The Design and Prototyping of Innovative Sustainable Material Solutions for Automotive Interiors

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Copyright statement

Abstract

This research explores the potential for using sustainable materials, in closed-loop systems applied to aspects of an automotive interior. I approached this by using materials in separate recovery streams: biological for industrial composting, and technical for recycling. The thesis sets out the challenges I faced when dealing with the messy reality of real-world designing. These were: working within established industrial systems, complex global supply chains, the marketing of materials and perceived expectations of how automotive products should look. The thesis explores how, as the research progressed, my thinking about the research question shifted, as the problem and solution spaces were further explored.

Changing one material element in a vehicle has a cascade effect: this is because each component is interdependent on another product within the vehicle. The car is a complex mix of industrially manufactured parts with established systems producing vast volumes of products for the automotive industry, making them difficult to change. Remanufacturing of parts, recovery for industrial composting and recycling requires systems to be created, as described by a circular economy. These are challenges I faced in making the prototype textiles and interior panels: first, as the work I made was only one component in a product, how would it be recovered from the other materials it was connected with, and second, what systems are in place for recovery as a circular economy proposes? Design for disassembly would partially resolve this issue, but this would involve a complete redesign of the seat and door, which would impact on the whole vehicle architecture. Another challenge was in the transparency of material supply chains and finding information on the true environmental impact of materials.

The prototypes were created using craft-processes and industrial manufacturing, the distinction between the two being that the hand-made pieces are imperfect due to the process and materials used in their fabrication, whereas the industrial recycled product is identical both technically and visually to a virgin product. This made me question expectations and perceived expectations of the automotive industry and their customers regarding material performance and an ‘always new’ look. These questions arose through making and reflecting on the practical work, which suggests that there is an opportunity for a new form language for using sustainable materials in large-scale industrial design applications.

The thesis includes discussion of the practical projects and reflections on the broader systemic questions that the projects raise, including the nature of practice-based research.

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Authors Declaration

During the period of registered study in which this thesis was prepared the author has not been registered for any other academic award or qualification. The material included in this thesis has not been submitted wholly or in part for any academic award or qualification other than that for which it is now submitted.

Signed Sheila Clark.

Date 15th April 2019.

Definitions

ABS	Acrylitile butadiene styrene
AG	Silver
AG+	Silver ions
APM	Automotive performance material
ASR	Automotive shredder residue
BFA	Bioplastic Feedstock Alliance
BMW	Bayrische Motoren Werke
CAD	Computer-aided design
CELC	The European Confederation of Linen and Hemp
CEO	Chief executive officer
CHyM	Compression hybrid moulding technology process
DFD	Design for disassembly
DFE	Design for environment
DFR	Design for recycling
DfX	Design for X
Dtex	Decitex
DXF	Drawing interchange format or drawing exchange format
ECM	Environmentally conscious manufacturing
ECMPRO	Environmentally conscious manufacturing and product recovery
ELV	End of life vehicle
EPS	Expandable polystyrene
GM	General Motors
ICI	Imperial Chemical Industries
IOM3	Institute of Materials, Minerals and Mining
JLR	Jaguar Land Rover
LCA	Life cycle analysis
LCM	Liquid composite moulding
MaaS	Mobility as a Service

NFPP	Natural fibre polypropylene
NM	New metric
OEM	Original Equipment Manufacturer
PE	Polyethylene
PET	Polyethylene terephthalate
PHA	Polyhydroxyalkanoates
PLA	Polylactic acid
POY	Partially orientated yarn
PP	Polypropylene
PSA	Peugeot Sociétié Anonyme
PTT	Polytrimethylene terephthalate
PU	Polyurethane
PUR	Polyurethane
PVC	Polyvinyl chloride
QOL	Quality of life
REF	Research Excellence Framework
SCENIHR	Scientific Committee on Energy and newly identified health risks
SEM	Sensory electronic microscope
SMMT	Society of Motor Manufacturers and Traders
STING	Sustainable Technology in Nettle Growing
TSB	Technology Strategy Board
UID	Umeå Institute of Design
UV	Ultra violet
VW	Volkswagen
WRAP	Waste and Resources Action Programme
WWF	World Wildlife Fund

Chapter 1: Introduction

Summary

In this chapter I set out key elements of the thesis and my approach to the practical elements of this research: the research questions, original contribution to knowledge and key insights.

In Chapter 2, I discuss the research methods I used aligning them with design research literature and thinking. Chapter 3 investigates the history of material use in automotive interiors and examines the different approaches of Henry Ford and General Motors (GM) at the beginning of automotive mass production. Chapter 4 looks at key literature surrounding sustainability in particular a *circular economy* and aligns this to elements of such practice in the automotive industry today. Chapter 5 describes the industrial process taken in the project ‘Mono synthetic material: textiles’ for recycling and the outputs. In Chapter 6, I similarly describe the industrial process taken and outputs in the project ‘Renewable materials for composting: textiles’. Chapter 7 discusses the craft approach used to create ‘Renewable materials for composting: hard, formed surfaces’. Chapter 8 is my closing discussion, conclusions and future research.

The chapters provide an account of what I did, what I learnt and my emerging understanding of the wider picture.

Background

Prior to starting this PhD I had conducted a project during which I produced a series of textiles for automotive face seating, which were dominated by performance attributes: these being conductive, light reflective, light responsive and with intended antibacterial properties. I worked with Ford and Lotus who trimmed Fiesta and bucket seats respectively. In addition I worked with a weaving mill, Bute Fabrics, to produce the fabrics and other suppliers. When I started the PhD research I intended to approach it in a similar way, that being:

- To visit material, automotive and design trade fairs to establish contacts and gain information.
- To take a ‘materials first’ approach by sourcing materials, gathering samples and experimenting with them.
- To work with industrial producers to obtain materials, make artefacts and to understand their systems.

Through visiting trade fairs, suppliers and meeting with Ford in conjunction with additional research I came to the realisation that a challenge for the automotive industry was using sustainable materials and their application within an ordinary vehicle interior. In focusing on this there were several research questions:

- What would be the challenge to established manufacturing processes in using different materials?
- Would performance requirements need to be altered?
- Would systems need to be changed?
- Would such materials challenge the conventional visual identity within the vehicle?
- Would the materials fit and work in the current vehicle form?
- How to communicate through the material to the customer that the material is sustainable?
- How to communicate to the customer that the recycled material is a premium not low-grade product?

These questions implicate a wide range of ‘stakeholders’ – including materials suppliers, manufacturers, marketing, sales and customers – as I discuss later in the thesis.

The nature of sustainability and industrial manufacturing

I have created the following table (Table 1) to address the environmental issues that support the need for industrial manufacturing to address sustainable approaches.

Diminishing raw material sources	Increase of waste in oceans, landfill and materials being burnt for energy	Pollution of air and water

Table 1: Environmental reasons.

Table 2 below, describes the problems with existing industrial systems and product manufacturing.

Product life-cycle, planned obsolescence and cosmetic obsolescence.	Disassembly of product to recover materials.	Remanufacturing.	Toxic pollution.	Product recovery and waste management.

Table 2: Existing problems.

Table 3 below, describes methods of environmentally conscious manufacturing.

Integration of environmental thinking into new product development.	Life-cycle analysis	Through design, material selection, manufacturing processes and end-of-life management.

Design for recycling (DFR)	Design for disassembly (DFD)	Design for the environment (DFE)

Table 3: Environmentally conscious manufacturing (ECM).
(Information derived from Gungor and Gupta, 1998).

Chapman (2005, p. 6) states that there are numerous strategies for sustainable design. Several of these focus on specific stages of the product life cycle, which are generically described as Design for X (DfX). Strategies for DfX include those in table 3, namely DFR, DFD but he also includes Design for reuse. There are other approaches that include: alternative energies, sourcing local materials and processes, collapsible objects to reduce landfill space, supply chain management, zero emissions and compostable products. From a material perspective, there are recycled materials for example polymers such as polythene, polypropylene, metals including steel, aluminium and brass. Renewable materials include renewable plant fibres for textiles, and high performance industrially compostable plastics from renewable plant sources (p.6).

My approach

In order to progress from the work I had previously conducted where I had isolated the seat cover as my focus I made the decision to develop the practical work on a whole vehicle. This would provide a template for the prototypes and an arena to fit them into. I wanted to not only explore the potential for a surface textile but to additionally investigate under-skin materials and formed panels. At this time I had not realised that I would be incorporating textiles within each piece I made. Ford provided a pre-production Fiesta, which gave me the opportunity to understand the complexity of each part as I took it to pieces and analysed its material composition. However, it was also problematic as it posed a series of challenges that I had not anticipated, these being:

- Housing the vehicle securely.
- Taking it apart without destroying the integrity of the interior.
- Re-creating parts at full-scale: where and how?
- How to refit the interior beyond a styling exercise?
- How to link the parts I had remade if they were put into the interior?

While some of these challenges were practical rather than interesting, others had broader implications for my methods and overall approach as a sole designer working within industrial processes.

The parts of the interior I was concerned with

The automobile is a complex mix of many parts and involves teams of designers, engineers, manufacturers and a myriad of materials to create one. Sparke (2002, p. 13) states that the complexity involved in their design requires large teams of people who each bring a different set of skills to the task. This may account for ‘global design’, which can be found at Ford, where all design decisions are approved by the global design teams, with few local adjustments. The design of an automobile is subject to technological, social, economic, ergonomic, and political forces and transformation. Le Quément (2002, p. 7), in reference to the design language of the automobile, suggests that it was developments in technology, materials and production that led the transformation of both the nature and look of the modern vehicle. Additionally, that it was designers that translated these into forms that were believable and valid in a cultural sense. There is now the opportunity for designers to embrace new challenges that are being presented as society shifts towards the use of autonomous vehicles, and the possibility that there will be a shift from car ownership to ‘Mobility as a Service’ (MaaS). When I started this PhD I thought that there was an opportunity for zero emissions electric vehicles to incorporate sustainable materials in the interiors to support the intention of 'being cleaner'.

Below (Figure 2) is an illustration of the respective components involved in a typical automobile.

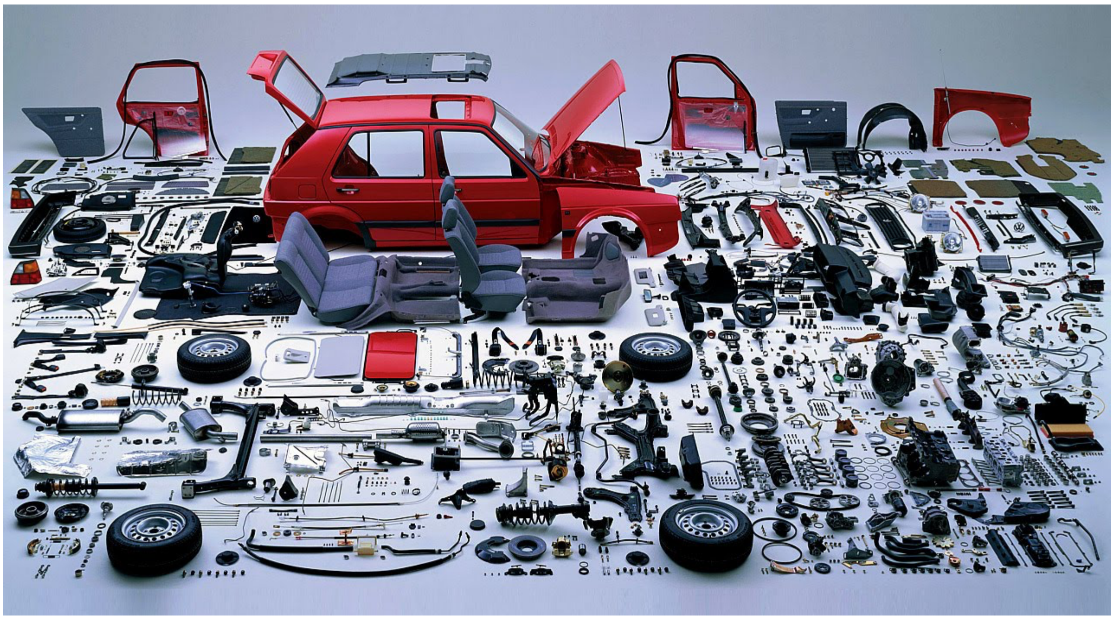

Figure 2: The essential auto parts guide. Autoxpat (2016).

Considering the number of parts involved in a whole vehicle it was necessary to focus on two types: the first group being the seat face textile, foam backing and seat foam, and the second the interior door panel and glove box lid fascia. I removed these from the Fiesta to examine them. The originals are illustrated below (Figures 3-8).

Figure 3: Seat foam back side.
Sheila Clark, 2015.

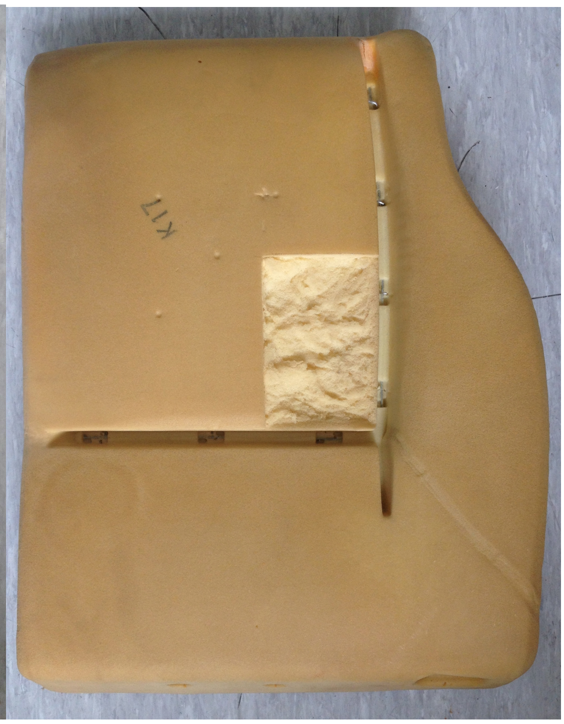

Figure 4: Seat foam face side.
Sheila Clark, 2015.

Figure 5: Seat face textile.
Sheila Clark, 2016.

Figure 6: Textile foam backing.
Sheila Clark, 2016.

Figure 7: Fiesta inner door panels.
Sheila Clark, 2013.

Figure 8: Fiesta glove box lid (after using to create moulds).
Sheila Clark, 2013.

Original contribution to knowledge

My approach from a design and making perspective started with material sourcing, experimentation with materials in various woven, knitted and moulded constructions. This led to creating prototypes at full-scale in order to visualise the concepts of the selected material combinations in vehicle interior parts. The originality is in:

- The artefacts themselves and the material combinations used to create them: these being suggested seat foam and textile solutions, the glove box lid, door panel and formed rigid surface concepts.
- Adjusting or adapting existing manufacturing systems to create some of the prototypes.
- Working with companies to close the gap between my research and sustainable manufacturing.
- Demonstration, through my practice and associated research, that the 'aesthetic' aspects of sustainable design cannot be neatly separated from the technical issues of manufacturing and the wider systems they operate in.

Components of sustainability

What I leapt to in the beginning was what I perceived or what was marketed as 'sustainable'. However, I discovered that this is a complex area, which can be misleading. What is marketed as being 'sustainable' may only be so in part, which led me to consider the complexity facing designers with their material choices specifically in relation to a complete vehicle which has so many component parts. Additionally, if there are not the systems in place to enable the materials to be recovered appropriately, as a circular economy requires, then only part of the problem has been addressed.

What I now consider to be the fundamental principles of sustainability for automotive materials are as follows. Critically, that the material is lightweight as this reduces fuel use and increases speed. The industry will accept a more expensive material if it reduces the weight of a vehicle as this reduces costs and has other benefits. The material must suffer no significant deterioration, either visible or more importantly in its performance. The fundamental aspects of materials in the wider understanding of sustainability are that there should be no negative impact on the environment: through its procurement – extraction and mining, including energy consumption to obtain them, impact on land use versus food supply chains, and their disposal at the end of life. The way the material is used in the design of industrial products should facilitate: that they can be either composted in industrial composting facilities or be recycled at the end of life, requiring that each material stream, either biological or technical, is kept separate in the product to enable this. The appropriate systems need to be established and in place to allow this to happen. The local use of materials can be beneficial to the more sustainable use of materials but should not conflict with land use or compromise on performance. The landscape of sustainability is further discussed in Chapter 4.

Early in the research I made the decision to keep the practical work in separate recovery steams: these being synthetic materials of the same composition for recycling, using recycled material in part, and natural materials from renewable resources for composting at the end-of-life.

Considering the textile and other parts in situ in a complete car had its advantages and disadvantages. It was only by considering the whole vehicle interior that I understood the impact of each separate part's material type on the recovery for reuse, recycling and composting. For that reason I had wanted not only to design them for that context but exhibit and appraise them within it. However, it became evident that this would lead to the under-skin materials being invisible, as they normally are, whereas they are an important aspect of the project. The materials themselves were the focus of the practical work. Perhaps more importantly, displaying them in an existing Ford could imply that everything around the textile part is intended to stay the same. As I understood through this study, no part of the vehicle can be taken as fixed in its current form. Each needs to be reconsidered, not only separately, but also as part of multiple systems and contexts.

In justifying why I had the Fiesta I recognised that it had functioned as a device to facilitate an exploration of material use and processes of manufacture or making in a real-life vehicle. The Fiesta was not a styling project - it was a deeper exploration of the potential for material contribution, and the subsequent form of the material, to increase the sustainable credentials of an ordinary vehicle.

Through the 'Material evolution in relation to design in automotive interiors chapter', Chapter 3, I have explored the origins of material use in the automotive industry that established the platform from which what exists today has evolved. By investigating the different approaches of Henry Ford and General Motors at the outset of their respective vehicle production lines demonstrates the polarities between their uses of materials. Ford sought to use waste both from his factories and from agriculture, as well as locally derived plant materials. In contrast General Motors used newly developed synthetic materials by DuPont. I found it informative to understand how the emerging automotive industry approached the use of materials. Looking back, particularly at the work of Henry Ford, may be informative for the direction the automotive industry may shift towards and ultimately adopt.

The projects, described in Chapters 5, 6 and 7, are my principal research methods: my research is conducted through the practice. The practical studio experiments and final prototypes are action research, which is partly intuitive. The problem and solution develop together, the prototypes are not intended to be conclusive: instead they demonstrate the complexity of the task in hand. I found that in considering one automotive part from a materials-first stance, that this then revealed the interdependence on another part: finding a solution for one area led to new questions about its relation to the whole. What I imagined I was doing shifted as the work progressed. The evidence of my progress is documented through the practical experiments, which I evaluated through laying out and establishing connections between them, then grouping them. This enabled an iterative ‘conversation’ with the things I had made. It was also a way of understanding the materials potential and scoping for possibilities with the outputs continually appraised in respect of application within the context of an automotive interior. Mine was a largely tacit, intuitive approach based on experience of materials and making, in particular textiles, yarn and fibre. Committing to solutions early was a method of problem setting or framing the research: the problem and solution developing together. There was tension between the theory and the practice. I discuss this form of design research in Chapter 2.

The project chapters describe the processes I followed to create the prototypes. This divides into craft making for the door panel and formed pieces, and linking with industry to produce yarn, textiles and foam replacement possibilities. These evolved from gathering materials from trade fairs and other sourcing methods, early experiments and conversations with suppliers and manufacturers. There were limitations in both processes. Working with industry I had to work within the systems that they use, to their timeframe and capabilities. In craft or hand making I had to establish my own set of methods to work with a limited supply of material. This meant I had to make, for example, the door panel, at the first attempt.

Project ‘Mono synthetic textiles for recycling’ described in Chapter 5 explores the use of polyester both recycled and virgin for the soft parts of a seat. Focusing on the face textiles, under-textile foam and seat cushion foam, my intention was to investigate the potential for using recycled material from industrial and consumer waste for the face textile and using polyester textiles for the hidden foam parts. This would enable end-of-life recycling of all the combined parts as one material. In this project I worked closely with industrial manufacturers of yarn and textiles creating fabrics and yarns and incorporating other existing materials to complete the concept. I wanted to demonstrate a proof of concept as closely as possible to an accepted automotive standard. Only later did I start to question the established idea of 'an accepted automotive standard' an issue I discuss in Chapter 5.

The project 'Renewable textiles for composting', described in Chapter 6, followed a similar trajectory in that I worked with a weaving mill to produce seat face textiles, using renewable materials. I then sourced various existing nonwoven fabrics as foam replacement possibilities.

In both of these projects I benefitted from the use of industrial manufacturing facilities, the capabilities of the respective companies and technical support. Additionally, I could discuss their perspective on the questions I was dealing with.

Chapter 7 describes the projects 'Renewable compostable composites: that were conducted through hand processes. They divide into two distinct parts. Firstly I remade the glove box lid fascia using bio-resin and waste jute coffee sack. Similarly, I recreated an inner door panel of the Fiesta using the same bio-resin and nonwoven flax. The second part of this project, which was only achieved on a small scale due to unavailability of appropriate equipment, was the making of formed low relief pieces using a woven flax and polylactic acid (PLA), which through heat setting I bonded to the fabric I had woven in the previous project. The intention for these prototypes was to have a fully compostable part.

There was a point in the research when I realised that the materials I was working with and the prototypes I had developed needed a more fundamental redesign of the part. For example the materials for the seat cover and foam replacement would benefit from a new form of seat that accommodated them better. Similarly, the processes I used to make the door panels and glove box lid were hand or craft making, which were not realistic in a real world scenario. Handling and controlling the bio-resin over the existing form of the original panel was problematic, which suggested that a simpler surface would benefit the use of such material. Existing manufacturing processes for inner door panels cannot accommodate such a material as they are established for other plastics: using the bio-resin in such a system would contaminate the equipment. For this reason, the prototypes that I have developed remain as stand alone suggestions, possibilities and explorations of materials.

I have investigated the landscape of sustainability and the ways these ideas can be applied, and in some cases, are being applied in an automotive interior context. Experimenting with materials from both technical, and separately, biological or renewable resources, and by creating prototypes I made an arena for discussion and communication. I have unpicked these processes in the thesis and aligned them with theories on research methods and the opinions and research of experts in the respective material fields. Supporting the doctoral work I looked at the history of the evolution of the automobile, in which I used the case studies of Henry Ford and GM as they represented polarities in material usage.

Main aims of the research

The main aims of this research were to investigate and source sustainable materials and apply these within an automotive interior. My intention was to create working sustainable solutions while at the same time investigating the underlying principles of sustainability. I aimed to demonstrate what could enhance the sustainable credentials of a vehicle, for real-world application within the automotive industry, through the materials selected. As the work progressed, these aims were expanded to include the wider meaning of sustainability, which was constantly changing, and to consider the systemic aspects of the industry. My research showed how sustainability could not be confined to simple changes in the sourcing of materials, but instead requires a comprehensive approach to many aspects of the industry.

In the next chapter, I discuss my Research methods in more detail.

Chapter 2: Research Methods

Summary

In this chapter I discuss key theorists of design research methods whose concepts connect with my processes and experience when conducting research through practice. The key issues I discuss are: how through making an understanding of the problem and solution is made, how the practical work is a conversation, an external representation that communicates the thought process and development of ideas, and how when faced with the reality of designing in the real-world it does not follow a straightforward or systematic approach.

The first section of this chapter explores the theory of the research methods that pertain to my project work, which is described and discussed in Chapters 5, 6 and 7. I align my practical activities with theoretical methodology in order to unpick, frame and position the research questions which evolved during the projects: this is briefly discussed here but is expanded on in the project chapters and overall conclusions. This process helped my thinking and is the reason that I justify my work as research through practice, as distinct from practice. I found that reflecting on my processes allowed me to explore the tension between 'ideal' models of research and the messy realities of practice-based investigation. I have used key texts from the history of design research as the main source for my ideas, referencing in particular the difficulties described in positioning practice as systematic enquiry when faced with real-life situations.

My projects are my principal research methods. These are combined with interaction with experienced industrial practitioners in materials and manufacturing, and background reading.

The key themes and understanding of my research methods through practice are as follows, which are expanded on later in this chapter:

- Co-evolution of problem and solution.
- Problem framing through the practical work.
- Craft making and industrial manufacturing, a process comparison.

My approach was:

- o Iterative.
- o Action research.
- o Reflective – in action.
- o Largely tacit and intuitive.

Design research theory in relation to my practice approach

In distinguishing my work as *research through practice* I looked at the work of Bruce Archer, an early pioneer in design research. He explored the reasoning of ‘research, design and development’ (Archer, 1971). Boyd Davis and Gristwood (2016), in their paper tracing Archer’s thinking on, and understanding of, the design process, state that his doctoral thesis completed in 1968, *The Structure of Design Processes,* demonstrates ‘a tension between theory and practice’ (p. 2). Their paper explores the shift in his understanding and how he tried to align his theoretical concepts with the realities he encountered from real-world design experience.

Prior to completing his thesis Archer had written a series of seven articles for *Design* magazine, entitled ‘Systematic Method for Designers’, in which he structures and analyses the processes of designing in stages. In ‘Part five: the creative leap’ he describes this part of the process as ‘the real crux of designing’, noting also that designers should ‘accept the transience of design’ (1964).

Archer’s definition of research as ‘a systematic enquiry whose goal is communicable knowledge’ (1995, pp. 6 and10) was challenged when he applied the principles to the output of real designers. He argued that equating the work of a practitioner per se with research activity is not straightforward. Acknowledging that the work even of a practitioner involves some element of research activity, he references his earlier decision or ‘uses’ of research in order to distinguish between them. This, he suggests, can be determined by asking the following questions, that he includes as guidance (p. 10):

- o Was the practice and enquiry carried out with knowledge acquisition as the aim?
- o Was it systematic in its approach?
- o Was the information precise?
- o Was the process documented in easily replicated, ‘transparent’ ways?
- o Was the information and result authenticated by suitable methods?

Archer (p. 11) identified three categories related to an understanding of the probable relationships between research and practice: research 'about', 'for the purposes of' and 'through' practice. He describes the last kind, in which the research activity is conducted 'through the medium of practitioner activity', as the point at which it becomes 'interesting': I connect my work in relation to this principle.

