 Design for a closed-loop polyester economy, Stroud International Textile Festival, Seminar with Dr Emma Neuberg, Stroud

Mar 2009 Creative collaborations: craft and technology, Cockpit Arts & Own It Event, LCF, London

Oct 2008 Upcycling & New Technologies InterPlas, Plastics Conference, (for MADE) Birmingham

Sep 2008 Interim Textiles; designing with borrowed materials, GreenGaged; Material Matters, at the Design Council, London

Sep 2008 Laser finishing as a tool for the forward-recycling of polyester, MADE, Technology Transfer Event, RCA

Jul 2008 Upcycling Textiles; adding value through design, Ever & Again Conference, Chelsea College of Art & Design, Millbank, London (available at http://www.everandagain.info)

Jul 2008 Upcycling and the role of new technologies, Presentation & Workshop, Science Museum Gallery, Dublin

Oct 2007 What Future for Eco Textile Design? TFRG Salon, Question Time Panelist, ICA, London

May 2007 The role of new technology & polymer engineering in the forward-recycling of synthetic textiles, Dressing Rooms; Current Perspectives on Fashion and Textiles. Oslo University College, Norway (Paper presentation)

10.2.3 Workshops

Nov 2009 Designing with Borrowed Materials Workshop, (with MA Textile Design students) TED Research Focus Group, Chelsea College of Art

Nov 2009 Interconnected Design Thinking for Textiles, (with MA Textile Design students & Prof K Politowicz) TED Research Focus Group, Chelsea College of Art

Oct 2009 Impact Workshop, with TED (CCW), HAW, Hamburg

May 2008 Interconnected Design Thinking for Textiles, with R. Earley at TechnoThreads exhibition for The Science Gallery, Trinity College Dublin

10.2.4 Published Papers and Articles

Apr 2011 Novel Laser Surface Finishing of Textiles for Recyclability, Paper presented at Industrial Laser Applications Symposium (ISLAS) 2011, Warrington

Oct 2010 Sustainability in design: NOW! Challenges and opportunities for Design Research, Education and Practice in the 21st Century, Proceedings of the LENS Conference, Bangalore, India Greenleaf Publishing, London ISBN-13: 978-1-906093-54-9

Jun 2010 Without a Trace, Commissioned article for Viewpoint Magazine, Issue 26; The New Normal (co-authored with Dara Lang) pp108-115

May 2010 Textiles, Environment, Design (TED): Making Theory Into Textiles Through Sustainable Design Strategies, Pedagogy and Collaboration, Paper co-written with Rebecca Early and Clara Vuletich, Published HAW, Hamburg

Nov 2009 Cutting Edge: lasers and creativity, Loughborough University, School of Art and Design [available at http://cuttingedgesymposium.com/20-minute-papers/kate-goldsworthy.html]

May 2007 The role of new technology & polymer engineering in the forward-recycling of synthetic textiles, Dressing Rooms; Current Perspectives on Fashion and Textiles. Oslo University College, Norway

10.2.5 Press and Publication

Sep 2012 Digital Visions For Fashion and Textiles, Made in Code, Work featured on p56 of book by Dr. Jane Harris and Sarah Braddock-Clarke, Thames and Hudson, London

Sep 2010 Eco Fashion, by Sass Brown, Laurence King, London [ISBN 978 1 85669 691 3]

Oct 2010 Textile Futures: Fashion, Design and Technology, by Bradley Quinn, Berg Publishers, London [ISBN-13: 978-1845208073]

Mar 2009 Textile Designers at the Cutting Edge, Work featured on pp 224-231 of book by Bradley Quinn, Laurence King Publishers [ISBN-13: 978-1856695817]

Jan 2009 Remake It Home: The Essential Guide to Resourceful Living, by Henrietta Thompson, Universe Publishing, New York [ISBN-13: 978-0789320568]

Sep 2008 Lighten Up, Exhibition Catalogue, Work featured on pp 42-43 of catalogue published by ReDesign [ISBN-13: 978-0-9557129-1-3]

Mar 2008 EcoChic: the fashion paradox, Work featured on pp 154-157 of book by Prof Sandy Black, Black Dog Publishing [ISBN-13: 978-1906155094]

Oct 2007 Ever & Again; rethinking recycled textiles, Exhibition Catalogue

Work featured on pp 14-15 of catalogue published by TED [ISBN-13: 978-0-9557269-0-3]

10.2.6 CD ROM

The CD Rom included with this thesis includes all images presented in this thesis (see Index of Figures, p11-12 for full listing) along with three short films which were made during the project to communicate the work to a range of different audiences.