Pahl and Beitz (1996, p. 54) outline general guidelines for systematic procedures which they explain are "heuristic principles" that is the method of creating ideas and discovering solutions. The systematic procedures they list as, firstly to define the goals, then to clarify the boundary conditions by defining constraints, thirdly to dispel prejudice to ensure the widest possibilities are considered. The fourth is to search for various solutions or possible solutions, to enable the best to be chosen. The next stage is objective evaluation in consideration of the goal and requirements, which facilitates the last step that is to make decisions. Similar to Archer they were aligning the activity of engineering designers to be systematic and mapped out before any designing takes place. Kannengeisser and Gero (n.d.) compare the classic approach of Pahl and Beitz to the actual processes of mechanical engineering students who are taught to be systematic in their design processes. They conclude that such an approach does in general terms match the student's activities in their design processes but that it is however incomplete.

This understanding of design research, where the problem is neatly defined, before designing begins and then not reconsidered is a classic approach that engineering and industrial designer researchers identified with. This came under question when they were faced with the reality of real-world designing.

My early understanding of my research through practice was that it should be systematic, transparent in process, clearly defined, ordered and follow incremental steps through material experiments that would show a logical progression of thought. However, as a designer/maker this was not the way I approached my material testing and experimentation. The way I tested materials and made samples was not conducted under controllable 'laboratory' conditions: there were always variable factors. This created a tension between what I *thought* I should be doing and how I *thought* I should be doing my research and the work that I was producing, and how I produced it.

When Archer and his design team worked on designing the hospital bed they realised that it was necessary to build prototypes of the beds in order to evaluate them. This is a standard engineering approach. However, they discovered that the creation of prototypes also led to new questions and revised objectives. I identify strongly with this in my design research, a need to work at full scale and consider the prototypes in relation to the whole vehicle interior to be able to evaluate them. This way of working in the case of Archer and his design team meant they had to deal with many issues that included materials, manufacturing, nurses, patients, and stakeholders. This real-world experience appears to have influenced Archer to question his original model for designing (Boyd Davis and Gristwood 2016, p.4). Similarly, I found that in realising full scale prototypes and applying these to the vehicle I encountered factors and situations that I had not envisaged I would: it was though making that I began to understand the whole set of systems that I was trying to work within.

I will next discuss authors who position design research as a reflective process that causes the designer/ researcher to continually question their original assumptions; and also to *make* as a way of beginning to understand the problem and solution.

Frayling (1993) discusses stereotypical assumptions regarding research in art and design in order to steer the discussion further. He differentiates between the definition of the use of ‘research with a little r’ as concerned with ‘searching’ for something defined in advance; ‘applied research’ and the use of ‘Research with a big R’ as ‘development’ or ‘action research’, through which the intention is to ‘generate and validate new knowledge and understanding’, or the Oxford English Dictionary definition as ‘work towards the innovation, introduction and improvement of products and services’ (p. 1).

Frayling (1993, p. 5) describes research through practice as ‘less straightforward but still identifiable and visible’, dividing this approach into three kinds: materials research, development work and action research. Action research involves practical studio experiments, which are documented with the intention to ‘*communicate the results’*, thereby framing the work contextually: differentiated from the amassing of reference materials as ‘*research’.*

I have included the work of Archer and Frayling because I came across their writing about research through practice and used it to understand what I was doing. The work I was making was intended for an industrial design/engineering output, which led to my looking at the work of Archer. In addition both had worked at the RCA. It was later, on reading Boyd Davis and Gristwood’s paper (2016) that I realised how much Archer’s thinking had changed through real-world research projects and this helped me position my practice methods as research.

Intuition, problem framing and conversation theory

A research scientist follows a systematic process to prove or disprove theoretical or supposed concepts through precise methods. Although research is perceived as an objective pursuit, Frayling argues that subjectivity has to be present, as tacit knowledge leads to the process of discovery (p. 3). Medawar (1969) discusses the importance of intuition in scientific research. He comments that, ‘Biology is complex, messy and richly various, like real life;’ (p.1), which is arguably comparable to design research. In considering the purpose of scientific methodology as a way to determine a system of enquiry he suggests that it there is no evidence to suggest that scientists adhere to such a process (p. 8). He argues that one way of understanding scientific methodology is that it is comprehended by scientists *‘intuitively’* (p. 12).

Through case studies of three ‘expert’ designers – product, engineering and vehicle designers – Cross (2004) identifies common approaches that they employed to deal with design problems. A wide ‘systems approach’ is taken, rather than following narrow criteria. The problem is ‘framed’ in a particular, individual way that can be subjective, which stimulates and positions emerging design ideas. The ‘first principles’ are the basis from which they design, that is in the ideation of their concepts and the development of them.

Schön (1983, p. viii) sought a better insight ‘into the epistemology of practice’ to ascertain the methods practitioners employ in the pursuit of knowledge through their work activities, acknowledging that practitioners use tacit, intuitive sensibilities in their work, on which they focus during the process: this he terms ‘reflective practice’. Within the diversity of design practices and the constant changes in the boundaries of each discipline Schön considered that the possibility of the existence of a common ‘generic design process’ may exist (p. 77). Schön acknowledges that there are distinct differences between the design disciplines in the way they ‘reflect in action’. These, he suggests, obfuscate the processes that the different design professions have in common. Therefore the way a designer operates this ‘reflective conversation’ is variable in relation to the individual and their practice. However, the overarching principle of the search is to frame the situation or problem (p. 270).

Schön (p. 269) identified that problem framing within the specific design area followed inquiry that in turn enables reflection on the results of experimentation within the parameters the designer has initially set. This he describes as an iterative process during which the designer continues to reframe, develop, explore, test, define and shape further, allowing the practice to crystallise thought, thereby shaping intuitive actions, which he described as “reflective conversation with the situation” (p.

268). Glanville (1999, pp. 80-91) similarly suggests that design is akin to a '*conversation'*, albeit between the selected tools and materials of an individual or group (an approach derived from Pask). He argues that the circular process of design is fundamental to research. Conversational theory sets up a system within which to view learning and embodies a systems approach to learning (Pask, 1976, p. 13). Pask (p. 12) believed that to understand complex human learning a conversation between the participants must take place. This provides evidence of learning which can be clearer if materials are used rather than solely verbal responses as this demonstrates understanding. Having external representations of the concepts, sketches or modelling, allows ideas to be identified and discussed. The subject matter is separated into core elements that are then reorganised into a map of topics (p. 24). McIntyre Boyd (2004, p.181) describes such practice as action-grounded conversations that enable the acquisition, production and evolution of dependable knowledge. To meet the criteria of understanding, the entailment structure requires a type of "cyclicity" that allows for an idea to be reassembled in a consistent way; enabling the identification of subjects involved and their connection (Pask, 1976, p. 16). Pangaro (1996) in his succinct paper on Pask's *Conversation Theory* states that we learn through our interactions with the environment, that being spaces, objects, processes and other people. These exchanges can be understood as "conversations" both in a metaphorical and formal sense. We respond to these external stimuli and interpret accordingly: learning through the interactions that we construct. Through these conversations the result is a "looping-around" across views that builds what we know. Pangaro concludes that conversation and identity happen together.

Within automotive design, BMW's 'Gina Light Visionary Model' (2008) was conceptualised in some ways as a conversation between the materials, the designers and others involved, as a way of extending the boundaries of current practice. Chris Bangle, then Director of Design at the BMW Group, described the concept as questioning the shape of the vehicle archetype and its function through an adaptive form. Bangle described the concept as 'a philosophy' that explored and allowed materials to guide the form over structural lines, to 'talk' in the space between. This, he argued, introduced a 'humanistic' and emotive element, adding value within the context of flexible thought processes and actions.

In my practice I recognise that the process involves a cyclical conversation that is evidenced through gathering materials, assessing them through handling and reading technical data, through experimenting and ultimately creating final prototypes. This method communicates not only to myself but provides tangible objects for discussion with others.

Polyani (1958) is credited with acknowledging the contribution that 'tacit knowledge' provides to research activity. The term is used to describe knowledge that is not encapsulated by words or numerical calculation: it is evidenced by action. In the context of design and making it is shown by the results of the actions and the artefact(s) rather than explicit, logical systems. (Polyani, 1958, 1962 and 1966; London School of Economics, 2017).

In discussing how various ways of 'representation' can endorse the use of 'tacit knowledge' in investigation, Rust (2004, p. 80) refers to the 'tension' between general and complex depictions. These, he suggests, mirror the approaches typified in a scientific approach and a design enquiry. In describing a research scenario which also involved creative designers, Rust notes that the outcome included several objects that were made or used in the duration of the project. Simply 'laying out' this collection of gathered material in one space, enabled the researchers to have an overview of the project and see 'evidence' of the process. Those who had been involved could comprehend and understand this as a visual record of the research.

The approach Rust describes was one I used during my research, that is laying out materials and my work in one space, in order to have an overall perspective on progress and to make connections between the materials I gathered, the experiments I made with them and possible outcomes. As I was working from the basis of the material in order to demonstrate sustainable origin, and use resulting in a product I used deductive reasoning in order to evaluate how they could be used. Seeking to further frame the problem or questions I gathered what I perceived to be appropriate materials at the time, by visiting materials-focused trade fairs. This allowed me to experience a wide range of products at first hand: to touch them, gain information about them from the supplier or manufacturer and to request samples of them. In conjunction I was able to establish a connection with the provider or representative through conversations about their material.

Having obtained material samples I then evaluated them in three phases:

- Through handling and manipulating them.
- By laying them out and grouping them: considering their appropriateness within the categories 'renewable and compostable', or 'synthetic for recycling' in a mono material stream.
- By aligning them with pertinent visual imagery and in colour themes: this included photographs both found and taken, sketches, diagrams and mapping, thereby creating mood boards or work in sketchbooks.

This evaluation was a way of visualising them in textile or composite form: enacting a scenario that facilitated a method of communicating and developing my ideas in a tacit way.

Action research

Throughout the materials research and assessment phases I continued with small-scale experiments in the studio. This action research helped to further frame the research questions within the parameters of craft-based manipulation. The processes I employed were as follows:

- Combining different fibres and yarns by twisting them together, hand knitting or weaving and Jacquard weaving.
- Finishing the textiles by washing, steaming, pressing and heat-setting them.
- Making and using existing moulds (silicone compartment trays intended for use in cooking or making ice cubes) to trial bio-based resin or glass combined with fibres or textiles.

I was familiar with textile fabrication and finishing processes, and created several trials which explored the materials in fibre or yarn formats. My intention in applying my work within an automotive context was loosely defined at this stage, and fluctuated between the suggestion of interior and exterior surfaces. I considered textiles as an exterior concept, for seat covering and through heat setting and forming for panel solutions.

The idea of flexible thought processes and actions is one that at the early stages of material gathering and experimentation was iterative and fluid in my work. Reason and Bradbury, (2008, pp. 3-4), describe 'action research' as a process that emerges and cannot be decided in advance, as the understanding of what needs to be addressed shifts and develops. Scott (2001) suggests that the emphasis for a 'radical constructivist' approach views the 'models' as an organism, which is built by tacit adjustments. The organisms 'knowing' is a process, and its 'coming to know' through objects and events resulting from its actions, is also a process, that Scott notes Pask refers to as a 'taciturn' process. In his paper Scott refers to Piaget (1956) who suggests that without a logical or mathematical device facts cannot be directly 'read'. He argued that because this device is necessary it is derived from experience, '[…] the abstraction being taken from the action performed on the object, not the object itself'.

Co-evolution of problem and solution

I developed my problem and solution space through visits to industrial manufacturers, suppliers and trade fairs, through materials research and sample collection, small-scale weaving and resin experiments. Following this, I framed the problem further by dividing the materials into technical or synthetic that can be recycled, and those from renewable origin that can be industrially composted at the end of life.

Considering how to use these materials posed a number of questions:

- How would the use of this material visually demonstrate its more environmentally considerate production process?
- Is it necessary to visually indicate that it is more sustainable?
- From a design perspective, how could this translate?
- What could I use the material for that would be innovative?
- If I combined a material with other materials in the car, would this negate the point I was making?

These questions recurred throughout the projects.

At various points in the research I questioned whether I had committed to, or fixed on, a solution too quickly. Cross (2011, p. 16), suggests that designers have guiding principles which they use as starting points that enable them to restrict the problem to something manageable. In conjunction with this they have an idea of a potential solution. In his study of expert design behaviour Cross (2004), suggests that by rapidly focusing on 'early solution conjectures' designers create a method through which to co-investigate and co-define the problem and solution. As the 'problem' cannot be fully defined as a separate entity to the 'solution', Cross (2004) argues that it is logical that 'solution conjectures' should be used as a way to examine and perceive the problem. Schön (1983) describes this as ‘framing’ or ‘problem setting’, which he sees as a method through which boundaries are established and specific things that need to be considered are chosen, thereby allowing a consistency in the circumstances that directs further action. This is a recurrent process throughout the project. Christopher Jones (1980, p. xxi) recognises the validity of moving from a structured design approach, after a period of time, to enter a state of confusion – ‘muddle, chaos, messiness, creative disorder’ – to allow one’s mind to consider unknown possibilities and limitations before fixing the design direction.

On reflection I now understand that my decision to commit early to working with an automotive textiles manufacturer was a way that I could explore the problem and solution within the parameters I had, at the time, loosely set. Cross (2011, p. 14) suggests that in trying to solve the problem, clarity in establishing what is necessary in order to understand the problem is achieved. Designers have the ability to work with uncertainty (pp. 15 and 26). In my practice, this ‘not knowing’ resulted in the creation of physical samples, material collecting and the creation of scenario boards with images (both found and created) and key words that indicate a theme or group. Cross, (2011, p. 74) describes this as parallel processes of cognition that all concurrently relate to the design task and allow the designer to interact with their constructs and reflect intuitively on the scenarios created. Jones (1980, p. 75) describes design strategies as actions taken to transform a design brief and the methods used to make a final design. Reflecting on the first design action allows the strategy to be adapted that in turn informs the next design action. Similarly to conversation theory it is a cyclical process, a pattern of loops that on reflection indicate the next move.

Craft making and industrial manufacturing

Cross (2011, p. 4) suggests that traditional societies, in using craft processes, design whilst making the object without necessarily mapping beforehand. Jones (1980, p. 15) observes that craft makers do not draw their work or give reasons for the decisions they make. The craft product is modified by several iterations over time. In contrast, industrial societies design prior to making: through the process of designing, the problem and solution develop. Sketching or model-making are tools of exploration that establish a series of ‘external representations’, visualising and therefore communicating the problem and its solution. This process allows the designer to consider many facets of the problem simultaneously, establishing a discourse through interaction with the external representations (Cross, 2011, p. 12).

Additionally, the designer will work with uncertainty, experiencing different levels of perception pertaining to the design problem concurrently (p. 26).

In his summary Cross considers that it is through case studies of designers at work that a ‘research- based understanding’ of the ‘natural intelligence’ intrinsic to design is better understood. Efforts to understand the design process by systematic ordering were insufficient to accommodate the importance of tacit knowledge and its contribution to the design process (p. 29). The methods of an inventive designer, he suggests, are not systematic: their strategic approach involves maintaining the activity of design at several levels at the same time. This is achieved by sketching, modelling and other ways of making that facilitate and support this ‘parallel working’ (p. 74).

As a designer/maker I use the act of creating an object or fabric through combining different materials as a way of understanding the potential and capabilities of the materials. The results tacitly suggest ‘partial solutions’, which Cross (2001, p. 82) identifies as one of three aspects of ‘design cognition’. He suggests that problems are defined by concepts for their solutions, the two working in tandem in an iterative way, the characteristics of design understanding being the formulation of the problem, the generation of solutions or part solutions and the process tactics employed (p. 81).

In his case study of Gordon Murray, the Formula 1 automotive designer, Cross (2011, p. 51) unpicks his design process and ways of working, revealing that Murray uses a full-scale drawing, similar to Harley Earl’s approach (described in Chapter 3). In my own practice I work to real-life scale as a tool to fully visualise the prototypes. It is not possible to make a scale model of a textile: one cannot scale down the fibre or yarn, and a small fabric sample gives only an indication of how it may behave and look when applied to a product, in this case to cover a seat or interior panel surface. Similarly, small-scale experiments with bio-resin can only indicate behavioural characteristics and visual identity; it is only when an attempt is made to construct the part at full scale that the consequences of using the material can be fully explored and assessed.

Problem and solution developing together

In communicating, mainly to myself, through the samples I made I was formulating the problems by making partial solutions. Cross (2001, p. 82) suggests that by creating solution ideas designers are defining the problem. From this he reflects that designers are ‘solution-led, not problem-led’. For designers their emphasis is on appraising potential solutions rather than examining the problem, which, suggest Dorst and Cross (2001, p. 425), is why solution ideas are employed to understand the problem. In their paper they locate aspects of creativity in design in relation to articulating the design problem and the idea of originality. They consider a core part of creativity is through defining and framing the design problem, which is achieved by co-evolution of the problem and solution (p.431). They suggest this is achieved with a continuous iteration between examination, putting together and assessment processes across the problem area and solution area. Cross (2001, p. 82) suggests that in this process designers exercise their right to alter the aims and limits they are working within as they gain a fuller comprehension of the problem and clarify the focus of the solution.

To some extent my working methods, particularly in respect of the textiles, rely on previous knowledge and experience, which can be described as tacit. It is also intuitive, which Cross (2001, p. 79) suggests is suitable for design processes, although it appears to be theoretically without principle.

Seitamaa-Hakkarainen and Hakkarainen (2001, p. 63), in their study of the differences in approach to weaving design processes between beginners and experts, conclude that the experts were able to work in parallel with the visual and technical aspects of the task, whereas the beginners tended to focus on the visual. I find that there can be a tension between the two areas, one pulling the other, informing the direction of the work, the decorative or visual element being only one aspect of the design process.

Problem framing

Cross (2001, p. 89) suggests that in the process of design incomplete representations of the problem area and solution area are made in parallel with the significant progress made through connecting or ‘bridging’ between the problem and solution through the articulation of a tangible idea. (pp. 89-90). The ‘bridge’ establishes the connection between the problem and solution. Cross (2001) argues that these two areas evolve together in the design process, and that it is through the search for solutions that the problem is fully understood and formed. Cross (2004, pp. 427-441) comments that in several examinations of expert design behaviour, in seeking early solution ‘conjectures’ designers use these as a tool to explore both the problem and solution in tandem. This allows the design problem to be ‘framed’ in relation to potential solutions. In addition, it offers designers freedom to shift their aims and restrictions through this parallel working as a deeper understanding of the problem and solution evolves (Cross, 2001, pp. 84 and 2004). He describes scoping within a wide context of the design problem as being typical of ‘reflective practice’, identified and described by Schön as ‘problem setting’. Schön suggested that in establishing the problem we ‘frame’ the design problem: establishing the edges, choosing certain things that need to be considered in order to place a consistency on the circumstance that will influence the next move (Cross, 2004, pp. 427-441).

Dorst and Cross (2001, p. 425), suggest that the ‘creative leap’ or sudden insight is an idea that is problematic, as there can be no assumption that this will occur: in addition, it is problematic to define how finding a solution can be considered ‘creative’.

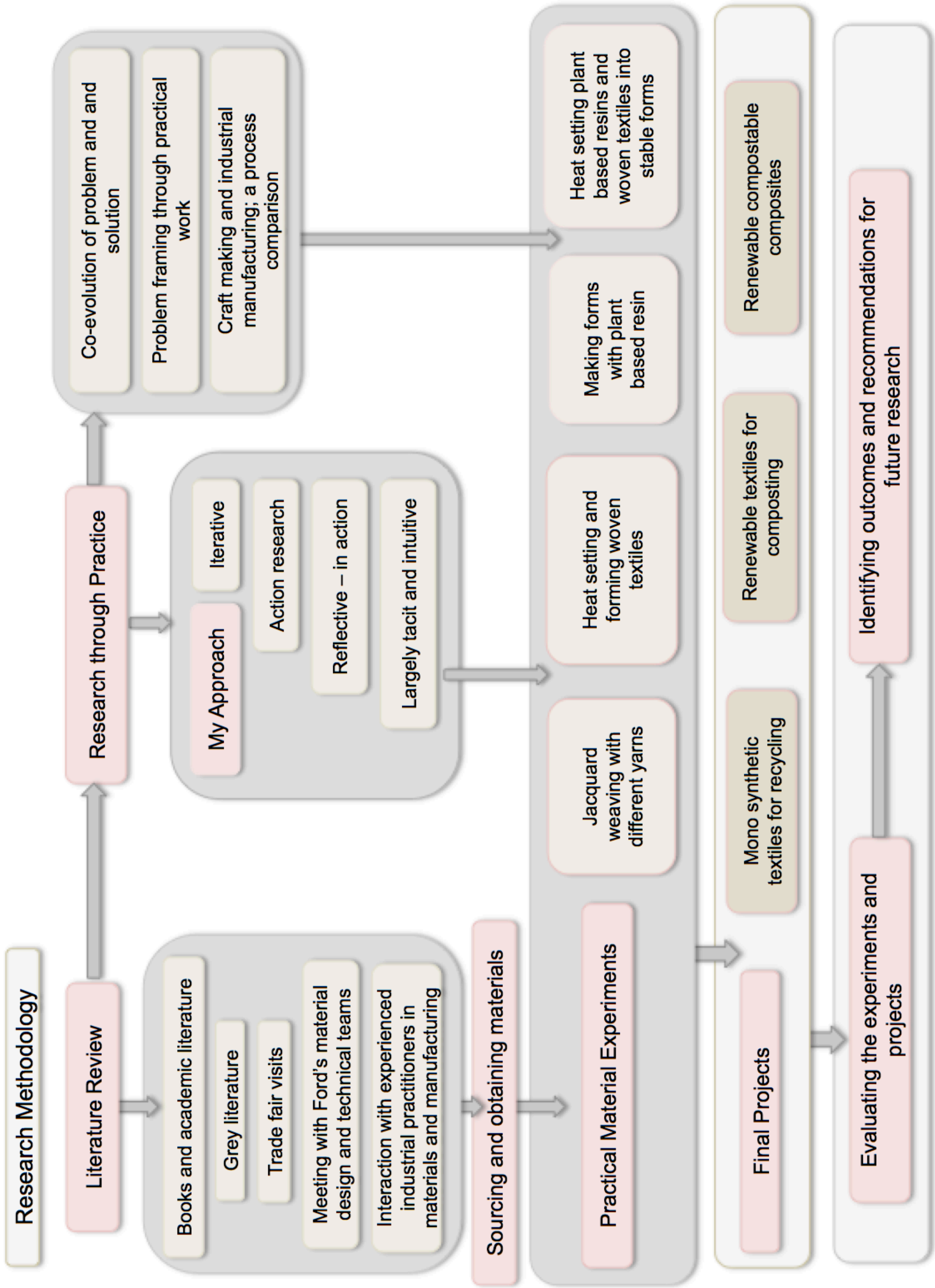

Diagram 1: Research Methods.

Research methods timeline

Research Method	2007/2008	2008/2009	2009/2010
Theoretical study.	Research methods course.	Research methods course.	Consideration of my research methods in relation to my practice.
Literature review.	Grey literature and books. Interior Motives Europe conference, June 2008.	Grey literature and books.	Grey literature and books. Natural Fibres' 09: Materials for a Low carbon Future - international conference.
I visited trade fairs, which allowed me to source materials, obtain samples of, to research trends and look for transferable ideas.	Pitti Filati January and July 2008. Geneva motor Show March 2008.	Pitti Filati January and July 2009. Techtextil June 2009.	Pitti Filati January and July 2010. Automotive Interiors Expo June 2010.
Experiments at the RCA.	Jacquard weaving with various yarns. Finishing the fabrics: washing, steaming and heat setting.	Jacquard weaving with various yarns. Finishing the fabrics: washing, steaming and heat setting.	Jacquard weaving with various yarns. Finishing the fabrics: washing, steaming and heat setting. Experiments with textiles in glass and moulded forms. Clear 'bio-resin' samples with textiles.
Meetings with the Ford Motor Company.			Meeting to discuss the PhD and agree the loan of the Fiesta, delivered 2nd March 2010. Meeting 17th May 2010.
Mono synthetic textiles for recycling project.			Meetings with Guilford Textile design and production teams.
Renewable textiles for composting.			Selected the shades and received Scholler wool yarns.
Renewable compostable composites project.			
Renewable compostable composites: biotex.			
Industry visits.			Lenzing AG, 9th November 2009. NSG (Pilkington) glass, 10th January 2010.

Research Method	**2010/2011**	**2011/2012**	**2012/2013**
Theoretical study.	Consideration of my research methods in relation to my practice.	Consideration of my research methods in relation to my practice.	Consideration of my research methods in relation to my practice.
Literature review.	Grey literature and books.	Grey literature and books.	Grey literature, books and academic journal papers.
I visited trade fairs, which allowed me to source materials, obtain samples of, to research trends and look for transferable ideas.	Automotive Interiors Expo May 2011. Pitti Filati January and July 2011. Techtextil June 2011.	Pitti Filati July 2012. Geneva Motor Show March 2012.	Pitti Filati January 2013.
Experiments at the RCA.	Experiments with bio-resin in silicon cooking moulds. Experiments with bio-resin in pobble moulds.	Experiments with bio-resin in pobble moulds.	
Meetings with the Ford Motor Company.		Meeting with Ford, 10th April and 6th September 2012.	
Mono synthetic textiles for recycling project.	Visited Guilford Textiles, 8th April 2011. Met with Ames.	Guilford Textiles received the recycled yarns from Antex, May 2012. Warp knotted in and designs woven, August 2012. Fabrics laminated to Ames spacer textiles November 2012.	
Renewable textiles for composting.	Meetings with Camira, 28th July and 8th August 2011.	Meeting with Camira, 2nd February 2012.	
Renewable compostable composites project.	Meeting with Cambridge Biopolymers, March 2011. Made glove box lid mould, 2011. Meeting at Bronze Age, 10th May 2011.	Meeting with Cambridge Biopolymers. Made bio-resin glove box lids, 2012. Made door panel moulds at Bronze Age, 2012.	Made bio-resin door panels, March and September 2013.
Renewable compostable composites: biotex.		Meeting with Composites Evolution, 12th January 2012.	
Industry visits.	Bridge of Weir Leather and Bute Fabrics 3rd/4th February 2011. Faurecia, 26th April 2011. Laxtons, 27th July 2011. Johnsons Control. 12th September 2011. Invent Interior Solutions, 26th July 2011.	Baltex, 11th April 2012. Composites Evolution, 12th January 2012.	Fiesta transported to Dove, Norfolk, May 2013.

Research Method	2013/2014	2014/2015	2015/2016
Theoretical study.	Analysis of my research methods.	Aligning my research methods with theory.	Aligning my research methods with theory.
Literature review.	Grey literature, books and academic journal papers.	Grey literature, books, archives and academic journal papers.	Grey literature, books, archives and academic journal papers.
I visited trade fairs, which allowed me to source materials, obtain samples of them, to research trends and look for transferable ideas.	Pitti Filati January and July 2014. Aircraft Interiors April 2014.	Pitti Filati January 2015. Index Nonwovens April 2015.	Pitti Filati July 2016.
Experiments at the RCA.	Laying out my work to evaluate and group.	Laying out my work to evaluate and group.	Laying out my work to evaluate and group.
Meetings with the Ford Motor Company.	Meeting with the colour, material & finish team and Cambridge Biopolymers, 21st August 2014.	Meeting with the colour, material & finish and trim teams, 29th May 2015.	
Mono synthetic textiles for recycling project.		Northhampton University 9th December 2014: SEM testing of nano silver textile.	Made children's car seat covers.
Renewable textiles for composting.	Meeting with Camira in London, January 2014. Weave designs sent to Camira April 2014.	Scoeller yarns sent to Camira, 12th August 2014.	Yarns split and warp made, 14th January 2014. Camira: wool/nettle textiles woven, 19th January 2015
Renewable compostable composites project.	Receive painted door panel and other parts from Mankiewicz, July 2014.	Dove fit painted door panel and bio-resin panel to car door.	
Renewable compostable composites: Biotex.	Meeting with Composites Evolution, 3rd December 2013.	Heat setting experiments with Biotex, my textiles and pobble moulds.	Heat setting experiments with Biotex, my textiles and pobble moulds.
Industry visits.	Meeting with Mankiewicz April 2014.		

Table 4: Research Methods Timeline.

Research Method	2016/2017	2017/2018
Theoretical study.	Aligning my research methods with theory.	Aligning my research methods with theory.
Literature review.	Grey literature, books, archives and academic journal papers.	Grey literature, books, archives and academic journal papers.
I visited trade fairs, which allowed me to source materials, obtain samples of, to research trends and look for transferable ideas.	Pitti Filati January and July 2017.	Pitti Filat January and July 2018.
Experiments at the RCA.	Laying out my work to evaluate and group.	Laying out my work to evaluate and group.
Meetings with the Ford Motor Company.		
Mono synthetic textiles for recycling project.		
Renewable textiles for composting.		
Renewable compostable composites project.		
Renewable compostable composites: biotex.	Larger scale heat setting experiments with Biotex and my fabrics.	
Industry visits.		

Chapter Conclusions

The main theme in my research methods is that the problem, solution and question developed from my engagement with the practice. Committing early to partial solution or solution conjectures allowed me to explore the problem and solution spaces simultaneously. What I thought I was doing changed through the emerging process of design. As the work evolved I recognised that what I had initially perceived as my design brief was not fixed because the work changed my thinking about what the brief should be. This connects with Cross's idea of bridge-building between problem and solution: the problem and solution developing together as the understanding of the task deepens. The problem is framed by this cyclical process and iterative way of working.

Having an iterative ‘conversation’ with the things I made and reflecting on them helped to connect and evaluate my thought processes and the things I had made. My thought processes and actions were adaptive as the work, thinking and evaluation developed.

Evaluation and reflection on my practice was done through laying out the samples and grouping them, which enabled me to see connections and themes emerging in the work. This was followed by mapping them out, assessing them, which facilitated decisions on further action. The work was an external representation of my thought processes. These ‘conversations’ with the work I had made allowed me to communicate my ideas not only to myself but also to others. In turn this encouraged verbal exchanges and new ideas and approaches in order to develop the practice further.

My understanding of research methods evolved similarly to Archer’s, that real world designing is a messy process that cannot follow a linear systematic approach. It involves intuition, is cyclical, iterative, tacit and is a search to understand and connect the problem with the solution.

Chapter 3: Material evolution in relation to design in automotive interiors

Summary

This chapter is intended to set the scene of material use in vehicles and how this evolved. I also discuss the transition from craft to mass production facilitating the growth of material consumption, and in turn the way cars were made and the materials that were used to make them.

As a precursor to Chapters 5, 6 and 7, which describe the projects, this chapter charts the evolution of materials alongside their application in automotive interiors. Using the work of Henry Ford (Ford Motor Company) and Harley Earl (General Motors) as case studies, the use of natural, man-made, synthetic and waste materials is followed in the context of personal mobility vehicles, in the setting of the period.

I have investigated these historic approaches in order to understand how material use in automotive interiors shifted from natural to man-made, and what economic, performance and manufacturing factors – in conjunction with the world situation at the time – contributed to this. Conversations with industrial material suppliers and manufacturers, and research into the automotive industry's contemporary material usage led to me look back in order to establish points that are relevant to the industry today and in the future.

As my projects developed I found that companies such as Ford (for example with their continuing developments with soy foam) and others were revisiting historic material use. In order to position the projects as viable today I wanted to understand the evolution of material use in relation to automotive interiors. Through investigating how and why things developed in the way that they did I intended to establish a context that would inform and position the practical work.

The move from natural to man-made materials is exemplified by the different approaches to material use by Henry Ford and General Motors (GM). Ford's work epitomises sustainable objectives such as the utilisation of waste and material developments from agricultural sources. His interest in the material science of 'farm chemurgy', in which he sought to source materials derived from plants, can be viewed as a precursor to bio-engineered and bio-derived materials today. Ford sought to be self-reliant in order to control costs, which can be aligned with today's

shift towards vertical production and manufacturing, of which Johnson Controls[1] is a contemporary example. To this end he aimed, where possible, to use locally produced materials: a modern example can be seen in the Fiat Brazil project, which is discussed in Chapter 4. Henry Ford wanted his materials to provide absolute precision in the parts that they were used for. At the time he noted that 'materials were abundant' but that the labour required to obtain them should be valued, which led to his conserving their use (Ford and Crowther, 1926, p.91).

GM's use of man-made materials was facilitated by their connection with DuPont: these materials were used to support their approach through styling. In promoting these 'scientific' materials an emphasis was made on their 'superior performance' to natural alternatives. External economic forces following the World Wars had pushed up costs and resulted in shortages of available materials. GM introduced the annual model change to increase sales, producing 'planned obsolescence', which is at odds with sustainable principles.

I have used the work of the styling studio of GM, overseen by Harley Earl, to evidence the influence of material use from a design perspective. GM used the work of their female designers as a marketing tool to influence customer purchase through a new design aesthetic. This included the 'modern appearance' of the man-made materials they employed, which connects their work with wider design influences of the time. It becomes clear that the aesthetics of vehicle materials cannot be considered separately from the sources, supply chains, manufacturing methods and so forth – the whole machinery of production and sales.

Materials provide function and performance, and contribute to safety in tandem with visual features through surface styling within the interior. These intertwined purposes combine engineering and technical considerations as well as contributing to the visual identity of the car. This juxtaposition of function and aesthetic is fundamental to the design attributes of automotive development. Material expectations - precision, consistent appearance, performance, safety and low cost, which are embedded in the automotive industry - are evident in the work of both Henry Ford and GM.

As the emerging automotive industry moved from craft making to mass production there was a shift from the use of natural materials to those that were predominantly man-made. The rationale for this was on many levels: to satisfy the increasing demand and to provide consistency of appearance, affordability and reliable

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[1] Johnson Controls are a Tier One supplier to the automotive industry.

[2] Rauch & Lang Electrics, Baker Electrics, Cleveland, Ohio.

[3] Pegamoid is waterproof varnish applied to surfaces in bookbinding and upholstery, imitation

performance. Marketing played a key role by presenting these new materials as 'scientific', as evidenced later in this chapter with archive material from DuPont and General Motors, which implied their superiority to natural materials.

From craft processes to mass production

In the late nineteenth century the emerging car industry adopted styles from horse drawn carriages and coaches. It was a natural progression to transfer coach-building skills to the production of automotive models for this growing market (Oliver, 1962, pp.19-25). Carriage builders used craft processes to shape the materials that were available at the time. In England they worked with varieties of wood such as ash or oak for the framework, mahogany for exterior panels, 'Quebec pine', which was a lighter, cheaper, more malleable choice, for non-visible parts and birch (Mclellan, 1975, pp. 21-23). Iron or steel were used for body plates that blacksmiths fitted to the frames.

Coachbuilders transferred their traditional 'composite body' concept, which Mclellan (pp. 24-25) describes as consisting of a frame made of wood covered with painted metal panels, to motor vehicles (Oliver, 1962, p. 45). Building the frame individually, by hand, meant that the materials could be adjusted to fit well ensuring that the overall finish was of a high standard (pp. 99 and 115). By using similar materials to create vehicle body forms the makers used their tacit knowledge of how best to craft them (Gartman, 1994, p. 28).

Mclellan (1975, p. 27) suggests that the shape and form of early motor vehicles was the result of an exchange between the coachbuilder and the client. Oliver (1962, pp. 98-99 and p. 115) discusses the interpretation that the individual craftsman would make in translating from drawings to vehicle bodies, through an intrinsic sense of proportion. Their experience of forming panels and building structural frames had led to an informal understanding of aesthetics (Gartman, 1994, pp. 29-30).

Car frames were delivered to coachmakers who fitted out the interiors, the last stage of body assembly. Gartman (p. 24) points out that early motor vehicles were intended to be chauffeur driven, subsequently having different material trim treatments in the respective sections. The driver's seating in the open-top cab area was trimmed with hard-wearing leather, whilst the enclosed passenger compartment tended to be upholstered with fabric. Oliver (1963, p. 53) describes the enclosed motor areas as being 'luxuriously furnished', treated like a domestic interior. Like Gartman he refers to the distinction in treatment between the high-quality material of the rear compartment and that of the drivers, which had more basic, ‘Spartan’ provision (p.69).

Individual ownership and use of early motor vehicles was the preserve of the wealthy, and representative of class status in society (Gartman, 1994, p. 30). A 1916 advertisement for an electric car by Baker, Rauch & Lang[2], refers to the ‘genuine coach work’ and their sixty years experience of building ‘Fashion’s equipages’ (The Henry Ford, 2017). The accompanying illustration is a drawn depiction of the vehicle with hat-wearing, female occupants in conversation (no driver is seen), attired in colourful floor-length dresses. Entitled ‘Comfort’, which references the spacious interior (to accommodate floor length clothing) and suggesting that the occupants will ‘find restful repose’, in conjunction with ease of use, suggests a context of the pursuit of leisure. Gartman (1994, p. 21) comments that this popularity in the social activities of the upper classes supported the transference of ‘elegant handcrafted coachwork’ to the interior fittings.

Descriptions of car interiors of the time detail the use of high-quality materials. Founded in 1720, Barker & Co., rebranded in 1905 as Barker & Co. (Coachbuilders) Ltd., constructed coach bodies for British royalty and the aristocracy. The quality of their work led to their selection by Rolls Royce as their sole supplier of car bodies (Oliver, 1962, p. 45-46). The materials employed in the rear compartment of a Barker body ‘mounted on a Rolls-Royce “Silver Ghost” chassis,’ (date unknown, Oliver, 1962, estimates this as 1914 or 1921), are described by Oliver as ‘not unrepresentative of the very high standard of design and workmanship that was a feature of this type of limousine.’ In reference to the materials, Oliver describes the seats, doors and lower partition as upholstered with ‘West of England cloth’ of a ‘light fawn colour’, which combined with the inlaid wood and privacy silk window blinds to create an opulent interior (p. 69).

By contrast, an early indication of the prioritising of cost efficiency in regard to material use in order to supply demand and increase profit can be seen in the *Autocar* article cited below. The labour of skilled workers hand-crafting the architecture of the vehicles was insufficient to meet demand at the time. The 1902 *Autocar* article reported on complaints from purchasers, ‘[…] cheap carriage bodies fitted by small agents who have economized by fitting unseasoned plywood bodies, upholstered in common cloth or pegamoid[3] and stuffed with hay or some kind of

[2] Rauch & Lang Electrics, Baker Electrics, Cleveland, Ohio.

[3] Pegamoid is waterproof varnish applied to surfaces in bookbinding and upholstery, imitation leather.

herbs. Even the cushions were not fitted with springs' (Mclellan, 1975, p. 29). This can be seen as evidence of the continued pressure to produce low-cost vehicles in which the affordability of the materials becomes a primary factor in relation to other considerations. However, customer demand continues to require good standards of performance and comfort. Volume car manufacturers have continued to be squeezed between customer demand for reliable, consistently high quality and fierce price competition.

Plastics, materials shortage and scientific developments

Looking back at the history of automotive materials demonstrates that the use of natural materials was challenged by man-made material developments. These were marketed in several ways, including their promotion as 'scientific', implying that they were superior to natural materials with improved attributes regarding performance, durability and wear, visual aesthetics and health benefits. Additionally, these new material developments could be manufactured to meet demand, as well as being uniform in appearance and lower in cost.

The history surrounding the development of man-made materials in the US by DuPont in conjunction with their connection to General Motors exemplifies how these became ubiquitous in automotive interiors.

In the early 1900s the American explosives manufacturer DuPont had established two approaches to research. Applied research, focusing on developing new products or new applications for existing products, was conducted at their Experimental Station (in Wilmington, Delaware), while their Eastern Laboratory focused on basic research that explored the potential for scientific experimentation to discover new possibilities unconnected with a particular product or field. To diversify from explosives, in 1904 they purchased the International Smokeless Powder and Chemical Company, which also produced pyroxylin lacquers (DuPont, 2017). Cellulose nitrate and pyroxylin are terms used for the lower nitrates, which although highly flammable are not explosive (the higher nitrates are explosive and are termed nitrocellulose). First used as plastic in England in 1855, cellulose nitrate was combined with camphor and castor oil, which hardened it and rendered it non-explosive. Called Parkesine, it is a tough thermoplastic (Brady, Clauser, Vaccari, 1997, pp. 185-186).

DuPont marketed its patented leather alternative as 'Fabrikoid, Motor Quality', the base being '…a specially woven, very strong cotton cloth' with a pyroxylin surface.

The coating process had been developed by the Fabrikoid Company, which DuPont purchased in 1910, similarly to broaden their activities from manufacturing explosives as well as to expand the market for 'soluble cotton' (*DuPont Magazine*, 1919, c, p.19).

Increase in demand for leather to furnish automotive interiors, in conjunction with its necessary use in military vehicles due to the 'severe requirements' specified by the US government resulted in supply being overstretched. Leather hides were split into layers, the top surface being thinly separated for bookbinding, the second level, which was thicker, retained a natural grain and was used for vehicle and furniture upholstery due to its durability in comparison to the underneath 'splits'. The third layer was even thicker, but had no grain, and the fourth was much thicker and pulp-like; both were coated and embossed to create the appearance of grain leather. Referred to as 'coated splits', they were described in an advertisement by DuPont in 1915 as being 'inferior to the material sold as *artificial leather* for upholstery of automobiles, furniture and buggies' (*The Literary Digest*, 1915, h, p. 427).

Several DuPont advertisements in 1915 indicated the need for an alternative to leather with the slogan 'How Many Hides Has a Cow?' (*Collier's*, 1915, a, p.35), 'How Many Hides Has A Cow? The Truth about Leather' (*The Literary Digest*, 1915, f, p. 1500). Followed by a sequel 'How Many Cars Have Hides?' (*The Literary Digest*, 1915, l, p. 1500) and they extolled Fabrikoid's benefits as having the '[…] artistic appearance and luxury of real grain leather, and in addition it is waterproof, washable […]' as well as resistant to 'grease, oil, perspiration and mildew […]' It was available in many weights, colours, embossed patterns and finishes (*DuPont Magazine*, 1919, b, pp. 26-27; 1919, c, pp. 17-20).

Evidence from this early marketing demonstrates the perceived need for substitutes for leather, which were initially put forward as a replacement due to military priorities. However, this perception is later presented as indicating that in some respects these substitutes were *superior* to naturally sourced equivalents.

Using the shortage of leather and its high price (*The Literary Digest,* 1915, l, p. 1500), due to priority use by the military in the First World War, as leverage to influence and encourage consumer choice toward this product, DuPont stated in its promotional material that 'What Uncle Sam has found by experience and tests good enough for the Government's severe requirements should be good enough for every loyal American.' (*The Review of Reviews,* 1917, p.101). This appeal to the moral conscience of patriotic Americans through marketing campaigns in order to influence their purchase choice is a method that could be construed as a precursor to contemporary consumer pressure regarding sustainability.

Insight into the division of material use for automotive upholstery is provided by a further advertisement in *The Literary Digest,* in which DuPont states that 'About 20 per cent of the new pleasure cars sold in 1915 were upholstered in hides or hides splits. About 10 per cent were upholstered in cloth. Of the remaining 70 per cent upholstered in leather substitutes, the majority were in Du Pont Fabrikoid, Motor Quality.' This 'majority' of 70 per cent might indicate a figure of just over a half, that is about 50 per cent of 70 per cent, or just over one third of the total, which is quite a considerable amount (*The Literary Digest,* I, 1915, p. 1500).

Performance

There are recurring themes in the Fabrikoid Motor Quality promotional material: an emphasis on performance and aesthetic appearance in conjunction with availability and low cost. Following the influenza epidemic, hygiene, the resistance to 'dust and germs' was an additional performance factor described as an attribute of Fabrikoid Craftsman's Quality, used in home and public interiors, such as cinemas (*DuPont Magazine*, 1919,d, pp. 20-21). Du Pont emphasised that these products were not competing with 'real grain leather' but were a 'scientific substitute' offering enhanced performance properties and aesthetics (*The Literary Digest,* 1915, I, p.1500). The advertising continued to emphasise that these leather substitutes were elevated 'from the weak position of an imitation of something better to one of superiority over three-fourths of the leather made' (in reference to splits) (*DuPont Magazine*, 1919, c, p.19).

In marketing the product as distinct from an imitation leather, Du Pont implied that their man-made material was more advanced than natural material equivalents. This communicated to the public a sense of security and confidence in choosing these products, subliminally implying discernment of choice and a forward-looking approach. Additionally, it can be construed as increasing expectations of perfection in the material product, through a uniformity of appearance and reliable performance.

Technical aspects of material use are referenced in articles and the marketing of Fabrikoid in which its lighter weight is connected to the vehicle's performance. Additionally, indication is given as to the variety of conditions that the material must withstand whilst retaining a good appearance and functionality, demonstrating the necessity for high performance.

Fabrikoid was used in aircraft at this time, when the interiors were open to the elements, mainly due to its property of impermeability. Moisture absorption followed by freezing at high altitude would increase weight and reduce the flexibility of materials used in the open-cockpit 'flying machines', affecting the performance adversely (*DuPont Magazine,* 1919, I, p. 18).

Reference is made to the effect of the material on driving experience, vehicle performance and cost in the advertising of Rayntite Fabrikoid: 'Light Tops Lessen Upkeep' (DuPont advertising, 1916), arguing that 'vibration' and 'side sway' are increased when there is more weight higher on the vehicle, resulting in extra stress on 'springs and bearings', which in turn requires more repair cost. DuPont proposed this 'waterproof, light and strong' solution as more effective than cloth layered with 'combiners', and claimed it to was 50 per cent lighter than comparable contemporary vehicle roof coverings (*The Literary Digest*, I, 1916, p. 1765). Enclosing the complete vehicle with metal was too heavy for the engine (Gartman, 1994, p. 27). Material performance requirements involved in driving the vehicle are described as 'Heat, cold, rain, snow, dryness, alkali dust, atmospheric gases,' alongside the ability to retain a consistent appearance and '…chemical stability'. The demands on the material suggest to the consumer that it is *superior* to a natural material.

Aesthetics

In an article in the *DuPont Magazine* in 1919, reference is made to the necessity for craft skills to be developed on a wider geographical scale, rather than merely in local areas, as required for the increased demand due to the popularity of covered roofing solutions (*Du Pont Magazine*, 1919, I, p.26). The skills for producing the 'tops' was noted as having spread from 'California and the West Coast' to the 'Middle West and the East'. The article describes the 'Class top', which was an addition to the ordinary open car as bringing 'elegance', 'individuality and beauty of the fine custom-built model'. The article continues by referring to automotive design in relation to, 'Moorish Fabrikoid', which is adaptable to any vehicle type, '[…] designed to conform to and accentuate the lines of the particular car on which it is built'. In order to provide functionality and protection from the elements, and to enhance the driving experience by lessening vibration the 'tops' were also marketed as adding to the aesthetic appearance of the vehicles. However, they did not consist solely of a material skin but were upholstered over a wooden frame. The frame was covered with webbing over which canvas was stretched, followed by a thick layer of curled hair: cotton wadding was then added and sculpted into the required form, then held with muslin with the final addition of the Fabrikoid stretched into place and secured (p. 26).

The automobile needed approximately 15 yards of leather alternative in five different grades for the roof canopy, upholstery and curtains (Ford and Crowther, 1926, pp. 64-65). Ford developed his own facility and recipe for a continuous coating and embossing process in order to be self-reliant and control costs. Outlining the contents of the coating substance as '[…] a mixture of castor oil and drop black with a preparation of nitrated cotton dissolved in ethyl acetate and thinned with benzol', Ford noted that there was no artificial lighting in the premises due to the volatile substances employed within them.

An alternative material solution for roof coverings at the time was rubber-coated fabric. The textile, coated with a thin film of rubber was bonded to another similarly coated piece and placed under pressured rollers. The sandwich filling of rubber made the material resistant to water seepage, whilst the double, woven textile layer increased strength and reduced the likelihood of tearing (Abraham, 1919, g, pp. 3-4 and 32). Calendaring was another method used, in which the fabric was coated with rubber, embossed with a texture or grain and then vulcanised. Its use in relation to vehicle design was described as '[…] making rubber highly impermeable, which together with its natural flexibility and wear resisting qualities make it peculiarly fitted to stand the rough usage and exposure to which an automotive top is subjected' (pp. 4 and 32).

Fabrikoid, Craftsman Quality was suggested as 'The Supreme Auto Finish' after it was bonded to the metal exterior of a 'Cadillac Eight' (*DuPont Magazine*, 1919, b, p.28). It was described as offering an individual, well-maintained look that would last and improve with time as the colours softened and darkened. It is interesting that DuPont promoted the changes in the material over time as an improvement, suggesting the shift in appearance as a positive benefit. It was marketed as an easy-care solution in comparison to paint and varnish that was liable to 'crack, blister, scratch, mar or chip off'. It also solved the problem of reflective glare of painted metal (*DuPont Magazine*, 1919, b, p. 28; g, p. 22). In addition it held parts of the exterior together in case of accidents and harsh weather conditions (Berwald, 1920, pp. 8-9). Citing its durability, and therefore ability to maintain a 'good appearance', in their marketing for Fabrikoid, DuPont extended its use for interior products to include flooring rugs, truck and railway seat covers and home furnishings.

In 1915 DuPont bought The Arlington Company, which further developed their market in nitrocellulose, pyroxylin-based plastics. At the time the material was focused on products such as toiletry accessories such as combs and hand-held mirror casings, or easily cleaned detachable collars: however, the material was also used for automobile side curtains. The research programme developed transparent pyroxylin plastics, including ‘Py-ra-lin’. DuPont acquired the Viscoloid Company ten years later, which continued their connection to pyroxylin plastics. Py-ra-lin was marketed as a safe, performance material for automotive windows, ‘Clear, durable, flexible, transparent sheeting…’ available in different thicknesses that would withstand the various stress factors of the vehicle (*DuPont Magazine*, 1919, d, p.21). It was also used in aviation for windscreens, which were described as evolving in a similar way to those in other vehicles, ‘[…] utility first, then the refinements.’ (*DuPont Magazine*, 1919, I, p.24 and p.32). In an article entitled. ‘The Menace of Glass’ (*DuPont Magazine*, 1919, g, p. 26) incidents were cited of car accidents in which impact had shattered glass windows, causing injury: the article described a product called ‘Safetee Glass’, consisting of Pyralin ‘welded’ with heat and pressure between two sheets of glass that did not shatter. The rise of synthetic materials was aided by marketing that presented them as, in the case of Py-ra-lin used in transport, safer, more efficient, and versatile than the use of a traditional material such as glass. Additionally there is the suggestion that these products are ‘superior’ to traditional materials because of ‘scientific’ advances at the time.

It was in 1917 that DuPont entered the paint and coatings market that proved unprofitable until 1920 when chemists developed DuPont’s most successful coating. The chemists were working on improvements to nitrocellulose film and developed a fast drying hardwearing lacquer. Marketed as ‘Duco’, in 1922. Duco had a significant impact on the car industry as it reduced the drying time of exterior paint from several days to hours. General Motors applied it to their models as standard a few years later: the first car was in production in 1923 (Sloan, 1963, p. 236; DuPont, 2017).

Gartman (1994, p. 29) describes the exterior paint process of the Overland automobile in 1911, which included ‘[…] the application of ten coats of paint varnish, and filler, which required two weeks’ of time.’ Sloan (1963, p. 235) comments that the process ‘[…] was slow and cumbersome’, taking between two and four weeks. Reducing the manual time spent on painting was aided by the introduction of spray and gravity painting. Drying in heated ovens between the individual applications of paint layers accelerated the process from weeks to days. The use of enamels was a temporary solution employed by Ford: however, the high temperature (175º to 200ºF) used in baking the paint dry caused the wooden frames to warp and colours to alter: using all steel for bodies and framework resolved these issues of distortion (Gartman, 1994, pp. 44-45). In 1914 Ford ceased using coloured finishes on the Model T, and produced them only in black. Credited with the comment that varies from: ‘Sell them any colour as long as it’s black’ (Mclellan, 1975, p. 85) to alternatively ‘any customer can have a car painted any colour as long as it is black’ (Gartman, 1994, p.46) Ford was, suggests Mclellan, referencing to the fact that the original enamels used in this baking process were only available in black.

Sloan discusses the expense, and limited colour options, of the ‘paint-and-varnish period’, which was succeeded by the ‘enamel period’, in the context of the introduction of Duco[4] finishes which lowered cost, increased colour options and significantly reduced drying time. The latter resulted in the quickening of the pace of production, allowing the completion of a car in ‘an eight hour shift’ (Sloan, 1963, p. 236).

Mass production

Individual ownership and use of automobiles was, in the early years primarily the preserve of the wealthy; it was Henry Ford who undeniably changed this by mass-producing cars and paying his workers decent wages to enable them to purchase them, to buy into an affordable vision (Ford and Crowther, 1926, p.9). The industrial manufacture of reasonably priced cars, specifically the Model T from 1908 - 1927, meant that hand processes were diminished, resulting in a reduction in the quality of finish (Gartman, 1994, p.39). In the UK, products from the Bridge of Weir Leather Company, founded by Andrew Muirhead in 1905, were used to upholster Scottish trams and buses before they began to be used for automotive interiors. When the first facility to manufacture the Model T outside the US was opened in Manchester in 1911, Bridge of Weir leather was specified for the interiors (Johnathan Muirhead, 2005, p. 2).

Henry Ford had a keen interest in material science, as well as engineering and manufacturing systems. He was brought up on a farm and was curious to investigate the potential of agriculturally farmed products for industrial use thereby increasing their commodity value (Wik, 1972, pp. 148-149). A new agricultural concept emerged in 1928: ‘farm chemurgy’, which allied science, specifically chemistry, with agriculture (Lewis, 1976, pp. 282-287). This combination of industrial and agricultural sciences had the intention of providing the needs of industry from agricultural sources. Later in life, 1937, Ford met George Washington Carver, a chemist from the Tuskegee Institute, who shared similar interests. Skrabec (2013, p. 5) describes their philosophy thus, ‘They believed in biofuels, clean alternative energy sources,

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4 Duco was developed by DuPont chemists in 1920 as a quick drying, durable lacquer. Marketed under the trade name ‘Duco’ in four years it became the standard finish on GMs vehicle models. (DuPont ‘Innovation starts here – 1917 Paints and Coatings).

recycling, conservation, new uses for plants, industrial materials from agriculture, and smokeless rural factories.'

Describing Ford's 'vision' as progressive and in alignment with 'the present day ecology movement' Wik (1972, p. 143) notes that he disliked waste, preferring to recycle used items in conjunction with his desire to find uses from plant sources. In order to research which plants or vegetable types would be the most productive for such an endeavour, Ford established a laboratory in 1929 at Dearborn, which formed part of the Edison Institute of Technology established by Ford with Thomas Edison (Lewis, 1976, pp. 282-287). Ford's perception of value in farm crop surplus encouraged chemists to investigate its conversion into products, which would give the waste, '[…]wheat, corn, carrots, cabbage, sunflowers, straw, weeds and corn cobs' value. Ukkleberg, reminisced that Ford would suggest, "Now, we've got all this waste. Let's see if we can't do something with it" (Bombard, 1951, p.5) The, laboratory was managed by the chemist Robert Allen Boyer who was tasked with finding ways in which, organic compounds and oils could be derived from farm crops for use in industrial applications. According to records, he discussed his initial work there as 'extracting oil from orange peels, furfural from garbage, as well as work on wheat, soybeans and carrots' (Ford, 1989, p. 276 and The Henry Ford Archives).

In 1932 the outcome of this research resulted in Ford's decision to focus on growing soybeans, as Ford decided that this had the most potential for both farming and industrial uses (Ford, 1997, p. 112; Shurtleff and Aoyagi, 2004). Soybeans are a good source of oil, protein and fibre; they also replenish depleted soil with nitrogen (Nevins and Hill, 1962; Ford, 1997, p. 113). Imported from Asia in 1804, soybeans grew well across North America, and Ford invested heavily to ascertain their capacity for industrial application. Between 1932 and 1933 he had over 300 varieties planted on the Ford farms (covering 8,000 acres) in order to determine the best performing variety (Wik, 1972, p. 149; Ford, 1997, p. 112).

Processing the beans to extract oil was done by machine, which Ford's researchers had developed in order to find the best method. It crushed them into thin flakes and simultaneously exposed them to a petrol solvent that extracted the oil, through absorption. The remaining protein-rich meal was converted into small automobile interior parts such as switches and window trim strips. Soy oil was used in the development of high-quality enamel paint for the cars, door handles and other sundry plastic like parts, as well as fluid for shock absorbers (Lewis, 1987, pp. 282-287; Wik, 1972, p. 149). An advertisement for the Model T in 1935 used the heading 'We Paint Ford Cars With Soy Beans' (Ford Motor Company, 1935). Industrial products created from soybeans by the laboratories of the Edison Institute[5] were categorised on a 'souvenir card' (circa 1934) as 'soy bean oil', 'oil-free soy meal' and 'soybean stalks'.

Between 1933 and1934 Chicago hosted the Century of Progress International Exposition, a world's fair, which was aimed to inspire positivity during the Great Depression that occurred in the United States between 1929 and 1939. Materials featured prominently in the displays in the Ford Exhibition Building, which covered a site of approximately 11 acres. The presentation areas showcased informative exhibits about wool, cotton, rubber, soybean and cork. These naturally sourced materials were all used in the automobiles that the Ford Company was producing.

Some years later, in 1937, Boyer revealed a rounded plastic sheet that he had created derived from soybean, that was reputed to be more resistant to force than steel. Ford demonstrated this to journalists by jumping on a piece, and later, when it was a panel in his own car (1940) he forcibly hit it with an axe to show its resilience (Lewis, 1976, pp. 282-287). Boyer and Ford subsequently produced a complete car body made with this plastic material that was showcased in 1941. In an advertisement the material was described as '[…] made from plant fiber and soy bean resin binder.' An '[…] *all-vegetable* plastic […]' (Ford Institutional Advertising, 1941). The panels were attached to a tubular steel frame, which served the purpose of providing a structural skeleton over which the panels were skinned. In conjunction with Ford's claims of superior strength, another advantage was the reduction in weight: it was approximately 30 per cent lighter than steel automobiles, weighing 2000lbs.

According to the information held at the Benson Ford Research Center in Dearborn, no records of the exact recipe of the soybean-derived plastic mix used in the fourteen panels were retained. Some accounts describe the soybean plastic as being mixed with hemp, wheat, flax or ramie into a composite material, although there is no official evidence to support this. The Center refers to a documented interview with Mr Lowell E Overly, who under the supervision of Boyer, had overseen the project: he stated that it was composed of soybean fibre in a synthetic *'phenolic'* resin. In the same interview Overly also stated in the same interview that the car had been destroyed by Eugene Turenne Gregorie from Ford's design division for manufacturing.
There are three main reasons that provide the rationale for Henry Ford's keen interest in constructing such a vehicle. First it demonstrated a synergy between farming and industry, 'the equilibrium of farm and factory'. Second he claimed that

[5] The Edison Institute is the formal name of the 'The Henry Ford' also known as 'The Henry Ford Museum and Greenfield Village'.

the car was more resilient than steel-bodied vehicles and thus provided greater safety: finally there was a shortage of metal, and this material could be considered as an alternative (The Henry Ford, 2017).

Ford had worked on weight reduction for the Model T, which he achieved using vanadium steel[6]. At the prototype stage, the provision of a five-seat automotive made with steel was too heavy. The inclusion of vanadium with steel produced the required strength allowing thinner sheets to be made resulting in a lighter product (Skrabec, 2013, p.71).

The soybean car project was never developed any further than the early prototype stage: the start of the Second World War meant that all production of automobiles ceased (Lewis, 1976, pp. 282-287). When the war finished in 1945, all efforts were directed towards recovery programmes, and the project was never reinstated. Records state that although the concept had received a not inconsiderable amount of publicity, due to the use of foodstuffs, there were pragmatic technical concerns, as well as the fact it was not cost effective due to the curing time required (Lewis, 1976, pp. 282-287, Shurtleff and Aoyagi, 2004). There was also an over-supply of steel, which would have lowered the price. During World War II, a vast new steel capacity was underwritten by the U.S. government, (15 million new tons per year), which was part of the war mobilisation effort (Barfield, 2003, p. 39).

Ford's laboratory also developed soybean protein fibres using a chemical process similar to that used to make viscose, which was unveiled to the public at the New York World's Fair in 1939 (Wik, 1972, pp. 150-151). However, his vision that it would become the staple fibre for textiles and overtake the use of imported wool was never realised and his appeal to the US Federal Government to use the fibre in textiles for the army uniforms in the Second World War was unsuccessful. Ford perceived that such textiles could be created locally, whereas cotton needed to be transported over long distances: additionally, it was less expensive than wool (p. 150). Ford produced a woven fabric and then a suit from a combination of wool 75 per cent and 25 per cent soy-derived fibre: similarly a textile of the same composition was apparently used in aspects of the automotive interiors of 'many Ford cars' (Shurtleff and Aoyagi, 2004; *Detroit Times,* 1941).

In May 1937, Ford sponsored the Third Chemurgical Conference of Agriculture, Industry and Science at Dearborn, with a presentation by George Washington

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[6] Vanadium steel – a steel alloy containing 0.15 to 0.25 per cent vanadium to harden and toughen it.

Carver, ‘What Chemurgy Means to My People’, which highlighted Ford’s work with hemp (Skrabec, 2013, p. 154). This occurred prior to the enacting of US legislation in October that year that prohibited the growing of any form of the plant, due to its association with the illegal drug marijuana. At the time, oil from the plant was used in paints and varnish, and the fibre was used for rope, paper and durable textile production. A comparable material, flax, was advocated as a substitute: the plant produced long fibres for spinning, the shorter ‘tow’ fibres were used for upholstery filling and linseed oil was used in paints. Materials derived from both plants were employed in the production of Ford automobiles.

Ford’s interest in the sourcing of materials extended to the use of other plant fibres for textiles, and was mainly practical and economic. Ford cites the unstable situation of cotton (the boll weevil had infested crops in the US by the 1920’s) along with a desire to secure his company’s requirements at a lower price, in conjunction with the cost of transporting the fibre and fabric, as the rationale behind investigating an alternative (Ford, 1926 and Crowther, p. 56). From research they concluded that flax, which could be grown locally in Detroit, would be more suitable for motor applications. With long staple fibres, spun and woven flax produced a textile with greater strength than cotton. Undaunted by the labour intensity the crop demanded, Ford’s team experimented with mechanically sowing, harvesting, drying and separating of the fibre prior to spinning and weaving (pp. 56-61). The resulting textile was intended to replace cotton as the base for artificial leather, the production of which Ford also experimented with (pp. 64-65).

Salvaging waste to use it positively was explored at the Ford plants, where the engineers converted as much as possible for new end-uses. These included briquettes from wood shavings swept from the workshops, oil and gas for heating, and fertiliser, amongst others. According to records the finances accrued from selling these derived products was $20m in 1928, a not inconsiderable amount even by today’s standards (Wik, 1972, p. 151). The River Rouge plant converted waste to alcohol; redundant scraps of textiles and paper were reconstructed into cardboard at the paper mill and subsequently used in manufacturing.

‘Fordite’ was a composite replacement for wooden steering wheels that resembled hard rubber. In reference to using the ‘best quality wood’ as wasteful in conjunction with the difficulty of creating ‘absolute precision’, Ford deployed the use of straw waste from the Dearborn farm in combination with a ‘rubber base, sulphur, silica and other ingredients’ to fabricate a mix that was extruded through tubes, coated, treated with pressure and finally heated (Ford and Crowther, 1926, pp. 63-64).

Ford's investments to develop the provision and use of agriculturally sourced materials intended for utilisation in industrial manufacturing were extensive. From this material-focused aspect of Ford's vision - his interest in converting waste farm vegetation and crops into products, in recycling used items, and in conservation and nature - to some extent mirrors the ecological concerns, solutions and experiments that are current today (Skrabec, 2013, p. 5).

Ford described the focus of his research activities as singular, towards 'making motors and putting them on wheels'. In his book, *Today and Tomorrow*, published in 1926, he refers to 'the possible depletion of sources, to the saving of material, and to the finding of substitute materials and fuels.' Elsewhere he outlines his viewpoint as a concern for saving labour, which he equates with wasting materials, arguing that time taken in obtaining them should be valued. Reclamation of materials was less effective or efficient than not creating waste in the first instance (Ford, 1926, p. 91): 'The ideal is to have nothing to salvage'. In the context of the period he viewed natural resources as sufficient for the needs of society; his focus was on saving labour.

In 1928 Ford invested in the development of rubber plantations in Brazil with the intention of establishing an independent source of this material, an essential component of automotive production at the time. The US government supported the search for alternative industrial sources of rubber because it was heavily reliant on importing 75 per cent of the material to supply its needs for the automotive industry. This followed the stabilising of the world of rubber by the British Stevenson Plan in 1922. Having successfully cultivated the wild *Hervea basiliensis* (rubber-yielding) trees in its colonies in the Far East, British production (1905) had successfully defeated competition from Brazilian wild rubber (1913) (Ford, 1997, p. 152; ref: Wilson, 1941, g, pp.185-186).

Ford established two plantations, firstly the Boa Vista site which was renamed Fordlandia and in 1933 Belterra, with the support of the Brazilian government, which gave free land concessions in return for 7 per cent of the annual profits, in conjunction with 2 per cent towards local governing bodies after twelve years (Ford, 1997, p. 153). Ford's efforts to transfer his model of providing good conditions for his workers, which included medical and educational facilities and accommodation, accompanied by high wages in comparison to local equivalents, proved culturally difficult (p. 156). Ford's agricultural experience was environmentally challenged by pests, crop selection, inexperience in propagation methods and weather conditions, which together were contributory factors to the lack of expected rubber yields from the ventures (pp. 155-156).

Ford employed Dr James R. Weir, a plant pathologist, who organised an experimental laboratory in 1933 at the Belterra site. Belterra was 80 miles from Fordlandia and Weir had recommended that it would be more successful for the cultivation of rubber trees. At the laboratory they investigated the potential for growing other indigenous material products: wood varieties included teak, balsa, mahogany, eucalyptus, tamarind and kapok; fibre-producing plants such as sisal, hemp and jute, and spices, tea, cocoa, coconut, citrus fruit and banana trees. Soybean plants were grown between the spaced rubber trees (pp. 156-157). The intention was to support the workers and further support the ‘model community’ he had envisioned.

Ford abandoned the projects in 1945, handing the plantations to the Brazilian government (p. 160).

Figure 9 (next page 58) is a diagram that maps the materials used in a Ford automobile circa 1950. The materials are presented in relation to the parts in which they are used, illustrating an interconnection of systems. Many of the materials are obtained from renewable resources or from mining.

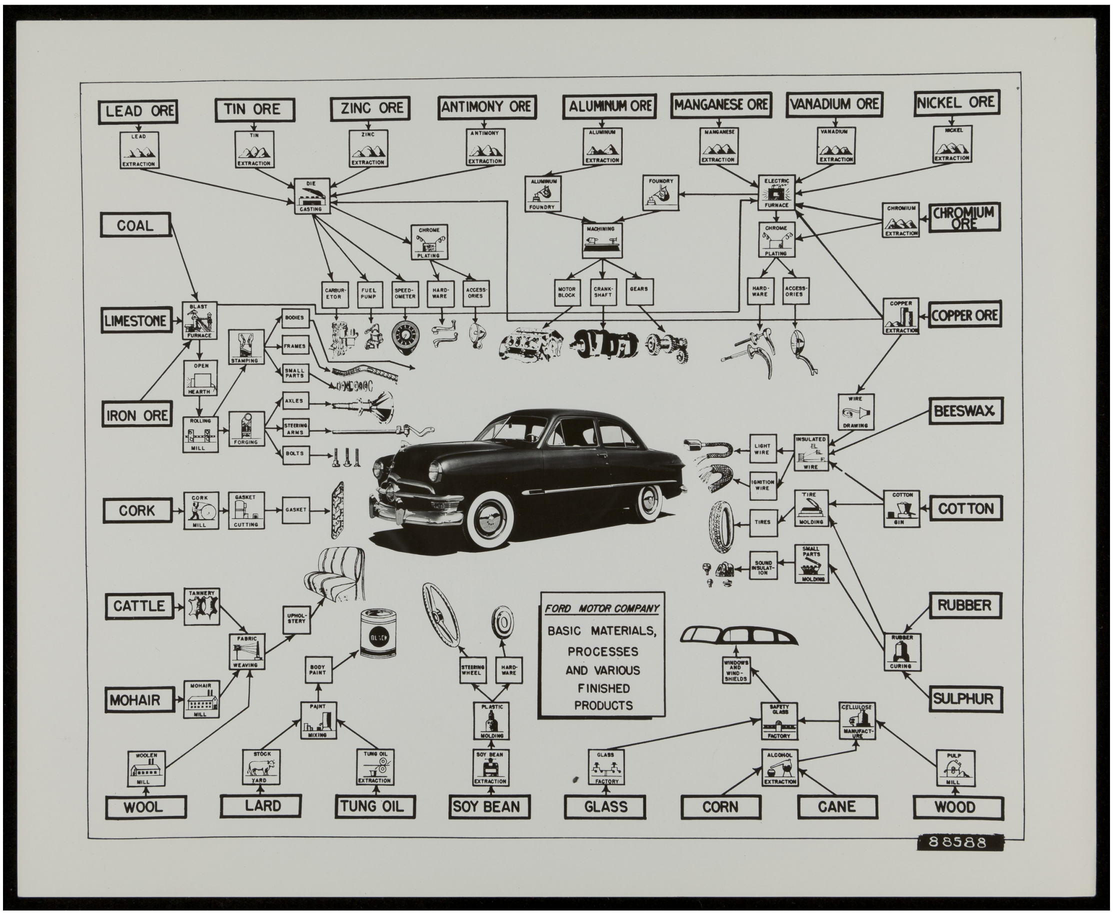

Figure 9: Basic materials, processes and various finished products, Ford Motor Company, 1950. The Henry Ford.

Styling, Harley Earl and General Motors

General Motors introduced the annual model change ‘planned obsolescence’, which is at odds with the principles of sustainability. Styling and the use of newly developed man-made materials were critical to creating their brand identity. Additionally, marketing was key in promoting the new models: most notably a team of female industrial designers were used in their publicity campaign, which affords some insight into their design procedures. These women selected colours and textiles as well as introducing new design features to the vehicle interiors. This evidences how the systems around material selection in relation to the design process were founded, such as the links with weaving mills and the way that textile craft weavers were employed to promote the new fibres and create ‘*discrete*’ designs for the vehicles (Brown, 1982, pp. 42-43). It also demonstrates the connection to the wider design influences that were involved in supporting the automotive industry’s growth, through their role in design education in conjunction with links to other innovative design areas of the time, such as architecture and furniture.

General Motors

Alfred Sloan categorised the growth of the American automotive industry into three distinct phases, the first being the elite, craft-fabricated motor cars that were based on carriage building produced up to1908, followed by and overlapping with the Ford Motor Company's single product strategy for a mass market, whilst the third phase he perceived as belonging to General Motors. According to Stephen Bayley, the intention was to capture 'the mass *class* market', the strategy being to offer '[…] a whole range of subtly graduated vehicles in the marketplace […]' (Bayley, 1990, p. 38).

In 1927 Harley Earl was invited by Sloan to establish a 'special new department' at General Motors to create and manage the art and colour aspects of the product line (Sloan, 1963, p. 269). The initial team, of 50 people, was briefed to research visionary vehicle concepts, integrating these with vehicle engineering. Earl had first-hand experience of the evolution from coach-building and the shift in 1911 to bespoke body-building for automobiles from his father's business, 'Earl Automobile Works', based in Hollywood, Los Angeles (Bayley, 1990, p. 23). The location eventually became synonymous with the disposable wealth of the movie industry moguls that supported the demand for custom-built vehicles.

Earl's division, renamed 'Styling' in 1937, was responsible for envisioning and then interpreting new ideas and applying these to actual models to test the public reaction to them, which later became known as 'planned obsolescence' (Bayley, 1990, pp. 104-110). The sales committee had, in 1925, introduced the concept of changing the identity of the vehicles on a yearly basis, integrated with production, which was slow to be realised (p. 57). Voting on a paper entitled 'Annual Models versus Constant Improvement' the committee were in support of innovation over convention in their strategy encouraged by Sloan (pp. 41 and 104). This is a concept that is profoundly at odds with sustainable principles; encouraging consumers to purchase a new vehicle because of its contemporary styling attributes.

With all resources and efforts directed towards the Second World War developments in car design were halted. In the immediate post-war period, ideas from the 1930s were revisited (Bayley, 1990, p. 69). Bayley (p. 65) describes the period of the 1950s as an 'ideas race' and Earl's view of the search for 'visual novelties' was that it was comparable to that of the entertainment industry. The concept of dream creation, and customers buying into an imagined ideal, resonates with Earl's Hollywood experience of producing bespoke, custom-made automobiles for movie stars, who were also creating imaginary lives on the big screen.

General Motors had five divisions and each product was aimed at a different customer in relation to price. The automobile form, or ‘architecture’, was developed by the Body Development Studio and employed across the divisions. Earl was responsible for the output from the studios and subsequently oversaw the design division’s application of differentiating concepts to the vehicle ‘architecture’. Bayley (1990, p. 86) describes the structure of the car as a main factor in limiting the designers’ input on the exterior to the front and back areas and the interior treatment, or ‘trim’. Each studio worked independently, unaware of the work of the other divisions, overseen solely by Earl, while automotive structures from the ‘Body Development Studio’ were used as tools to build individual visual identities for each division through the application of colour and materials (pp. 86-89).

The 1950s witnessed the increased emergence of competition between the manufacturers, led by automobile styling. Culturally, in Europe and America, cars were increasingly becoming status symbols, inspiring dreams and aspirations, evocatively sexual, powerful as well as functional. Predominantly seen as a male domain, automotive exterior design, with its roots embedded in engineering and mechanical origins, increasingly used women in its design teams. Their roles were, however, in the ‘low-ranking interior studios’ (Gartman, 1994, p. 166), involved in deciding on colour and fabrics, which, suggests Sparke, draws parallels with home-making (Sparke, 1999, p. 102). Sloan writes that General Motors was perhaps the first company to employ female automotive designers, aiming ‘to express the woman’s point of view’ (Sloan, 1963, p. 273)

General Motors hired one of the first female industrial designers Mary Ellen Green Dohrs after she graduated from the Pratt Institute, New York in 1950. Dohrs responsibility was to design the interiors of the show cars and those for VIPs (GM Heritage Center, 2015). Earl acknowledged the influence that women held in relation to automotive models, commenting, ‘And make no mistake about it, America’s women have a lot to say about what they want in the new family car’ (GM archive; Bayley, 1990, p. 122). Other female designers from the Pratt Institute and Cranbrook Academy of Art (CAA), hired by Earl, were subsequently employed in the styling studios of General Motors, in 1958. The Pratt Institute and CAA were significant in providing the design education of the female designers that were employed at GM, linking them to a wider network of leading architecture, furniture and textile design innovators and thinkers of the time, including Eliel Saarinen (the first president of

CAA). In 1950 the first phase of the GM Technical Center was designed by Eliel and his son Eero Saarinen.

At General Motors' Motorama in the spring of 1958, each studio presented concept cars: the female designers had responsibility for their appearance. In total there were ten models. Commonly dubbed the 'Feminine Auto Show' or the 'Spring Fashion Festival of Women-Designed Cars' and described as a fashion show of feminised cars, Earl commented that 'the damsels of design have won their spurs with this 1959 collection' (Stork, 2015; Bayley, 1990, p.123). However, their innovations went beyond styling, with ideas for safety, portable phones, gadgets for children and storage. I have included the work of these women as the reports focused on the styling, how things looked, but their influence went beyond colour co-ordinating paints and fabrics.

Marianne Strengell designed and developed automotive textiles for the Chatham Manufacturing Company, a mill producing the fabrics for the Detroit car manufacturers including, General Motors and Ford. She says that, 'at the time they had to go into synthetics' explaining that the shiny finish caused 'one' to slip off the seat (Brown, 1982, p. 42). Working on the loom to create hand-woven samples, using yarns provided by the mill, Strengell developed what she describes as '*discrete*' designs for the cars as well as textural fabrics. She felt that these small patterns, or slightly larger motifs in unified colourways, worked best in the car interiors (pp. 42-43). The automotive companies selected from the collection of fabrics they were presented with for specific models.

In a paper presented to the Society of Automotive Engineers (SAE) in 1956 by Richard T. Chatham, Jr. from the Chatham Manufacturing Company this process is further detailed. He describes how the automotive stylists chose the pattern that the mill then translated into woven textiles with the necessary performance considerations as follows: 'weight, tensile strength, shrinkage, stretch, resistance to abrasion, dye and light stability, soil resistance, and water repellency.' Additionally, the fabric designer had to work within constraints in relation of cost and available equipment, ultimately producing a durable product that was desirable to the automotive client and their customers. Prior to sampling on mechanised equipment, sketches and hand-woven samples were employed to demonstrate possible outputs to the automotive stylists (Chatham, Jr.1956, p. 253).

Summarising the development of automotive fabrics, he describes how textiles were originally selected from pattern books and custom woven for high-end models. The next trend was mohair plush fabric that dominated the late 1920s, followed by wool in the 1930s, when limited colour patterning was introduced, which continued into the 1940's. Following the Second World War the use of synthetics was aided, in part, by the dramatically increasing cost of wool at the beginning of the Korean War.

Insight into the type of fabrics and yarns used is described in general terms:
'In the 1956 models you will find gig-finished woollen system broadcloths, tweeds made with spun yarns, Jacquards with spun metallic and filament yarns, dobby patterns on both worsted and woollen systems, and a wide use of bouclé or novelty yarns. Some of the fabrics are heavily textured; some are bright and quite gaudy, and others extremely conservative.' (Chatham, Jr. 1956, p. 252) also notes that the general specifications for automotive textiles from clients are comparable; however there are requirements that are individual to each respective automotive manufacturer.

Looking back at this time it was interesting to see how female industrial and textile designers became involved in the automotive design industry and what they contributed. As a female designer working with materials as a way to challenge and explore their potential for use in automotive interiors, in the context of sustainability, through textiles and other parts this resonated with me. The materials visual appearance can influence the styling within a vehicle but they have an important part to play in the whole set of systems related to the performance of and engineering within the car and the impact on the environment.

Transferable ideas

The Styling Section described their design process and influences in *Modes and Motors*, which the General Motors Corporation public relations department published in 1958. Reference is made to the potential for new scenarios of existence that could be created following '[…] the merger of art, science and industry' in the post-war era. In conjunction with sketches, 'fashion trends in other fields', such as clothing, architecture and domestic interiors, were researched and along with consumer surveys to inform the styling work of new models (General Motors, 1958, p. 16). Acknowledging sources of inspiration for transferable ideas, Earl said that 'They don't realize how many of our ideas come from the public and the aviation industry' (Bayley, 1990, p.122).

Consideration of all these ideas resulted in focused possibilities for the contemporary production with the remainder catalogued for future application when they might be more fitting or able to be realised. There is no reference made to their criteria for the process of selection or elimination regarding these ideas. However, there are details of limitations regarding materials and processing equipment resulting in a compromise ‘between what ***might*** be done and what ***can*** be done now’ (General Motors, 1958, p. 18). The engineers and production teams were included in these early stages to ensure the viability of the design in relation to existing materials and processes. Detailed full-scale chalk drawings allowed measurements to be assessed, ensuring practical use.

Scale models were used as a tool early in the process to translate from two-dimensional sketches into three dimensions. It was in the later stages of the design process that full-size prototypes were made to ensure the form flowed well (pp. 20-21). Earl is credited with pioneering the use of actual-size models as a design tool and quoted in reference to this method as follows: ‘The trouble with small models is your eyes don’t shrink with the model’ (King Rose archives, 2009). The process Earl initiated involved using clay over a wooden shape, which he transferred from his experience in custom shop techniques. Using malleable modelling clay allowed the curves of the form and exterior details to be created, studied, amended and resolved with flexibility (previously hammered metal had been used) (Bayley, 1990, p. 51). The clay was then replicated in wood, mahogany and poplar with hand crafted metal parts added, followed by the interior in which trimmed seats, the instrument panel and glass windows were fitted The exterior was then wrapped in cloth and painted to imitate the smooth, gloss surface appearance of a production car.[7] (General Motors, 1958, p. 22). Realising the shape and form of the new concept shape at full-scale was part of the process towards production approval (Bayley, 1990, p. 89). This prototype was the foundation from which accurate measurements were taken, allowing patterns, dies and master drawings to be made, which in turn enabled the technical conversion to final manufacture of the new automotive model (General Motors, 1958, p.22).

I followed a similar process, making small-scale models to test ideas, then worked at full-scale in order to evaluate my designs and the materials. The process of, hand-crafting in clay, can be compared to my working with the bio-resin to make the door panel and glove-box lid, in that I was not using an industrial process to create in order to evaluate the prototypes.

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[7] Bayley (1990) describes how following management approval of the full-size clay ‘a full-scale fiberglass model would be made, using the clay as a male mould’. This was ‘given a realistically high finish,’ ‘Harley Earl’ p. 89 chapter ‘the golden age of gorp: the cars of the nineteenfifities’, which conflicts with their records.

The exterior was designed to suggest speed in motion whilst the interior, which was developed simultaneously, was intended to be a relaxing and comfortable environment (Bayley, 1990, p. 22). It was approached from a design perspective by using similar methods to those of domestic interior design, 'as in designing a living room "cozy corner"'.

In reference to colour and materials, consumer preferences were sought through surveys and consultation with colour groups with an overall 'harmonious' look (p. 24). Exterior paint was tested for durability or 'weathering', by leaving sample pieces 'for long periods to the action of the hot tropical sun and the salt air' at a testing facility in Florida (General Motors, 1958, p.25).

General Motors and DuPont

The connection between General Motors and DuPont began in 1914 when Pierre S. du Pont purchased stock, which was followed by his appointment as a director and then chairman of the board in 1915. After the end of the First World War the directors at DuPont invested $25 million in General Motors, influenced by their former treasurer, John J. Raskob, who was at this time an executive at General Motors. The war had been profitable for DuPont as manufacturers of explosives. In 1920, Pierre became the president of GM. The stocks in GM owned by DuPont accounted for 50 per cent of their income and gave the company a controlling interest (DuPont Heritage site, 2017).

According to Alfred Sloan, investigation by the Federal Government found reference to Raskob's written statement that the investment '[…] will undoubtedly secure for us the entire Fabrikoid, Pyralin, paint and varnish business of those companies, which is a substantial factor' (Sloan, 1963, pp. 13-14; Frame, 1996). In 1949 the government antitrust prosecutors filed a suit against DuPont and General Motors, arguing that the acquisition by DuPont had secured business of their products from General Motors. The District court ruled that there was no evidence to prove this and dismissed the case. The Supreme Court, on further review, determined that it was illegal and reversed the dismissal ruling eight years later against DuPont. Their decision was based on the probability that the acquisition was likely to cause restraint of trade, contractually requiring GM to use DuPont's products. Sloan (1963, p. 14) argues that the finding was merely academic and not indicative of the situation in reality. In 1961 DuPont's disposal of shares in GM was completed.

Chapter conclusions

I have investigated the historical use of materials to contextually situate the projects in Chapters 5, 6 and 7.

The work I have created in the projects differentiates the use of man-made and natural materials, keeping them separate to facilitate composting or recycling. Within this framework I explored materials through craft processes and industrial production. In this chapter I have evidenced the shift from hand-made vehicles to mass production and how material use inevitably adapted to supply the demand, shifting, from natural to man-made. At the time it was the hand-crafted vehicles that were superior in look and methods of making to those that were mass produced. By contrast now, industrial manufacturing processes create a uniform, perfect and always-new product, and craft production is perceived as niche and bespoke as with Morgan cars (discussed in Chapter 7). Global economic and political contexts were instrumental in the shift from hand-made to mass produced vehicles, but there were additional factors that encouraged these developments, such as the business development at DuPont that shifted their products from explosives manufacturing to man-made fibres, which they widely promoted. Marketing played a key role in supporting consumer choice: this provides insight into the evolution of material use and the rationale behind it. As the demand for personal mobility vehicles grew so did the understanding of the manufacturer about engineering material requirements for the optimum performance. Material use was driven by availability, aesthetics, engineering performance, durability, lightness and affordability.

Aesthetics of materials are inseparable from the cultural frame in which they appear and are bound up with, the entire chain of sourcing, supply, availability, production, marketing and sale. The way of embedding a particular material aesthetic in such a huge system makes changes incredibly difficult to achieve. It is evident that outside influences affected the materials used and the way materials were made.

The role of women at GM has provided insight into the processes followed at the time and the strength of marketing to promote new ideas. The interior studios they worked in were considered ‘low ranking’. However, materials, colours and textiles have proved to have a significant impact beyond the visual appearance of the vehicle that supported the overall approach to developing the vehicle architecture. Their design education backgrounds, connects them and GM to design education and influences of the time.

In their respective ways both Henry Ford and General Motors were using material innovations to support precision, performance, durability and styling, which influenced the design aesthetic of the vehicles they produced. The work of Henry Ford, in particular demonstrates some consideration of sustainability, though at the time this was not his concern, it was in reducing the amount of labour in acquiring materials and in constructing the automobiles. His use of waste and agricultural, renewable materials can be useful to consider today regarding the sustainable use of materials. I found it relevant to look back at how these two companies developed their material use and how that could inform sustainable use of materials today.

Following the First World War and the Depression, new material discoveries were considered and marketed to be superior to natural materials and scientific alternatives. At this time, the combined forces – paucity of available materials, new developments and increased demands for products – the public were keen to embrace new labour saving products, comfort, leisure pursuits and perceived luxury.

Since the Industrial Revolution, post the First and Second World Wars material use in products has exponentially risen. The result, being concern regarding material use, disposal and reduction in finite resources has culminated in a major challenge to the existing systems that evolved from these times. Industrial manufacturing has become global manufacturing. Expectations of perfection, uniformity and high performance from both the automotive manufacturers and consumers, alongside a general stipulation for low cost vehicles, continues to challenge material suppliers, producers, manufacturers and the whole supply chain.

It is conceivable that concerns regarding material use and disposal - sustainable material use – could shift established systems towards other economically viable ones, in order to preserve finite material resources, utilise materials in an optimum way and to recycle and reuse materials as efficiently as possible. In addition a multi-layered proposal that is economically viable and profitable. The compelling argument for this is discussed in the following Chapter (Chapter 4), which describes the circular economy, and theoretical arguments and practical examples supporting the realisation of it.

Chapter 4: Literature Review

Summary

The automobile epitomises a meeting of several design interfaces in one product. Common to all products is the composition of materials that are selected, configured and assembled for the specific function required. It follows, then, that where these materials derive from, how they are obtained and where and by what method they are disposed of when the product is redundant is of critical importance to ensure a sustainable future. To understand these various aspects I have primarily focused on the literature surrounding the circular economy, in particular Stahel and Reday (1981), McDonough and Braungart (2001 and 2002), Stahel (2010), Webster (2015), and the Ellen MacArthur Foundation (2017). I have also looked at the work of Charnley (2015) and Moreno et al. (2016). My literature review is not confined to academic sources but also includes ‘grey literature’, such as communications and publicity from manufacturers. In the project chapters I use academic literature to support the rationale for my material choices. I have researched in depth the potential of the materials themselves, and this is supported by some necessary technical and, where applicable, chemical explanations.

This is not primarily a literature-led PhD: my sources of knowledge have been my developing practice, my interactions with companies and individuals in relevant industries and a survey of relevant texts and industrial practice (including its historical context).

The Literature Review is divided into five sections that underpin the core focus areas of this research, as follows:

- Definitions of sustainability for the automotive industry
- The circular economy
- Design for disassembly
- Automotive interiors, materials and sustainability – industry approaches
- Materials from agricultural or food production waste
- Renewable plant-based plastics, oil and foam

The European Commission (2016) states that in Europe the disposal of end-of-life vehicles creates between 7 and 8 million tonnes of waste per annum. In September 2000 The European Parliament and the Council of the European Union published their Directive 2000/53/EC, (2000) which set targets for the management of end-of-life vehicles, for which the producers or manufacturers have to take responsibility. This includes components and materials. The objective was, and continues to be, waste prevention and reduction through reuse and recycling. It also sought to improve the environmental effectiveness of all concerned in the life cycle of a vehicle, with an emphasis on end-of-life treatment. It states that new vehicles should be designed and produced to facilitate dismantling, reuse and recycling as part of the brief to ensure that targets can be met, and that systems should be established to accommodate this objective (Directive 2000/53/EC, p.4).

In Europe the targets for reuse and recovery from the start of 2006 were set at a minimum of 85 per cent, with reuse and recycling at 80 per cent per average vehicle. In January 2015 the re-use and recovery target was increased to a minimum of 95 per cent and re-use and recycling increased to 85 per cent (Department for Environment and Rural Affairs, 2010).

I have focused on my projects from a material and manufacturing perspective, investigating how the sustainable credentials of a vehicle could be increased and what could be used to do so. While my research has taken place there have been significant advances in systems and material considerations from the automotive industry in response to this European Directive.

Car interior materials can be divided into those that are visible and non-visible and subdivided into soft and hard (Table 4).

Example of material usage	Visible	Non-visible
Hard	Plastic interior panels – acrylonitrile butadiene styrene (ABS), polypropylene (PP). Metal parts – steel, aluminium. Windows – glass.	Metal seat frame, floor – steel, aluminium. Parcel shelf - hardboard.
Soft	Seat covering – textile, leather or similar. Seat belt. Carpet. Floor mats. Face of parcel shelf. Seat belt.	Seat foam and textile backing - polyurethane. Non-woven recycled textile waste as sound dampening inside door panel.

Table 5: Examples of material usage.

Ford estimates that an average contemporary vehicle may be constructed of up to 40,000 parts composed of approximately 1,000 material types, which are made from approximately 10,000 chemicals (Ford, 2016, p. 54).

End-of-life vehicle treatment

European cars must now be returned to a treatment facility at the end of life. Volkswagen (VW) describes their SiCon process of recovering materials from the vehicles in a short film (Volkswagen, 2009). After the vehicle is delivered the initial stage is to manually remove the battery, tyres and drain fuel, oil and other liquids. The battery and catalytic converter are recycled. The engine, gearbox and other steel parts are taken apart for separate shredding, which then is used as ferrous scrap input at steel mills and feedstock for high-grade steel. The remaining vehicle is compacted and moved to the shredding site. It is shredded into small pieces: magnets remove iron, and other metals are recovered. The remaining shredder residue is a mixture of textiles from seats and carpets (shredder fibres), plastics from interior parts (shredder granules) and shredder sand containing glass, rust, paint particles and other materials, which would previously have been sent to landfill. Technological developments in material separation sort these materials for re-use. Shredder fibres are sent to a sewage treatment facility, where they are mixed in a tank with sewage sludge to facilitate the solidifying of the liquid material, which is then pumped into a diaphragm filter press, which removes the water content. The resulting 'cake' is then burnt in a fluidised bed incinerator generating heat and electricity.

The Bayrische Moteren Werke (BMW) Group (2017) similarly removes hazardous fluids and materials from the vehicle (Boeriu, 2015). The next stage is to dismantle marketable used parts and materials and then core scrap, such as the engine. Following this the remainder is compacted and sent for shredding where it is reduced to ground materials. The mix of materials is sorted and classified and metals are extracted with magnetic separators. Post-shredder technologies recover more materials, such as plastic, for use as secondary raw material.

The context of sustainable design/design for sustainability

The understanding of sustainability in relation to materials and design continues to evolve as it is re-evaluated and redefined to embrace new knowledge, approaches and systems. For the automotive industry there are key factors that support the move towards more sustainable vehicles.

- Lightweight materials or parts, reducing fuel consumption and consequent pollution
- Design for disassembly

- Mechanical recycling of synthetic or technical materials
- Renewable plant-based resources, fibres and plastics, that are either recyclable, if used in conjunction with a plastic, or wholly industrially compostable.

‘The circular economy’ descriptively embodies the generic concept that has developed from various recognised schools of thought. These are identified and grouped into categories for the purpose of definition: however, they are interlinked in origin and connect through their shared objectives. The most relevant concepts for my doctoral work are McDonough and Braungart’s development of the ‘Cradle to Cradle’ concept (2002), Stahel’s ‘performance economy’ (2010) and Webster’s ‘circular economy’ (2015).

In 1977 Reday and Stahel published a report for the Commission of European communities in which they conducted two case studies on the automotive and construction industries respectively, which were selected for their importance to the economy (Reday and Stahel, 1977, p.2). It was in this report that they sought to reduce energy consumption through altering patterns of behaviour. Three possible approaches were identified: firstly, to reverse the energy-for-labour substitution trend particularly where mechanisation has caused an increase in jobs that do not require skills, secondly, the introduction of recycling loops for energy-expensive base materials that were not being recycled and lastly the redefining of industrial production processes through the introduction of reconditioning loops in the life-cycles of industrial materials and products (Figure 10).

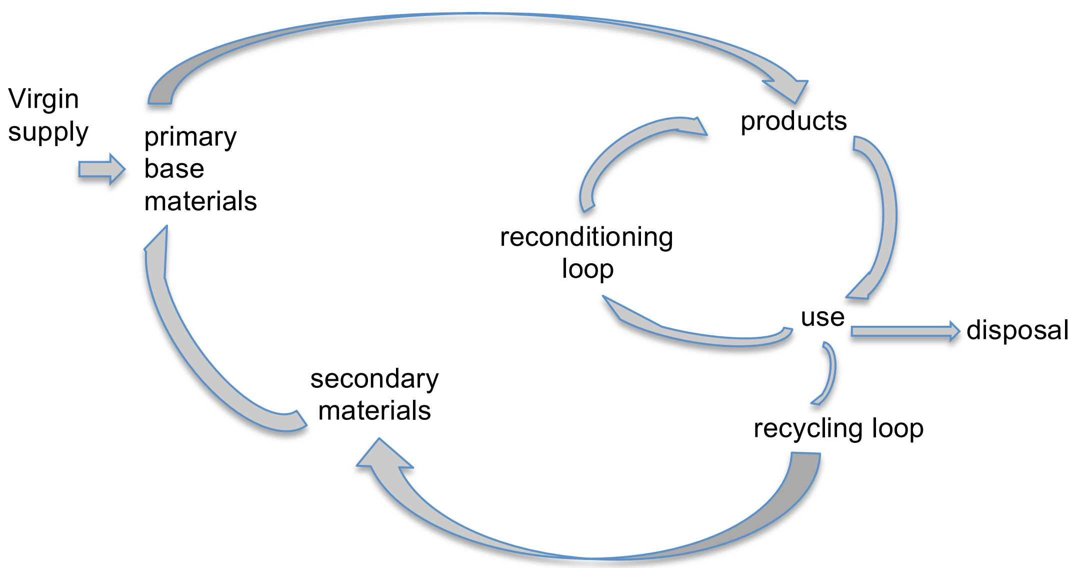

Figure 10: Life-cycles of an industrial product (Reday and Stahel, 1977, p.3, Stahel and Reday-Mulvey, 1981, p. 70).

They suggested that the automotive industry could make significant energy savings in the production of vehicles by making cars with a longer life expectancy due to the use of better materials or by planning to periodically change parts (p. 4). In turn the development of the maintenance, repair and reconditioning sectors could decentralise activities related to vehicles and create skilled employment in regional, less privileged areas (p. 90).

These ideas were expanded on in 1981 in their publication *Jobs for tomorrow: the potential for substituting manpower for energy* (Stahel and Reday-Mulvey, 1981). They state that the creation of new skilled jobs, alongside a significant reduction in energy use, could be achieved through prolonging the useful life of materials and products. In addition that the linear "production-use-dump" models should be replaced with recycling or reconditioning loops or spirals in order to reduce utilisation costs and environmental changes (p. xv). The automotive industry would save energy and material costs by creating more durable cars with programmes for parts replacement and reconditioning: two thirds of the expense of a car being in the materials, components and energy used in its manufacture (p. xx). Their approach is that a vehicle is designed for a longer lifetime of about 20 years, which would have different conditions and impact in several ways on energy use and labour. There are four stages to consider: the production of basic materials, manufacturing, maintenance/repair and reconditioning (pp.71-72). Such a new industrial strategy could result in a shift of manufacturing production to a supporting service sector focusing on long term leasing, maintenance, reconditioning that could include both hard and soft technologies (p. 93).

Stahel and Reday used the term 'loop economy' to describe methods for the production of long-lasting products and systems for repairing items, with the overarching aim of preventing waste (Product-Life Institute, 2017). This can be described as a 'service economy' approach to manufacturing. Historically, the repair of car parts was integral to ownership, and was carried out either by an employed mechanic or the owner themselves. As manufacturing systems have become more efficient supporting consistency in products, ensuring high standards of performance and safety in order to reduce liability in the event of a fault, this has resulted in a reduction in the potential for repairing parts independently or at a local level. In less affluent communities where resources are scarce, redundant items are often dismantled to allow materials of value to be extracted, repaired or customised to extend product use.

Stahel (2010, p.1) suggests that industrial nations and their economies are connected by their characteristically extensive use of resources and subsequent waste creation. His model aims to grow wealth and the economy through the reduction of resource use by employing smart materials, goods and solutions that are created through science and knowledge. This he terms the ‘performance economy’, which integrates products and services and in turn lowers the use of resources (p.2). He argues that this shifts the economy nearer to sustainability by reducing the use of materials and energy and by its aim to increase wealth and employment (p. 5). He proposes the transformation of a ‘linear economy’ into a ‘circular economy’ (p.6).

Stahel (2010, pp. 283-284) suggests that stand-alone systems that are interrelated should be the basis for sustainability: he visualises these as ‘pillars’. The first of these is ‘nature conservation’: the second is ‘limiting toxicity’: these two pillars, he states, are based on control and order. The third is ‘resource productivity’, which requires innovation and creative thinking, the intention being to lower the consumption of resources by industrialised countries. The successful accomplishment of these three objectives will enable a sustainable economy. But to reach a sustainable society the fourth and fifth pillars will need to be addressed; these are ‘social ecology’ and ‘cultural ecology’ (Product-Life Institute, 2017). The ‘performance economy’ will not replace the manufacturing economy, but there will be a move towards it.

McDonough and Braungart (2001, p. 70) use the term ‘eco-effectiveness’, which they coined to replace the term ‘eco-efficiency’; they believed that the latter was not a strategy for the long term, because it operated within the system that had caused the problem (World Business Council, 2017). They argued that eco-efficient practices of ‘reduction, reuse and recycling’ merely slowed down the contamination and depletion of resources, and did not stop them. Perceiving that the cyclical series of systems and the regenerative approach observed in nature is ‘effective’, they transposed the term to describe their ideology. Like Stahel they advocated a circular ‘loop’ approach to manufacturing products. This ‘cradle to cradle’ model was designed to replenish not diminish material resources, in contrast to what is commonly described as the ‘cradle to grave’ approach, where consideration is not given to the end of life of the product.

The term ‘cradle to cradle’ is attributed to Stahel, although when it was first used and where cannot be precisely referenced (Product-Life Institute, 2017). Braungart and Stahel had met on several occasions. McDonough and Braungart (2002) used the term for the title of their publication *Cradle to Cradle: Remaking the Way We Make*

Things. In this they explain the approach that views materials as nutrients that are technical, which can be recycled (p. 109), or biological, that are renewable in nature (p. 105). Maintaining the separation of the two and not mixing them in products would enable them to be either recycled, if synthetic/ technical, or composted if created from naturally renewable materials. Braungart and McDonough (2002, pp. 90-91) suggested that established systems should be redesigned to eradicate waste.

Webster (2015, p.9) likens many existing systems as a 'linear economy', in which the sequence of the life cycle of a product is as follows: material mining and manufacture, parts manufacturing, product manufacturing, service provision and consumption/use and at the end of its life the product is collected and either used to recover energy or directed to landfill. This he identifies as being wasteful of material resources and products. He proposes an alternative system, described as a circular economy that is restorative by design (p. 19).

The Ellen MacArthur Foundation[8] (2017) describes the concept of a circular economy as a continuous flow of materials in either technical or biological circles. A model such as this is described as restorative of investment, either in respect of 'financial, manufactured, human, social or natural.' It is illustrated in the diagram below (Figure 11):

[8] Formed in 2010 the Ellen MacArthur Foundation is a registered charity with the aim of speeding up change in the circular economy through education, business, government and communication, and providing evidence of the advantages.

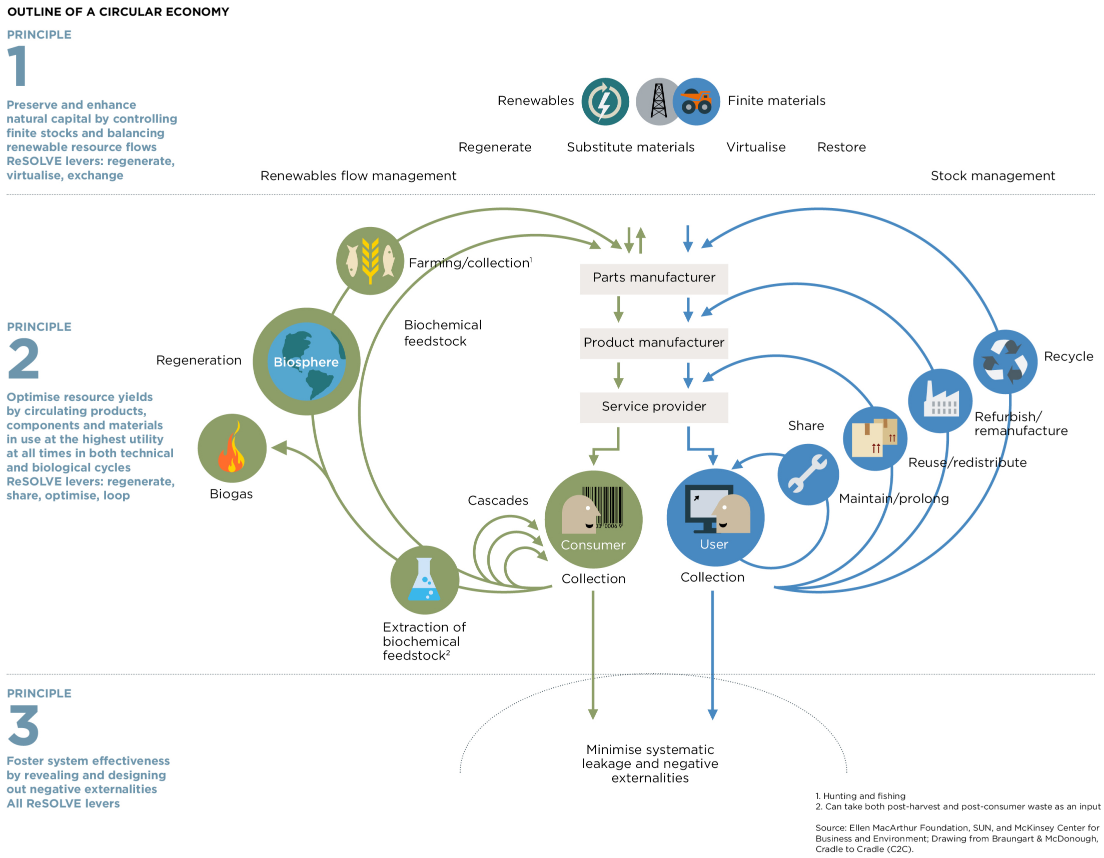

Figure 11: Circular economy system diagram. Ellen MacArthur Foundation (2017).

The Ellen MacArthur Foundation's and Webster's concepts are linked through their publications and shared ideals.

Describing their activity as operating 'in the space between governments, businesses, communities, thinkers and individuals', the Waste and Resources Action Programme (WRAP) (WRAP, 2017) supports the replacement of what it describes as the 'design, make, use and discard' linear economic model (p. 10). WRAP suggests that its 2015-2020 plan 'Resource Revolution: Creating the Future' should demonstrate an efficient use of the world's resources, which they argue can be achieved through a more circular economy. Their aims includes 're-inventing' design, making and commercial activities, 're-thinking' the way we utilise materials and 're-defining' the potential for end of life uses for products (pp. 6, 7, 10, 13)

A circular economy and the potential for design

The circular economy stems from the analysis of a non-linear system - in particular, living systems (Pollard et. al., 2016, p. 23). To enable a circular economy to operate in an optimum way, systems need to be established to create the infrastructure necessary to allow recovery from the technical and biological cycles. Additionally, the way products are designed needs to take into account their end-of-life treatment. Pollard et al. (2016, p. 23) argue in their paper that a vital aspect of a circular economy is the optimisation of systems. Natural or biological materials need systems to manage the flow of materials: that is, to return them to the biosphere to replenish and restore it. To achieve this aim end-of life-procedures need to be considered in the product design process. Technical materials, similarly, need to be designed to be recycled at premium levels without entering the biosphere. They argue that to achieve this, materials and components need to be reintroduced to new value streams, which they visualise as recirculating loops.

As a circular economy recognises the difference in the use of materials, material choice and consumption, Pollard et al. (pp. 23-24) and Charnley (2015) suggest that both products and services need to be redesigned. ‘Take back’ services need to be established. Products should be hard-wearing and be easy to disassemble or refurbish. They suggest that a circular economy proposes something other than closed-loop recycling: that is, open-loop thinking (Pollard et al. 2016, p. 25). This would allow biological nutrients to be reused and ultimately cascade back to the environment, replenishing it. A ‘structured cascade’ such as this for biological and technical nutrients, they argue, requires business models, organisations and the revision of policies and regulatory aims. In addition Charnley (2015, pp. 15-17) argues that designers and practitioners need to be well informed, with knowledge of all aspects of the value chain in order to fully influence the advancement of a circular economy.

Moreno et al. (2016), through an analysis of the literature on design for sustainability, and by connecting approaches to circular business models, develop a theoretical outline of strategy for design for a circular economy. Their classification was based on three ‘design for sustainability’ approaches: first, design for resource conservation, second, design for slowing resource loops and lastly ‘whole systems’ design (p. 3). They suggest that the role of the designer within a circular design approach becomes that of a ‘systems thinker’, as the complete system must be studied (p. 6). They locate five approaches to circular design: design for circular supplies, which concentrates on biological cycles; design for resource conservation, which concentrates on both biological and technical cycles, ensuring that products are designed with the least number of resources; design for multiple cycles, which again concentrates on both biological and technical cycles, ensuring that materials are reused in several cycles; design for the long life of products, which concentrates on the technical cycle and the potential for reuse and repair and for services and sharing of products, and design for systems change, which covers both biological and technical cycles and concerns design thinking to identify problems and locate innovative solutions (p.10). By mapping these approaches to circular business models – circular supplies, resource value, product life extension, extended product value and sharing platforms – they developed ten recommendations for circular design (pp. 11-12). These include: designing for 'systems change': identifying the circular business model that the product or service is designed for; designing for several cycles, not solely end-of-life; designing by thinking in living and adaptive systems, and to designing by understanding where each material is from and where it ends up.

The circular economy and the automotive industry: case studies

The impact of the Directive 2000/53/EC' (European Parliament and of the Council, 2000) has led to shifts in, and exploration of, material use and end-of-life recovery and disposal. I outline here recent case studies in which the industry has adopted a circular approach.

As one of a growing number of global partners of the Ellen MacArthur Foundation, Renault demonstrates the application of a circular economy within an automotive context in its 'Project ReDesign' (Ellen MacArthur Foundation, 2017, and European Remanufacturing Network, 2017). Citing the cost of raw materials, their potential scarcity, finite resources and the securing of supply chains as areas for future concern, 'remanufacturing' makes economic sense (European Remanufacturing Network, 2017). Repairing and reconditioning automotive parts commensurate with the vehicle's age and lifespan is a more efficient use of material resources. Potentially viewed as a return to old values and methods, remanufacturing allows for the equating of value between the vehicle and the reconditioned/repaired part. Parts that have been discontinued in manufacturing can be repaired, lengthening the life span of the vehicle. Renault's factory at Choisy-le-Roi, France, is where this circular model is in operation, which services and operates within a local rather than global market (Ellen MacArthur Foundation, 2013). This began in 1949 and has been significantly expanded (Ellen MacArthur Foundation, 2017, and Renault, 2017).

Renault uses the term 'short-loop recycling' to describe recycling that is contained within the automotive sector (Ellen MacArthur Foundation, 2017). The EU LIFE programme supported Renault in establishing a trial for end-of-life (ELV) recycling, entitled '**I**nnovative **CAR RE**cycling**95**%' (ICARRE 95) (Renault, 2017). The intention of the project was to recover materials from ELVs and reuse them at the same performance level as virgin materials in new models. Renault's aim in the project was to develop a consistent and reliable route for obtaining recycled plastic. In the short term this enables Renault to produce vehicles which both have a lower environmental impact and are economically viable. The future goal is to reduce the price of material derived through recycling compared with the cost of virgin material, in order to encourage this practice. The case study notes that legislation is playing its part in driving such an initiative forward notably the Directive 2000/53/EC (European Parliament and of the Council, 2000). The study notes that the example of Renault's short-loop cycle programme demonstrates the four key aspects of the circular economy, with a key element being collaboration (Ellen MacArthur Foundation, 2017):

- Circular design and production
- New Business Models
- Reverse cycle
- Enablers and favourable conditions

Vehicle servicing provides an opportunity for recovering parts that can be recycled. In Europe Ford dealers now return damaged bumpers for recycling when they fit new ones. In the US, Ford reimburses dealerships with the cost of new parts when they return the replaced originals to their Core Recovery Program. These are either restored for reuse or broken down into pellets for remanufacture. Ford estimates that over the course of the decade between 2003 and 2013, 120 million pounds (54.4 metric tonnes) of vehicle waste has been diverted in this way from landfill (Ford, 2015, p. 401).

Recycling materials to produce the same standard as the original, often described as 'closed-loop recycling', is being utilised and further explored by Ford. Ford cites two examples in its 2015/16 Sustainability Report: first, in collaboration with their aluminium suppliers the waste from production of the F-150 is used to regenerate it for use in other new models. Recycled aluminium uses 95 per cent less energy than refining raw aluminium. Each month Ford recycles aluminium scrap to create 30,000 F-150 bodies. Second, the waste from seat fabric production is reconstituted into yarn used in new textiles for the F-150 and other models (Ford, 2016, p. 55). Investigating ways of recovering and reusing face plastic and bumpers for equivalent products is again carried out in association with their suppliers, supporting both parties and lowering landfill contribution and raw material usage (p. 55).

Under the surface, the development of non-visible materials, although these are required to meet stringent performance demands, is an area in which post-consumer or post-industrial material waste can be more easily accommodated. The appearance of the material is not a determining factor in selection. Ford's use of 'recycled content' in line with their 'sustainable materials strategy', can be found in a range of parts and purposes, such as sound absorption panels hidden behind surfaces: these originate from a variety of sources including redundant textiles and plastic drinks containers. In striving to consume less virgin material through initiatives such as these, Ford have found benefits such as product improvement through weight reduction in conjunction with financial savings (Ford, 2016, p. 55). Ford's global materials approach stipulates that several plastic parts that are not visible must be made from post-consumer waste outside of the automotive industry, such as drinks bottles, nylon, tyres and the casings of batteries. There are added advantages, which include weight reduction in some parts, such as rear wheel textile liners that are half the weight of plastic ones, utilising 40 per cent recycled material. Ford also state that there are monetary savings too from this practice: in North American vehicles, approximately $10 million per annum is saved by using 50 million pounds of recycled material from these sources in the vehicles' non-visible parts (Ford, 2016, p. 55).

The challenge in using recycled materials for visible interior surfaces is primarily the matching of their appearance to perceived customer expectations (Ford, 2016, p. 55). Ford outlines its current areas of focus for growing this practice as 'seat fabrics, seat components, carpets and headliner fabrics'. The REPREVE yarn was first used by Ford in 2012 in their Focus model (during the same period that I had developed my version in Europe). Unifi Inc., a US-based company, developed the polyester yarn from post-consumer waste, specifically water bottles (those bearing the impression of the figure '1' within the recycling symbol, which indicates the material is polyethylene terephthalate (PET), chemically equivalent to polyester). Using REPREVE in the F-150 seat fabrics utilised 5 million plastic water bottles in 2015 (Ford, 2016, p. 55). Companies such as Patagonia, Adidas and other sportswear and apparel manufacturers use the material in their clothing products. Teijin developed 'chemical recycling technology', a process by which they reconstituted polyester from used garments of the same material. In a system called Eco Circle established in 2002, Teijin, in conjunction with retail companies who collect old clothing from customers, converts or 'reclaims', the polyester for new wearable products, which are returned to the stores and ultimately sold back to consumers in a fresh garment configuration (Teijin, 2017).

Critical and significant to the success achieved with Eco Circle is the fact that the material is solely polyester, rather than mixed with any other material type, which would contaminate the material stream and render the process less effective. Automotive seat polyester textile covering is strengthened by its adherence to polyurethane (PU) foam backing, facilitating its endurance throughout the cycles of wear and rub testing and actual performance. Inextricably combining these synthetic materials renders the recycling process more complex. At the end of life of a vehicle its non-metal materials, such as textiles and foam, are shredded, resulting in 'automotive shredder residue' (ASR), which has been directed to landfill. Ford supports its initiatives to investigate and apply technologies that treat post-shredder residues, which result in more economically feasible end-of-life recycling that is also more environmentally sound (Ford, 2016, p. 58).

Jaguar Landrover (JLR) describes its business development as inclusive of sustainable and environmental goals. Through their analysis of the complete life cycle of their vehicles the impact of manufacturing, performance and on-road emissions has been, and continues to be, reduced.[9] Alongside these concerns the Land Rover Discovery Sport has been designed specifically with 'end-of-life and recycling considerations' in mind. Recognising that the use of lightweight materials lowers fuel use and increases speed efficiency, JLR have focused on the use of aluminium to replace steel for exterior body panels, reducing body weight by approximately 40 per cent. Extending their research and development further has resulted in the achievement of 'closed-loop' processes for this material, demonstrated in the REALCAR project (Recycled Aluminium CAR). This was followed by REALCAR2, which investigated making light vehicle forms from sheet aluminium (Jaguar, 2017). Using a percentage of recovered material from 'scrap recovery and separation programmes', JLR aim to source a further 25 per cent from such methods by further research into separation methods. By recovering excess aluminium from their sheet pressing process they reclaimed 50,000 tonnes in one year (to April 2016) (Jaguar Land Rover, 2016, p.9). JLR's Executive Director, Mike Wright, describes their strategy as 'innovation-led' on a foundation that understands that 'embedding a new level of environmental awareness and urgency starts with cultural change' (p. 8). Building on the REALCAR project JLR launched the REALITY project in late September 2017, which recycles aluminium from end-of-life vehicles into new product forms for new vehicle bodies. The project partners, alongside JLR, are Axion Recycling, Innovate UK, Novelis, Norton Aluminium, Brunel University London, WMG University of Warwick and Innoval Technology. Advanced sorting technology will be investigated and the assessment of new aluminium alloys to increase recyclability. Already the project has evaluated aluminium grades both chemically and at microstructure levels to augment recycling tolerance. JLR state

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[9] Manufacturing CO2 emissions by 30 per cent since 2007 – Building a sustainable future. jlrsustainabilityreport201415fullreport (p.2)

that this closed loop system towards a circular economy will generate both financial and environmental benefits (Jaguar Landrover, 2017).

The Toyota Environmental Challenge 2050[10] aims to eliminate any environmental burden. From a material perspective this involves establishing recycling-based systems, which the worldwide Car-to-Car Recycle Project and 100 Dismantlers[11] Project will further develop (Toyota, 2017). Toyota outlines six challenges for 2050: the fifth is to establish a recycling-based society and systems. This will involve the promotion of end-of-life treatment and recycling technologies. The four keys areas of focus will be the use of 'eco-friendly' materials, using parts for longer, the development of technologies for recycling and the 'manufacturing of vehicles from end-of-life vehicles' (Toyota, 2017, p.14). To promote recycling for ELVs Toyota has used designs that facilitate dismantling and the separation of parts (Toyota, 2017, pp. 5-6). The Toyota Green Purchasing Guidelines were revised at the start of 2016 to increase awareness of the journey from the raw material to disposal and recycling, considering the complete life cycle of the vehicle, and to improve the environmental management of the complete supply chain (Toyota, 2016, p. 16).

BMW (2016, p. 71) notes that as the group grows globally the supply chains become more complex. As a result it must meet the challenge of ensuring environmental and social standards throughout the complete supply chain. In order to achieve transparency and the efficient use of resources the group has established Supplier Sustainability Standards, which set criteria for these standards for their suppliers and the supplier sources. Dreyer (2016, p. 52) states that the complexity of the supply chains of global automotive groups can be opaque, rather than transparent, which poses challenges for sustainability. Dreyer continues by discussing the importance of collaborating with vehicle dismantlers, shredder and recycling companies to determine the best ways of extracting high-value parts. By improving waste separation processes, recycling and reuse possibilities for respective waste categories BMW minimises the amount of materials being disposed of. Dreyer (p. 52) comments that the opportunity a circular economy can provide across the value chain is increasingly being investigated by automotive manufacturers. Design for recycling at BMW aims to enable a flow of parts back to the relevant material cycle at the end of the life cycle. Factors that influence the choice of material, as well as the potential for the recyclability of components, are decided at the development stage.

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[10] The Toyota group comprises seventeen companies these include Toyota Motors, Toyota Boshuku and Toyota Tsusho.

[11] The establishment of automobile dismantling points for the disassembling of vehicles in order to recover parts and materials.

Life Cycle Assessment (LCA) facilitates the implementation of BMW's Design for Recycling strategy (BMW, 2016, p. 24).

Renewable Materials – Fibres

Along with research and development regarding the utilisation of renewable sources for automotive plastic and foam solutions, the use of natural fibres as an alternative to glass fibres in reinforced composites has increased. These divide into two categories: bast fibres obtained from renewable sources and fibrous matter recovered as waste, a by-product from a primary material source such as straw from grain harvesting. For use in composites the fibres need to be free from any significant water or oil content, which is a quality of bast fibres, along with stiffness combined with flexibility (Summerscales, et al. 2010).

Bast fibres are found inside the stems of certain plants underneath the outer bark; they are extracted through mechanical or chemical means. Traditional methods use water to separate and open the outer bark, separating the fibres. Laying the stems in streams is known as water retting: alternatively, leaving them on land after harvesting for the fibres to naturally secede, is known as dew retting. This would be followed by manual stripping to release and gather the fibres. Flax and hemp are grown in moderate climates whilst jute and kenaf thrive in tropical conditions; all have a yearly crop cycle.

The intrinsic properties of bast fibres that are pertinent to composite application, specifically in relation to automotive use, are their low weight, tensile strength, uniform consistent quality, and good acoustic and insulating properties, in conjunction with their low cost. From an environmental perspective, the plants are resistant to pests and disease, absorb carbon dioxide (CO2) and release oxygen[12] (Bast Fibers LLC, 2009).

Evidence of the use of kenaf fibre in compression-moulded interior automotive parts is demonstrated by Ford in its Ford Escape door panels, in which kenaf fibre comprises half of the material content, providing a weight reduction of 25 per cent (Ford, 2016, p. 56). Research in Indonesia conducted by Toyota Boshuku[13] involved the complete process, starting with kenaf seed development, followed by plant cultivation, harvesting, retting, fibre drying and cutting (Toyota Boshuoku, 2016, p.

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[12] Jute absorbs 6 metric tonnes of CO2 giving out 4.5 metric tonnes of oxygen (O2) per acre. http://bastfibersllc.com/environment.html

[13] Toyota Boshuko manufactures automotive seats, textile components, door trims, headliners, exterior components and unit components. It is part of the Toyota Group. https://www.toyota-boshoku.com/global/products/

48) and finishing with the production of ‘pre-board’ (Toyota Boshuko, 2008). These flat sheets will be compression moulded into invisible door ‘base’ panels (in the Lexus LS, Mercedes Benz and BMW), parcel shelves and seat backs, but are more easily transportable in flat form. The kenaf fibre is mixed with polypropylene (PP), with the inclusion of an additive to facilitate the compatibility of the two materials with each other (Toyota Boshuko, 2017).

In collaboration with BMW, the international automotive supplier Dräxlmaier has achieved a door substrate and instrument panel using kenaf fibre, which is visible although covered with a micro-thin clear layer (Dräxlmaier, 2017). Dräxlmaier perceives that from a styling perspective, in accordance with the sustainable objectives of BMW i series vehicles, the visible use of natural materials is a trend that will become increasingly important. The panel and substrate is achieved using a kenaf non-woven materials mixed with PP fibres, which is laminated with a PP film and compression moulded. Dräxlmaier argues that the current perceptions from premium sector original Equipment Manufacturers (OEMs) would not allow a raw surface appearance. The BMW i3 production model incorporates this development, with the natural fibres visible beneath the surface layer (Dräxlmaier, 2017). BMW are working with the Dräxlmaier Group in Bangladesh to establish the supply chain of kenaf. This involves training activities for farmers to increase the yields and quality of the fibre. In addition, the programme also is developing a more transparent and leaner supply chain, at the same time as implementing measures to increase sustainability in the supply chain (BMW, 2016, p. 78 and Dräxlmaier, 2017).

Through this combination of synthetic and natural the two material flows are excluded in the end-of-life context from the purest methods of recycling and reuse. Neither stream of independently compostable or recyclable materials can be followed, as each is effectively contaminated by the inclusion of the other material. Toyota Boshuku have produced closed-loop products that include a spare tyre cover foundation material and a decorative door trim ornamentation (Toyota Boshuko, 2010).

Flax and hemp bast fibres are similarly being employed as reinforcement materials for composites. The European Confederation of Linen and Hemp (CELC) extol their environmental credentials as deriving not only from renewable but also from local resources too (Masters of Linen, 2017). In comparison to glass fibre they provide more rigidity; when compared to carbon fibre their heat retention is higher, offering good insulation. They offer better vibration and acoustic properties than either glass or carbon fibres. When combined with an organic plastic or resin they are regenerative to the soil through composting. Ford B-Max in Europe has a 50 per cent flax fibre content combined with a 50 per cent polypropylene matrix in its armrest substrate (Ford, 2016, p. 56). This mix of materials from separate technical and biological cycles means that at the end of life the fibre cannot be composted but will remain with the polypropylene if possible for recycling. Arbelaiz et al. (2005) concluded, following their experiments with modified flax fibre bundle and polypropylene composites, that mechanical recycling was a feasible option for re-using the material. They had passed such composites several times through an injection-moulding machine and noted that the characteristics were only marginally altered.

EcoTechlinen[14] produce flax non-woven needle-punched felts that are combined with thermoplastic materials such as PP or PLA for compression moulding. FibriMat LCM (liquid composite moulding) comprises flax and a bio-sourced, sugar-derived resin which is capable of being composted (EcoTechlinen, 2017). In the form of woven fabric, flax fibre and PLA are commingled into a composite, termed Biotex produced by Composites Evolution. A Biotex combination of flax and PP has been used to make prototype interior door panels for the Land Rover Defender and Jaguar XF models. These concepts have been tested to gauge their performance in relation to existing parts used in production models; the results showed that the Defender part was 60 per cent lighter than the existing steel panel, with equivalent stiffness. The XF rear door component proved to be 35 per cent lighter than the existing part that was composed of glass fibre and PP of an equal depth. Problems concerning noise, vibration and rigidity were also reduced. In addition to providing good mechanical performance these partially bio-based parts allowed fixing points to be incorporated in the moulding process, thereby offering a solution for a common failure point (Composites Evolution, 2017).

Automotive Performance Materials (APM), a French joint venture between an agricultural cooperative and a major automotive manufacturer, has developed the use of hemp fibres for injection-moulded plastic interior components from seed to production. APM markets the product NAFILean[15], a PP compound with 20 per cent hemp fibres (APM, 2017). Faurecia[16] employed this product to manufacture inserts and fascia areas of the interior door panels for the Peugeot 308 in 2014. The material can be processed using traditional injection-moulding equipment; it also offers a weight saving of 25 per cent compared with alternative materials. When it is recycled

[14] EcoTechnilin: produce "natural fibre nonwovens and bio-sourced composites (using sugar based bio-resins). http://www.ecotechnilin.com
[15] NAFILean (natural fibre for injection).
[16] Faurecia is a French Tier One supplier.

it is possible to separate and valorise in the recycling of polypropylene (APM, 2017). The safety data sheet states that if possible the material should be recycled otherwise the options are to send it to landfill or incineration plants (APM, 2012). Faurecia states that the automotive industry has validated its use for recycling in standard treatment and regeneration procedures for plastic (Faurecia, 2016).

In 2015, Faurecia launched Flaxpreg, a product that was weight-bearing and intended for automotive trunk flooring structures. The project was initiated in 2011 and conducted in conjunction with Peugeot Société Anonyme (PSA) Groupe (Formerly PSA Peugeot Citröen), Lineo and the University of Reims Champagne-Ardenne (France). The main aims were to develop a low-weight product using renewable resources within the parameters of automotive cost restrictions that is also suitable for large-scale manufacturing. Using FlaxTape, a nonwoven in which the fibres are aligned in one direction, eliminating any spinning or weaving processes: after being saturated with an acrylic resin, the FlaxTape forms the outer layer of a paper honeycomb structure (Faurecia, 2015).

Faurecia's other bast fibre composite products are flax-based Natural Fiber Polypropylene (NFPP), developed in 2005 and Biomat (2014) which contains 65 per cent of bio-derived material – hemp/resin. Volkswagen used NFPP for the door panels in their 2015 Golf (Cunningham, 2014). At the 2015 Frankfurt Motor Show Faurecia showcased their Urban Liftgate, which employed flax composite in the roof and spoiler of a concept vehicle as an alternative to carbon fibre. The company cited lightness and reduced cost as factors contributing to their use of flax in addition to environmental considerations. The flax-resin composite is coated with a clear metallic tinted finish.

At the North American International Auto Show, Detroit, in 2013, Johnson Controls[17] showcased a 'door panel substrate component' made from natural fibres and thermoplastic, created through a process termed 'compression hybrid molding process technology' CHyM (Johnson Controls, 2013 and 2015). This procedure allows the material placement to be optimum for performance enabling a low weight to be achieved with improved qualities such as stiffness, strength and ease of assembly of the part to other interior vehicle body aspects. A combination of natural fibre and glass-filled PP, from a material perspective the door panel equates to a complex mix of synthetic and natural fibres. However, the development of a process to engineer the materials, placing them specifically to realise their best performance

[17] Johnson Controls Automotive Experience is a Tier One supplier of automotive interior solutions with a vertical operation having purchased Recaro, seating manufacturers, in 2011 and Michel Thierry, automotive fabric and lamination suppliers, in 2010.

potential, could represent a shift from adapting existing processes towards creating new ones suitable for more sustainable material use.

Ford in partnership with Coca-Cola, Heinz, Nike and Procter & Gamble, co-founded the Plant PET[18] Technology Collaborative to speed up progress in the use of plant-based PET materials and fibres (Ford, 2016, p. 56).

PSA Groupe employs and categorises three groups of ‘green materials’, identified as: ‘recycled plastics, natural materials (wood, vegetable fibre etc.) and bio-sourced materials (polymers from renewable rather than petrochemical resources).’ Using the Citröen DS5 as an example they state that it contains 19 per cent ‘green materials’ in its overall use of polymers, of which 30 per cent are natural and 70 per cent are recycled. Seat casings are made from flax/PP composite: recycled PP is used in other parts. The Peugeot 208 contains 25 per cent total polymers from ‘green materials’ (PSA, 2017).

Dunne et al. (2016) suggest that legislative changes and regulations resulting from environmental concerns have encouraged renewed interest in the use of natural materials for industrial applications. Synthetic fibres have dominated these markets since they were developed (see Chapter 3). This has resulted in the reduction of natural fibre usage. In turn, agricultural production has diminished in the developing countries exporting them. In their paper Dunne et al. (2016) include details of 19 automotive manufacturers and several models and applications in which natural fibres have been used.

However, this increase in demand for natural fibres from automotive companies raises concerns over the provision of these renewable resources, suggest Adekomaya et al. (2016). They observe a void created through this resurgence in their usage that is eroding ‘nature’. Perceiving these fibres to be ‘exploited’, they suggest that considered and maintained action is necessary to renew the amount being used. They state that it is the plants that are ‘renewable and sustainable’, not the actual fibres extracted from them. Additionally they discuss the wider issues in relation to agricultural production of these fibres across the world and the quality of life of the communities dependent on farming them.

[18] PET (polyethylene terephthalate) is a thermoplastic resin of the polyester family.

Renewable materials – plastics

Polylactic acid (PLA) bioplastics are derived from renewable sources such as sugar cane or beet, cassava, corn or tapioca starch. Fermenting sugar results in the production of lactic acid; connecting two of these molecules form a dimeric ring molecule lactide, followed by the process of ring-opening polymerisation that results in a chain of PLA molecules (Stepanski, M, Wackerlin, M and Sulzer Chemtech, 2008). Early developments were targeted towards and adopted for use in the medical sector and for food packaging and disposable vessels due to its compatibility with human organisms. Further research identified the adaptability of PLA, which allows selective engineering to enable short or long life products and controlled degrading, which has widened its potential applications. Synterra PLA is a high-performance polymer, free from genetically modified organisms, made by the Synbra Group using polymerisation technology developed in 2011 by Sulzer Chemtech. Investigative development has resulted in the production of different grades and types of PLA for a range of applications, including the capability of matching the high performance demands on materials in the automotive industry (Synbra, 2017).

First-generation feedstocks are plant crops that are suitable for consumption, for example cane or beet sugar, corn and cassava, which are commonly used in bioplastic production. This is because these plants have high yields and need less land to grow. Second-generation feedstock are those that are by-products unsuitable for consumption, and include wood, stalks from corn, straw and bagasse – the redundant fibrous parts of sugar cane after the juice has been extracted (European Bioplastics, 2017). Researchers at Total Corbion Purac have developed a laboratory-scale equivalent of first-generation material PLA with second-generation PLA of cellulosic origin. The industry is researching further ways of utilising such inedible by-products from food production for the production of bioplastics. Total Corbion associate PLA with the notion of the circular economy through the end-of-life options: recycle and reuse, composting, incineration with renewable energy recovery, anaerobic digestion and feedstock recovery. They have developed automotive standard Luminy PLA plastic, which is resistant to heat, strong and suitable for automotive applications (Total Corbian, 2017).

Toyota has used plant-derived plastics in the side trim, pillar covers, headliners and sun visors of the Toyota SAI hybrid sedan passenger vehicle and for parts in the i-REAL Ann and i-REAL Kei personal mobility vehicle prototypes (Toyota, 2016, p. 27 and Toyota, 2010). Toyota Boshoku, manufacturers of automotive interior components and fabrics, co-developed this ‘ecological plastic’, a term used to describe Toyota plastics which contain plant-derived elements and match automotive performance standards (Toyota, 2010 and Toyota Boshoku, 2010). Bioplastics cover 60 per cent of visible surfaces in the Sai hybrid sedan (2009). PSA Peugeot Citroën Group aspires to fully explore the use of natural resources: in 2015 30 per cent of the Groups models contained 'green polymers' (PSA Group, 2017).

European Bioplastics define bioplastics as being biobased, biodegradable or both (European Bioplastics, 2017, p. 3). However, there needs to be a standard specification if a material is described as 'biodegradable'. They recommend that if a plastic is claimed to be compostable this needs to be supported with certification as evidence that it can be treated in an industrial compost plant. The seedling label is a mark to show that the material or product is suitable for organic recycling: that is conforming to the criteria for industrial composting in Europe EN 13432. Describing a plastic as biodegradable can be misleading, as the ability to be so is not dependent on the materials origin but on the chemical structure of the polymer. 'Oxo-degradable' plastics are mixed with additives to imitate the process of biodegradation but are ultimately not compostable: the process breaks the plastic into tiny particles that stay in the environment (European Bioplastics, 2017).

Biobased plastics, either completely or in part, includes polyethylene (PE), polyethylene terephthalate (PET) and polyvinyl chloride (PVC). They reduce the carbon footprint in comparison to fossil-derived plastics, yet are equal in their performance properties. They can be mechanically recycled in separate plastic-type streams alongside conventional plastics that are derived from fossil sources (European Bioplastics, 2017).

Converting waste from renewable resources and successfully incorporating this into products could have a negative impact on the environment if the balance of use shifts without consideration for, and management of, resource yields: for instance, if the primary objective becomes the use of the material for products which then diverts land use from food production. In 2013, in order to ensure a balance between using land for food and for material sources the Bioplastic Feedstock Alliance (BFA) was established (Bioplastic Feedstock Alliance, 2017). This is a consortium of globally recognised consumer brands, including Ford, and the World Wildlife Fund (WWF) conservation group (Bioplastic Feedstock Alliance, 2013 and Ford, 2016, p. 56).[19] The emphasis of BFA's remit is on advising on and steering the use of farmed source materials for bioplastics, such as sugar cane and corn, to ensure sustainable growth and prevent conflict with land use for food production (Bioplastics Feedstock

[19] The Coca Cola Company, Danone, Ford, H.J.Heinz Company, Nestle, Nike, Proctor & Gamble and Unilever.

Alliance, 2017). BFA perceives the bioeconomy to be an essential part of the circular economy, as new resources need to be added in order to sustain it. Using responsible, renewable materials in products reduces the reliance on finite resources and lessens the impact of growing such materials. They visualise a scenario in which products and materials are recovered and reused or recycled multiple times until they are too degraded to use, which they describe as a cascading-value system.

Industrial composting is a controlled biotechnical process for converting biodegradable waste of biological origin into clean products for agricultural use. The feedstocks include food waste from catering, waste from public markets, garden and park waste and wood waste. The process is controlled and separates into two phases: the first part is active composting, which takes a minimum of 21 days, during which microorganisms grow on organic waste, break it down to carbon dioxide and water and use it as a nutrient. Some of the energy produced is released as heat, which increases to temperatures of 50 and 60 degrees Celsius. In order to eradicate pathogenic microorganisms the temperature must stay at above 60 degrees Celsius for a minimum of seven days. The second phase is the curing phase when the rate of decomposition slows and the compost matures at lower temperatures – under 40 degrees Celsius. There are different technologies for industrial composting; these include window composting, aerated static piles, tunnel composting and in-vessel composting (Euorpean Bioplastics, 2009). Bioplastics can be reused, mechanically recycled, organically recycled and used to recover energy (European Bioplastics, 2017).

Agricultural waste and food production waste

Ford continues to explore the potential for using agricultural and food production waste in automotive components today, following Henry Ford’s established research into uses for farm crop residue in the 1900s. In collaboration with H.J. Heinz Company, Ford are investigating ways of converting tomato fibre derived from the skins, leaves, stems and seeds of the fruit after ketchup manufacturing into bio-plastic (The Sustainable Investor, 2016). The bioplastic that has so far been developed is currently being tested for long-term use and resistance to wearing for specific in-vehicle applications, namely ‘wiring brackets and storage bins’ (Ford Media Center, 2014). Ford describes the ways that development of renewable materials can be developed in tandem with the employment of agricultural waste from established crop production in automotive contexts. The materials that they have utilised in vehicles to date include cellulose fibres from managed tree forests, wheat straw, kenaf, flax and rice husks, all of which can replace fibreglass as a reinforcement material in plastics (Ford, 2016, p. 56).

Restore Mushroom Packaging is a material created from agricultural fibrous waste by North American company Ecovative Design (Ecovative, 2017). The waste is cleaned then mycelium[20] is added and the mixture is bagged in plastic and left for a few days, during which time the mycelium grows around it, forming a matrix; each fibre is now coated with mycelium. The substance is removed, broken into small particles and placed in a tool within which they grow, filling the empty space in the mould. When solid (within a week), the form is taken out and dried, which halts the process, preventing further growth into spores or mushrooms. It is compostable in appropriate conditions and otherwise stable. It has potential for automotive use, such as interior panels, bolsters and foam. In 2011 press reports stated that Ford were collaborating with this development: there is no up-to-date information on the progress of this collaboration. Charnley, (2015, p. 11) describes their approach as 'material-first design'. In creating a 'System analysis of Ecovative', (Charnley, 2015, p.12) utilises four systems within which Ecovative operates. The 'Societal System' is the conceptual landscape, or awareness, of toxic landfill scenarios resulting in the development of a material that can safely be composted in biological loops. The 'Socio-Technical System' refers to Ecovative's system and market innovations, which develop the material from a renewable resource to be compostable.
The 'Product-Service System' describes how the product meets performance expectations but is environmentally compatible. 'Product Technology' describes innovations to support the uptake of a new generation of materials.

Revisiting Henry Ford's research into using agricultural waste and his enthusiastic investment in utilising soy, Tier One supplier, Lear[21] in conjunction with Ford, has developed and manufactured SoyFoam (Lear, 2017), a bio-based composite which has been increased in seat foam content from its original 5 per cent to the current 40 per cent. BioFoam, an Expandable Polystyrene (EPS), is derived from wholly renewable sources, and in its pure form is compostable (Synbra Technology bv, 2017).

Potential applications for oil derived from locally grown plant sources are being developed further at Ford, when there is a surplus. In the US the potential for using soy oil continues to be explored; the development of oil from mustard seed in Canada, castor oil in tropical regions and palm oil in Africa and South America are all

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[20] Mycellium is the tissue that hosts fungus.
[21] Lear is a Tier One supplier with a vertical operation.

being investigated. Ford used ‘plant-based castor oil foam’ containing in excess of 10 per cent renewable material, in its Focus 2012 instrument panel and its Escape and Mustang 2013 (Ford, 2016, p. 56). Soy oil has been used as a component in the seat foam of all North American vehicles since 2011 and in the headliner of the Ford Escape (Ford, 2015, p. 403 and Lear, 2017).

Concept cars as a showcase for sustainable material innovation

Concept cars provide automotive manufacturers with an arena to showcase innovation in material application and developments, allowing them free rein in styling direction without the financial constraint necessary for production models.

In 2009 Lotus Cars presented the Eco Elise: the project focused on producing a sports car using renewable materials that shifted emphasis away from an emissions-centric approach to addressing the issues concerning the environmental impact of automobile production and use. By definition a sports car is not considered an ecologically considerate version of personal mobility; however, employing hemp fibres in composite exterior body panels, spoilers and seats, in conjunction with other measures such as the use of a water-based paint system developed with DuPont enabled Lotus to concentrate on reducing weight, thereby increasing fuel efficiency in relation to speed. Wool, sisal and hemp grown locally in East Anglia, also contributed to the reduction in CO2 during the life-cycle analysis of the concept car (Lotus Cars, 2009).

Fiat’s Uno Ecologica concept car (Fiat Brazil, 2010) demonstrated a collection of regionally sourced, renewable and recycled materials that were used in both the interior and aspects of the exterior. Described as influencing the development of design (*‘influências no desenvolvimento de design’*), it was intended that the materials used should have a minimal impact on the environment. Agricultural production in Brazil includes sugarcane, coconut, soybeans, cocoa, coffee, wheat, corn and rice. Fiat used bagasse from sugarcane, together with PP, for both the interior and the exterior panels, and bagasse mixed with ash from rice husks for invisible injection-moulded parts. The indigenous natural coconut fibre waste was compressed to shape parts and seat foam replacement: the natural characteristics of this materials include durability and suppleness, thus ensuring, comfort. Ford used coconut coir fibres in its Focus Electric BEV concept car at the Frankfurt Motor Show in 2009 (Ford, 2015, p. 404). Containing natural tannin, the fibre inhibits growth of mould and mites. (Fiat had previously used coconut fibre in woven fabrics in the

Panda Aria concept car 2007 (Green Car Congress, 2007). Recycled PET was needle-punched into non-woven carpets and flooring, door panels and seats (Ford, 2013, p. 6).

Initially a satellite project within BMW that focused on innovation, the ‘i’ series is an electric vehicle in which the material use adopts the concept of CO2 reduction. In her UID (Umeå Institute of Design) Design Talk at Umeå University, Sweden (4 June 2015), Daniela Bohlinger, Sustainability Manager at BMW, discussed her holistic approach to automotive design and the i3. Starting at BMW in 2002 as a colour and trim materials designer, in 2005/6 Bohlinger shifted to the sustainability division, recognising that material use, as well as manufacturing was significant to automotive sustainability. In her presentation, she cited BMW’s CEO, Norbert Reithofer as saying: ‘In the future, premium will also be defined by sustainability.’ Bohlinger views simplicity as efficient, design as an aspect of sustainability and materials as driving design. She aims to understand what products are made of by disassembling them, analysing their materials and redesigning them following the principles of sustainability.’ That is, to reduce and to substitute: ‘From nothing to something valuable through clever tooling and responsible usage of materials’ (Umeå University, 2015).

Following the unveiling of BMW’s electric concept car in 2011, mass production of the BMW i3 started in 2013 and continues today, with successful sales globally (BMW press, 2015 and BMW Group, 2015). An emission-free vehicle, the i3 concept is followed through by demonstrating, from a materials perspective, a high quality ‘resource-friendly approach’ to material use, (BMW Group, 2015). Materials in the interior are sustainably produced or derive from recycled materials. These include leather that is 100 per cent tanned with extracts from waste olive leaves, a by-product of olive farming, and a eucalyptus wood interior trim from responsible sources, which is moisture-resistant and therefore requires less finishing than other types of wood. Kenaf fibre is used in the seat covers, as previously discussed, in the 40 per cent pure new wool blend fabric (marketed as thermo-regulating, therefore saving on heating and air-conditioning systems).

Chapter Conclusions

The fact that my PhD has taken several years to complete has been advantageous in some respects, particularly in terms of the distinct shift in the adaptation of sustainable practice and materials towards a circular economy that has taken place during this period. In fact the concept of the circular economy has been refined and advanced throughout the duration of this PhD. There is evidence of:

- A shift towards a circular economy within the automotive industry.
- The adoption of renewable materials within the industry: but these however, are often mixed with those from a different material stream.
- Innovative methods of recovering materials from automotive shredding.
- The reuse and recovery of material parts, by companies such as Renault, Ford and Toyota.
- Design for disassembly.
- The swiftness of the industry to embrace materials that reduce weight without compromising on performance.

Conceptually there is now greater recognition that:

- Sustainability is a socio-technical issue that enmeshes technologies and human behaviours.
- It must be approached systematically rather than in a piecemeal way.
- Systemic change involves cultural change.
- Design has a crucial role to play, but designers must themselves think in whole-system terms.

Chapter 5: Mono synthetic textiles for recycling

Summary

This chapter sets out the intention of this project which is to explore the use of one synthetic material, that can be recycled, in a car seat textile, foam backing and seat foam. I describe the processes that were involved in the practical realisation of this and the systems that are necessary to enable this to be viable. I started with the face textile: as the practice developed I realised that each part of the seat needed to be considered.

Introduction

The automotive industry's reliance on oil derivatives to fuel vehicles extends to its use for seat coverings, in which polyester (polyethylene terephthalate: PET) is commonly used, meeting the stringent requirements demanded by the industry concerning performance and safety. Comfort is provided by seat foam and fabric backing commonly made from polyurethane (PU). Its typical features include malleability, wear resistance, noise and shock abatement, vibration minimisation and 'low density' (Zhao and Chen, 2014, p. 145). The interior environment of a vehicle is a confined arena where function combines with design aesthetics. A vehicle could potentially be used in any environment across the world, and therefore be subjected to any circumstance during use; it therefore follows that the materials employed are required to be capable of sustaining their functionality and appearance. Retaining a good visual look sends a subliminal message in relation to reliable engineering (Fung and Hardcastle, 2001, pp. 9-10).

The following table (Table 5) describes the tests that fabrics and other materials are put through and must pass before bring used in a vehicle interior.

Purpose of test is to measure	Method of testing	Requirements	Characteristic to ensure requirements are met
Abrasion – caused by ingress and egress and general use.	Testing abrasion machine motion using Martindale, Schopper or Taber equipment.	No visible wear – details specific to OEM.	Close set fabric, no floats.
Antistatic – generated by clothing rubbing against polyester seat cover, which is hydrophobic, and is influenced by ambient air conditions in the car.	Under the correct laboratory temperature and humidity the conductivity meter measures surface resistance in ohms.	Low or no static A resistivity of about $1x10^{10}$ ohms is considered reasonable	Application of an anti-static finish, which is hydrophilic, ensuring a small amount of moisture is present on the car seat surface. Antistatic properties can be permanently conferred using conductive yarns in small quantities.
Breathability and comfort - measure of the permeability of a material to human perspiration, giving an indication of thermal comfort.	Sweating hot plate test. Evaporative tests.	Good thermal comfort.	There are no breathability requirements for the fabric producer to meet.
Bursting of fabric – fabric strength.	Multi-directional test load. Fabric is clamped in a machine over a rubber diaphragm. Pressure is applied with water (or fluid), which stretches the diaphragm applying a force to the fabric.	Fabric should resist bursting.	Close set fabric.
Clean ability and soiling – when faced with items such as chocolate, coffee, tea, ice cream, hair products, engine oil, sunscreen, anti-bacterial hand sprays.	Materials that may be spilt on the interior surfaces are applied to test pieces in the laboratory and then cleaned off using a special procedure. Degree of soiling is tested in artificial daylight.	Ability to resist staining and ability to be cleaned after soiling.	Surface treatments on the fabric such as nano coating to resist water may be used.

Purpose of test is to measure	Method of testing	Requirements	Characteristic to ensure requirements are met
Colour fastness	Tested by simulated human perspiration liquor, which is applied to the textile to wet it. It is then sandwiched between two white pieces of fabric, one cotton the other possibly wool or mixed fibres. The textile layers are sandwiched between glass sheets and placed in an oven at 37ºC for four hours.	Staining of loose dyes is assessed using grey scales[22] – one to assess the amount of dye transfer to the white fabric and another to assess any change of shade.	
Crocking - perspiration fastness, cold water leaching and rubbing fastness.	Rub fastness when wet and dry is assessed using a Crockmeter. A machine with a wooden peg around which white cotton fabric is secured. The machine's action rubs the fabric sample 10 times then any dye staining is assessed.	Rating 5 indicates no change of shade (COS) and no staining off. 4 indicates a slight but acceptable changes in COS and staining off.	These fastness checks especially on dyed polyester ensure that reduction-cleaning treatment after dyeing has been properly completed.
Dimensional stability for fabric laminates	Visibly examined for curl and other dimension stability tests. Tests measure the shrinkage of the fabric after soaking in cold water and then heating in an oven for several days at various temperatures.	Stable fabric.	Good lamination.
Environmental and ageing – tests to represent several years of ageing in the laboratory in two weeks.	The sample is exposed to heat for approximately two weeks at over 100ºC and humidity at 100 per cent. Tests often involve a cycle of extreme conditions; both hot and cold.	Shade change, dimensional stability and peel bonds are also examined after ageing. OEM specified.	Ideally, little change.
Flammability	USA standard FMVSS 302 horizontal burn test. It is assessed by the burn rate, which is the distance in cm burnt in one minute.	OEM specified.	Flame retardant chemicals can be added to the foam and fabric coating. This adds to the overall weight and cost.

[22] Grey scales standard were made in accordance with the International Standards Association and are specified in BS1006, (ISO 105-A02).

Purpose of test is to measure	Method of testing	Requirements	Characteristic to ensure requirements are met
Fogging – caused by volatile materials vaporising and is related to mal-odours. It is a mist like deposit that forms on car windows reducing visibility and often difficult to remove.	A specified amount of fabric is put in a beaker, which is covered and sealed by a glass plate – its light reflectance has been measured. The glass plate is cooled by a metal plate and cooling water, usually at room temperature, is pumped through it. The beaker is heated at 90 to 110ºC for 3 to 6 hours. Following this, the glass plate's light reflectance is re-measured to determine the reduction is reflectance caused by the condensation of volatile materials.	No fogging.	No volatile materials to cause fogging.
Frosting – the fabric appears whiter	Following abrasion testing.	Defect specific to OEM	No frosting.
Odour	Electronic nose.	No or low odour specific to OEM.	Material selection
Peel bond strength - to ensure the face fabric, foam and scrim do not delaminate	Samples are taken and tested in the warp (lengthways) and weft (width) direction with a Universal Strength Tester. Tested on the fabric as received, after heat ageing, while wet and after treatment with solvents.	Rate of separation and procedure are specified by the OEMs.	
Pilling – associated with abrasion resistance. Is the formation of small fibre clusters on the fabric surface as a result of being rubbed by other materials or against itself.	Random tumble pilling tester or Martindale, with a cycle of about 1000 rubs and the number of pills counted.	Specified by OEM.	Can be minimised by chemical finishes, increasing the thickness of the yarn filaments, use of higher twist yarns and by brushing or cropping the fabric.

Purpose of test is to measure	Method of testing	Requirements	Characteristic to ensure requirements are met
Seam strength	A test seam is prepared and a Universal Strength Tester will attempt to separate the fabrics from either side of the seam simultaneously.	No separation. OEM specified.	
Snagging	Mace snag test to determine the fabric's resistance to snagging. Mace snag tester is a series of spiked metal balls that are abraded against the fabric for a set period of time. The degree of snagging assessed on a scale of 1 to 5.	Minimal snagging. No broken threads. OEM specified.	No floats, close set fabric.
Stretch and set – important because after cutting the panel may elongate under its own weight, which would cause a mismatch in the seat and panel trimming	Strips of fabric of specified dimensions are tested on a computer controlled Universal Strength Tester at specified rates of extension	Minimal. OEM specified.	Stable fabric and lamination.
Tear strength – fabric strength and tensile strength.	Single rip using tear (avoids transfer of tear) and Elmdorf tear (energy loss during the tear process).	Good tear strength and resistance to tear propagation important for car seat fabrics.	Twill woven structures have better tear resistance than plain weave. Yarn and fibre type determines fabric strength - polyester is stronger than wool, continuous filament yarns are stronger.
Tensile strength – fabric strength	Straight load or tensile strength tests.	Specified by the OEM.	

Purpose of test is to measure	Method of testing	Requirements	Characteristic to ensure requirements are met
Ultra Violet (UV) degradation and lightfastness resistance - Due to the variation in sunlight conditions in the world, angle of the sun in the sky, weather and cloud cover all contributing to variations in UV radiation it is difficult to accurately test. Glass in vehicles allows sunlight into the interior, which can heat up to temperatures as high as 130ºC in Arizona. As temperatures fall as the sun sets the humidity is affected and dampness is caused.	Xenon arc lamp, Weather-Ometer (Atlas Material Testing). Fabric tested when foam laminated, or with the foam underneath it. The foam acts as a heat sink replicating the in-vehicle conditions more accurately.	OEMs specify the test method, machine type, filter system, humidity, test chamber temperature and exposure time. The test standard is assessed by Grey Scales.	Ideally, fast to light and resistance to UV degradation in the most extreme conditions.

Table 6: Automotive testing and requirements (Fung and Hardcastle, 2001, pp. 166-189).

Worldwide, 90 per cent of car seat textile covers are made using polyester (Fung and Hardcastle, pp.10-11: Pamuk and Ceken, 2009, p.47). However, its use extends beyond seat textile covers to include other surfaces and parts in the interior (Mukhopadhyay and Partridge, 1999, p. 4-5). The rationale for its ubiquitous use stems from its capability to remain consistent in performance over a period of time with sustained use. Polyester's main attributes, which are considered crucial in automotive interiors, include its ability to withstand aggressive abrasion, resistance to ultra-violet light (albeit with the addition of absorbing chemicals) its inherent flame-retardant property and low cost. In addition it is odourless, making it suitable for enclosed space, it emits no fumes that could potentially affect window glass visibility with smearing or fogging and is reliably uniform in appearance. Other benefits can be perceived as also having negative side effects for example its resistance to moisture prevents mildew but this does not enhance thermal comfort in hot conditions, as moisture is not absorbed (Fung and Hardcastle, 2001, pp. 9-16).

The construction of the polyester fibre – the spinning of the yarn and the textile fabrication process - also has an impact on the performance of the material, which is engineered to be technically suitable for its intended end use. However, to further support these qualities and reduce the tendency to crease, the polyester textile is laminated to a layer of polyurethane foam: commonly either polyester or polyether polyurethane foam. Underneath this a nylon or polyester scrim textile is laminated: this facilitates sewing, allowing the three bonded layers to glide easily through the machine in the process, additionally strengthening the seams (pp. 13, 111 and 270). The process of flame lamination is used extensively: this procedure melts the surface of the polyurethane foam, allowing it to function as a glue and creating a strong bond between, and cohesion of, the material layers. Emissions that are produced from burning the polyurethane need to be controlled and contained, because they are hazardous and possibly poisonous. Other processes, such as hot melt adhesive to bond the layers are alternatives. However, the low cost of the process even with the additional expense of fume controls, alongside the ensured performance and appearance of the materials following flame lamination contribute to supporting its continued use (pp. 111, 143-145).

Post-use shredding of the soft automotive seat parts results in a combination of different types of polyurethane foams, which are contaminated with other types of non-urethane substances, including polyester. In order to recycle this combination of polymeric material types they need to be separated. This can be achieved by any of three different methods: mechanical recycling, chemical and energy retrieval including burning, and decomposition following chemical intervention (Nikje, 2016). There are four main processes associated with chemical recycling: hydrolysis[23], glycolysis[24], pyrolysis[25] and hydrogenation,[26] (American Chemistry Council, 2017). For mixed polyurethane waste, the appropriate method is hydrolysis, which will deconstruct the mix into basic chemicals for reuse (Fung and Hardcastle, 2001, pp. 270-271). Sendijarevic (2007, pp. 31-46) discusses the patented process developed by Troy Polymers, Inc. (2004) for the economically viable chemical recycling of

[23] Hydrolysis: 'polyols' and 'intermediate chemicals' created by reaction of the polyurethanes and water.
[24] Glycolysis: high temperature activates polyurethane into a chemical reaction forming new 'polyols': these are used to make polyurethanes.
[25] Pyrolysis: thermo-chemically separates polyurethane in oxygen free conditions making gas and oils.
[26] Hydrogenation: also creates gas and oils through heat, pressure and hydrogen.

polyurethane foam and other waste materials from the shredder. However, using one material in a product allows for the simplest and optimum recovery of that material.

I wanted to make the practical work believable to the automotive industry in real terms. It was therefore important to make the textile equivalent to an automotive standard fabric. Consequently, I sought to work with a supplier of polyester textiles to the automotive industry. My initial visit to Guilford Performance Textiles in Derbyshire was on the 8 April 2011. It followed the suggestion and introduction of contacts within the company by designers at Ford.

Established in 1946 in the US, Guilford's main business initially was the supply of knitted textiles for lingerie. In 1963 a finishing plant assisted its growth as a vertically integrated textile company. Automotive textiles were one part of the company's market, which additionally included interior textiles and apparel. During the 1980's Guilford was the largest global supplier of warp knitting. The company was restructured to concentrate on technical textiles, and in 2012 Guilford became part of the Lear Corporation, manufacturers of automotive seating (Guilford Performance Textiles, 2017).

My meeting was held with representatives from the design and technical teams respectively. The discussion centred on the potential for sustainable material use in automotive textiles. From the designer's perspective their concern was how to create visibility of the use of recycled material to the customer as a premium not a low-grade product. The technical considerations emphasised the need for performance standards to be met in conjunction with the overall equation involving the use of energy for manufacturing.

Polyester yarns are used by Guilford for their automotive textiles, which are engineered at every stage of the process including spinning, weaving, knitting and finishing for optimum performance. The expertise within the technical team was not only informative but provided a conduit through which I could see a way to progress the project with their support.

Intention

The primary intention of my Mono synthetic project was to recreate aspects of the Fiesta interior demonstrating the use of materials following the principle outlined in McDonough and Braungart's 'Cradle to Cradle' approach: to create

"[…] products that, when their useful life is over, do not become useless waste but […] return to industrial cycles to supply high-quality raw materials for new products" (McDonough and Braungart, 2002, p.91).

This would be achieved using one synthetic material, polyester, that can be recycled if kept in a pure material stream uncontaminated by other synthetics. It would in part include the reuse of polyester from both industrial textile and consumer waste.

Focusing on reproducing the soft parts for a seat centred on three main areas:

- Face textiles for squab[27] insert, cushion[28], and rear
- Under-textile foam
- Foam

I used the Fiesta seat coverings as a template for dimensions with the initial objective of applying and trimming the original seat frame with the results. The intention was that the seat fabric and foam replacements could easily be detached from the frame at the end of life of the seat. They could be reused in an equivalent scenario to the one I was developing. However, as the project progressed the concept evolved. This did not interfere with the face textile and backing foam aspects. However, the seat foam was subsequently designed to fit an abstract suggestion of a seat form, which is discussed when I detail the process (p. 115-117).

Integral to each project was the production of work that would be commensurate as far as possible with accepted automotive standards. This would demonstrate proof of concept in real terms. Manufacturing within an established industrial facility is one aspect of this: it shows that volume production can be realised within existing current technologies. In addition the yarn and textile face fabric specifications would comply with standard performance requirements for automotive use.

Process

Starting with the textile face fabric the first decision I made was that the fabric should be woven: Guilford has the capability for both knitting and weaving. During the sampling stage early in the research I had used Jacquard weaving to test various yarns at the College. In doing so I had gained insight into the potential of the fabrics produced. The designers I had met at Guilford worked on developing Jacquard woven fabrics, and would be invaluable for their expert advice.

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[27] Squab: seat back.
[28] Cushion: seat bottom.

Guilford introduced me to one of their polyester yarns manufacturers and suppliers, Antex.[29] I subsequently visited their facilities in Girona, Spain, on the 31 August 2011 and discussed the processes they use to mechanically recycle waste polyester into the equivalent of virgin polyester yarn, which I also saw in progress.

In 2007 Antex started their recycling process.[30] During 2008 the production plant as well as the master batch development was established. The master batch provides control, allows for additives and enables the recipe for the spun-dyed process to be produced. Shades are tested scientifically as well as by eye.

When I visited they explained the main rationale for their investment in recycling. The cost of the virgin raw material was €1 to €1.50/kg whilst they estimated that 600 – 800 tonnes of residual waste was available, which was cheaper, even when taking into account the cost of transporting the material.

One supply route for Antex is the repurchase of selvedge waste from their customers, woven textile manufacturers whom they have supplied with polyester yarn. To ensure that the waste is 100 per cent polyester the selvedge feeder yarn, which is independent of the weft or warp, was changed, by Antex, to polyester. Other waste used for mechanical recycling is fabric, yarn and texturing waste. The recycled fibre is only available in black due to the variable colour mix in the selvedge waste resulting from the inevitable variety of cloth designs and colourways of the woven textiles from which it is sourced. When the waste is combined and melted down in order to reconstitute the ‘new’ raw material it results in a grey tone that is then mixed with master batch that renders it black.

Logistically, the waste fabric needs to be compacted into bales to reduce the overall volume, then transported to Antex where storage space is required prior to the recycling process. The mixed fibre waste passes on a conveyor belt through a heated chamber in which it is melted to a thick liquid sludge resembling oil. From here it is then solidified and chopped into small pellets ready for use.

Similarly, waste drinking bottles are deconstructed through heat back to a viscous liquid state. Being more or less colourless, recycled polyester chips from waste drinking bottles provided the possibility of including colour in my designs, and were

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[29] Antex is an independent Spanish group founded in 1968. It also has factories producing the same products in Cinitiha, Brazil. Antex introduced spun dyeing (not package dyeing) in their spinning mill, opened in 1996.

[30] The Antex recycling process is endorsed by the following environmental standards: ISO/4001 certificate: OEKO Tex standard 100: Aenor and CCP for recycling process.

dyed to match my selected shades. My colour scheme consisted of a broad range of shades to allow for a variety of options when designing and weaving the fabric samples and lengths. As the Fiesta was a particular shade of blue I decided to take a monochromatic approach with highlights of other colours. These coordinated with the leather hides and wool yarns that I had already received from Bridge of Weir and Scholler respectively. Although I had design references and ideas for the textiles I had not finalised these at this stage when selecting colour choices. I envisaged that for the main sample lengths for inclusion inside the Fiesta I would use a range of blue tones and colours, which might include highlights of bright colours. With this colour selection I would be able to create a range of coordinated woven samples that would be visually commensurate with the wool yarns already chosen for the 'Renewable textile' project. At this stage I wanted to keep colour options wide for when I fixed the colours and designs: but I had decided to work mainly with shades of blue to complement the Fiesta and ensure they worked well in the interior.

The material-driven consideration was that the material, yarn and subsequent textile would be equal to existing automotive polyester textiles but be made from recycled material. From a practical perspective it would perform to an equivalent standard when tested. The main aesthetic consideration was that the designs and colour scheme would work in the Fiesta interior and complement it. The design challenge was how to visually demonstrate that the material was recycled in origin? I discuss my design considerations (pp. 106-109).

In order to ensure that the textiles would pass performance tests I decided to follow the technical specifications for the yarn that the team at Guilford had suggested in discussions. The count, texture and twist of the yarn would be of a standard quality that would be suitable for use on the looms at Guilford in both the warp and weft. Both types, recycled fibre and recycled chips, were 600dtex 144 filaments air jet textured with twist. Air texturing would give a softer handle to the fabric. A false twist was another option that would have resulted in a more synthetic feel. Following technical guidance from Antex, the yarn was constructed through the melt spinning and extrusion process. Partially orientated yarn (POY), in which the filaments are stretched during spinning to conform to predetermined properties of strength, elongation (130 per cent), recovery and uniformity, was the production method used. During production the molten polyester is extruded through spinnerets, which determine the yarns resultant decitex count and filaments through differently shaped and numbered holes, followed by air texturing. Fung and Hardcastle (2001, pp. 51-52) suggest that the process of air texturising supported the increase in the use of textiles in automotive trim applications by technically improving the quality and longevity of mainly woven fabrics. POY's are passed through an air jet, which intermixes and distorts the filaments, thereby fixing them in place. The resulting yarn is consistent with a high abrasion resistance. False twisted texturising is a process in which the twisted yarn is thermally set then untwisted in cooler conditions (pp. 49-51). The filaments of the thermoplastic thread strive to regain the position in which they were set thereby forming a light bulky yarn with stretch capability.

The quantity of yarn that would be needed was based on the length and width of my sample warp. Guilford advised that a minimum of 30 metres of fabric would be needed for finishing and lamination. I proposed that the warp would be 50m in length, which would allow for 8m of production waste in both weaving and laminating.

As my intention was to trim an existing Fiesta seat I used the original cover to provide estimated measurements in planning sections of the warp. To maximise the versatility of the warp regarding the use of colour I divided the width into two sections, one black the other pale grey (Figure 12). From experience I was aware that some shades would work better on one option but with less success on the other. Each warp section was 90cm wide, which would allow sufficient fabric for the placement of the shaped pattern pieces of the seat at the trimming stage. Antex dyes the yarn in packages[31] of either one, two, four or seventeen, with each pack weighing approximately three kilograms. For the warp colours I requested seventeen packages, for highlights one package and for main weft colours two or four packages depending on the dominance of the shade.

[31] Package is the term for the cone or tube on which yarn is wound.

Figure 12: Split warp: on the left black warp threads on the right pale grey warp threads. Sheila Clark, 2015.

Antibacterial fabrics

During the previous project that led to this doctoral study I had investigated the potential for antibacterial fabrics through the inclusion of silver twisted yarn in a textile construction. Whilst visiting Antex I mentioned that such properties in a car seat fabric would be beneficial, especially for children's seats (Gao and Cranston, 2008, p. 61). Through the use of a treatment with silver ions (AG+) yarn can be endowed with this performance attribute[32] (Barwick, 2013). I requested this treatment for the black weft yarn. However, on testing the resulting textile at Northampton University, 9 December 2014, the sensory electronic microscope evidenced negligible AG content. I subsequently tested the fabrics in petri dishes to determine if there was any difference in bacterial growth that could be distinguishable by eye.

The use of nanosilver in consumer products is being questioned as the effect it has on the environment, people and on bacterial resistance is a continuing area of research. The increase in use of nanosilver will have possible impact when it enters

[32] The use of nanosilver silver was questioned by The Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) at the request of the European Commission in relation to the environment and potential associated risks.

the environment either through waste water treatments, as it separates from the textile through repeated washing cycles, or when sewage sludge is used as fertiliser for soil (Fullum, 2013). Silver release at some levels may be toxic to some aquatic organisms (Scientific Committee on emerging and newly identified health risks [SCENIHR], 2014; Hartemann, et.al., 2015). This example illustrates the way in which well-intentioned design decisions can have unforeseen disadvantages that are only apparent when considered systemically.

Design

During the project I had been collecting imagery that I found inspirational for design reference. As I accumulated materials such as leather from Bridge of Weir and wool yarns from Schoeller I included samples in sketchbooks alongside these images. I decided the colour palette needed to be the same for all the materials in order to visually link the projects, which at this stage I still imagined would be fitted into the Fiesta. As the projects were being conducted at varying times this gave a reference point to return to for each.

As synthetic materials were used for this project I wanted to create a series of designs that were reminiscent of molecular structures and chemical engineering. The intention was to reference the way synthetics are made with a retrospective allusion to their discovery. Initially, I investigated the literal use of molecular patterns to give a technical look to the textiles. I discovered that similar motifs had provided the inspiration and templates for the so-called ‘Festival Pattern Group’ in 1949 (Jackson, 2008, p. 9). Dr Helen Megaw[33] had, in 1946, suggested that photographs of crystals taken by x-ray diffraction and diagrams of atomic structures would translate well into surface designs. Mark Hartland Thomas, Chief Industrial Officer from the Council of Industrial Design, saw the potential for the image transference in a manufacturing context following his attendance at an illustrated crystallography lecture to the Society of Industrial Artists in 1949. His involvement with the Festival of Britain, intended ‘…as a platform for British ingenuity and creativity in science, technology and the arts’ (2008, p. 8) prompted him to suggest a project that combined these areas. Along with crystallography, Hartland Thomas wanted the recent emergence of synthetic materials to be represented in designers’ collaborations with textile (for interiors as well as fashion) and ceramic producers. As an example, the Imperial

[33] Dr Helen Megaw was a crystallographer at Birkbeck College, London in 1946 when she moved to the ‘Cavendish Laboratory’ Cambridge. She instigated the Festival Pattern Group and advised on ‘Crystal Structure Diagrams’ that were used for the exhibition for the Festival of Britain, October 1949 to May 1951.

Chemical Industries (ICI), a major British chemical organisation at the time, supplied crystal structure diagrams of their products, including nylon and polyethylene (p. 18).

On consideration I decided the textile designs that the Festival Pattern Group had achieved without computer aided design should only be a point of reference in my design work. Furthermore, I wanted to represent the cycle of construction, deconstruction and reconstruction of the material in the imagery, which led to the main design.

It was important that my designs were credible for use in automotive seat fabrics, as well as suggesting that I was using technical materials. The scale of motif should be small in order to reduce waste in the pattern-cutting process. Scarf Deco, the main design, is a graphic inspired by elements associated with Art Deco with texture in the weave structure: it aims to visually suggest a pause between the alternating construction and, deconstruction of the components: a hiatus in the respective processes (Figure 13). Referencing Art Deco for design inspiration is intended to evoke the period when Du Pont first began its research into synthetic polymers.

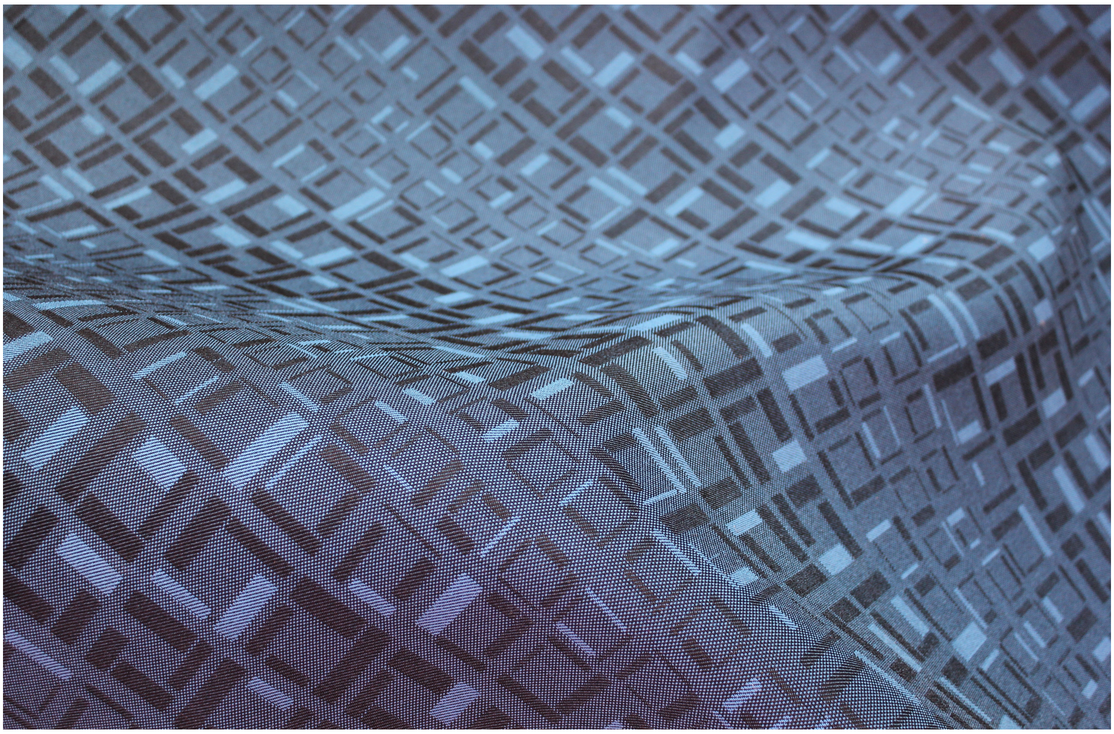

Figure 13: Scarf deco main design.
Sheila Clark, 2015.

The second main design, TechDesign consists of a hexagonal geometric structure, intended to be reminiscent of molecular diagrams without the literal use of crystallography (Figure 14).

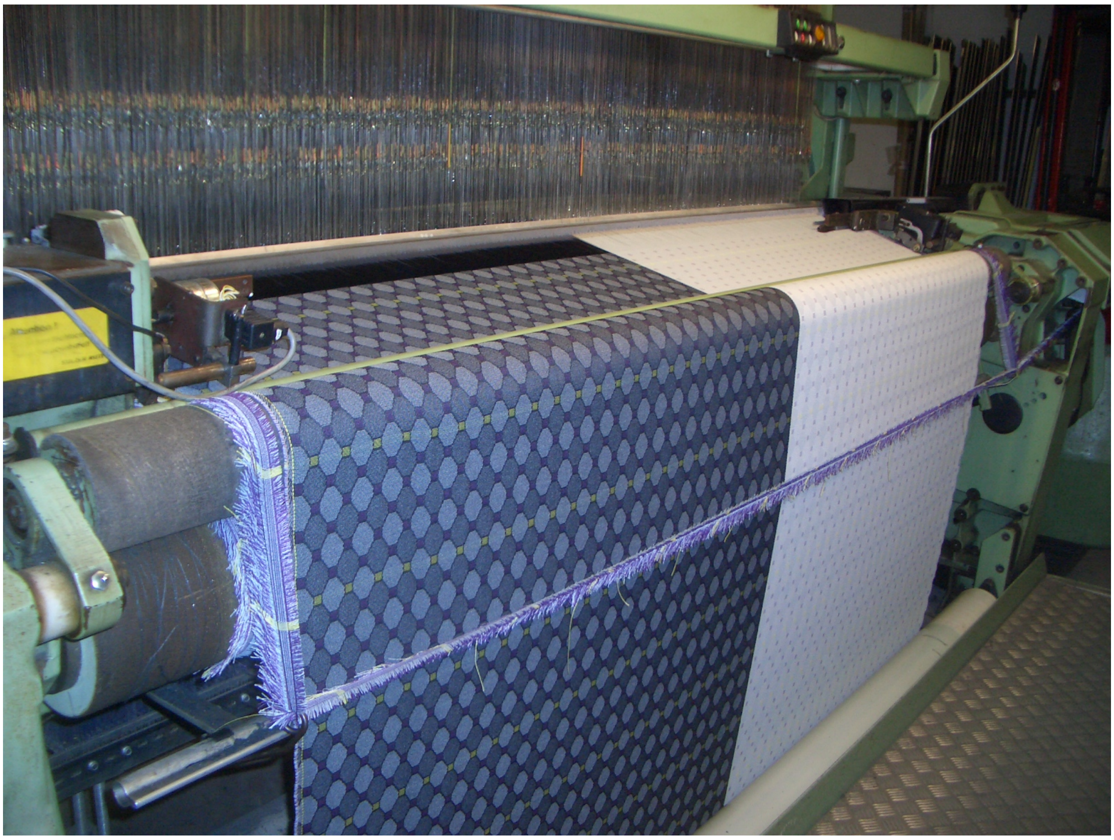

Figure 14; TechDesign being woven on both black and pale grey split warp.
Sheila Clark, 2012.

Further designs were prepared but some were not translated into woven fabrics. Figures 15 and 16 show design simulations and technical data on the loom.

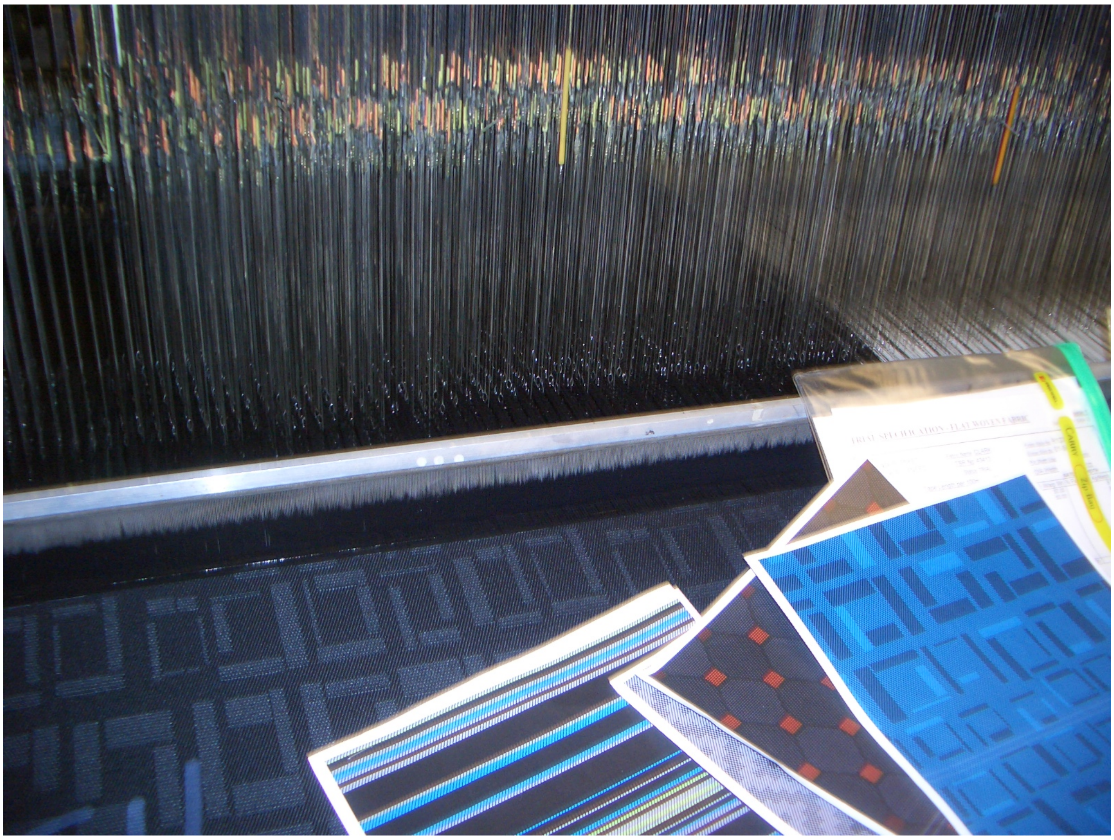

Figure 15: Design simulations pictured on the loom. Sheila Clark, 2012.

Figure 16: Stripe design being woven with the weft pick sequence pictured.
Sheila Clark, 2012.

In order to fully demonstrate and utilise the yarn colours I had requested and that Antex had prepared, I had sample sections of stripes woven. Using the different colours in horizontal striping of varying thickness enabled me to group the main colour ways and add bright colours as highlights. Incorporating several colours into other designs would not be conducive to the overall representation of materials that I was aiming to achieve. I had to keep to the overall aim of using a monochromatic palette for each colour, using tonal variations to distinguish the design elements.

There were time limitations regarding available computer space at Guilford when I could work on the weave programme software, Scotweave[34]. Jpegs of my designs were imported into the programme and the design repeat corrected and adjusted as necessary. Following this process the next stage involved cleaning up the footings. These are areas from the design input that were not in alignment when the weave structure was applied: correcting them ensured that the edges of the design shapes and lines would appear fluid and clean in the woven fabric. This involved stepping each shape edge or line pick by pick to eradicate long floats, which would otherwise appear as faults in the resulting textile. Automotive fabric structures need to be closely woven due to performance requirements otherwise snagging would occur from contact with pointed or coarse items such as sharp blades, keys or Velcro (Fung and Hardcastle, 2001, pp. 178-179). The tendency to snag is measured using a mace snag tester[35] which imitates such contact against the fabric over a set cycle. The design team at Guilford supported my work by advising, checking and adapting the translation in order to perfect the textile outcome. Their considerable experience in this process was invaluable.

The weave structure was selected from archives at Guilford to ensure it would be commensurate with automotive performance requirements in addition to visually supporting the designs. Using Scotweave several visualisations of the designs with different weave structures and colour representations were experimented with on screen before the final decision was made.

Once the designs had been translated into Scotweave the next stage involved detailing colour sequences in preparation for weaving. Each weft colour pick was decided and noted, in order to provide instruction to the weave technician during fabrication at exactly which point to change the weft yarn package.

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[34] ScotWeave, is a computer-aided design (CAD) system that allows designs to be put into repeat, and applies weave structures, colour and yarn characteristics to enable a realistic simulation of the final fabric, prior to weaving (Fung and Hardcastle, 2001, p.30).
[35] A mace snag tester is comprised of metal spheres with protruding conical spikes.

I planned that the, Scarf Deco design would be used for the seat area, the squab cushion, and facing back of the seat, which would be complemented by the solid black 2/2 twill fabric. Sections that were likely to be touched by hand, such as the edge of the cushion were to be trimmed with the silver content textile. This decision influenced the length of each design that would be woven.

Weaving and laminating of the textiles

In May 2012 Guilford had received the yarns from Antex and stored them in a lorry container, which subsequently proved difficult to locate for the weaving. As my project was a trial outside of the normal factory processes this was understandable. By the 29 August, my warp was knotted in and ready to be woven.

As the preparations that had begun with yarn creation, followed by design, weave structure, and colour sequencing were complete the process of weaving the fabrics was relatively straightforward. I was present on the day and observed the main design lengths being woven then the smaller sections showing alternative colourways. The last pieces to be woven were the striped fabrics that allowed me to use the brighter shades.

At the beginning of November 2012, the fabric was adhesively laminated to the 4mm spacer; Ames provided 60m for this purpose. The warp knitting company Ames-Europe (based in the Netherlands) manufacture synthetic technical textiles, including spacer fabrics[36], and supply their textile products to Guilford. I had had contact with the UK agent earlier whilst working on the project that led to this research. By coincidence she was visiting the technical team when I was there too. A discussion about my project aims and the involvement of Guilford and Antex resulted in the idea that a polyester spacer fabric could be a substitute for the lamination of polyurethane foam. This would create a mono material seat fabric foam backing replacement that could be recycled in one piece.

After lamination, I asked for the sample colourways and designs to be cut into 0.5m sections: prior to cutting this length measured 14.5m. Each piece had been woven across the split warp of black and light grey, which meant that some colours worked better visually on either the light or dark section. As planned, the remainder divided into the seat areas for trimming as follows: 8m of the main design for the insert, 5m black for the bolster, 1m of two-coloured for the bolster in blue/black and 10m for the bolster in the black with silver yarn.

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[36] Spacer fabrics are warp knitted instead of continuous thread weft knits.

All the fabrics were sent to me with a view to being sent for trimming with one of the Fiesta seats to Lear. I also considered having a second seat fabric and foam trim made, to be sent to Antex for recycling to pellets illustrating the full circle of recycling. In my communication with Lear (26 March 2013) they had expressed concern that adjustments to existing patterns and procedures for seat trimming would be necessary as I was changing standard material elements.

Foam replacements

During the meeting with Antex I had raised the issue of textile waste specific to the automotive industry with particular reference to the practice of bonding polyester fabric to polyurethane foam. They were working on a confidential customer trial to chemically separate the two materials in order to recycle them. The potential for recycling would be increased if the polyurethane foam backing had not been used: recycling is facilitated through the use of one material. In my records from the meeting I note ‘Re-design the product without the foam’.

We also discussed the issue of textile waste resulting from cutting the pattern shapes during the seat trimming. The use of computer-aided design (CAD) optimises fabric use by maximising the potential of the pattern block placement with consideration to the design and direction of fabric structure.

At the meeting I sketched the following model/diagram based on our discussion regarding the possible reuse of waste (Figure 17):

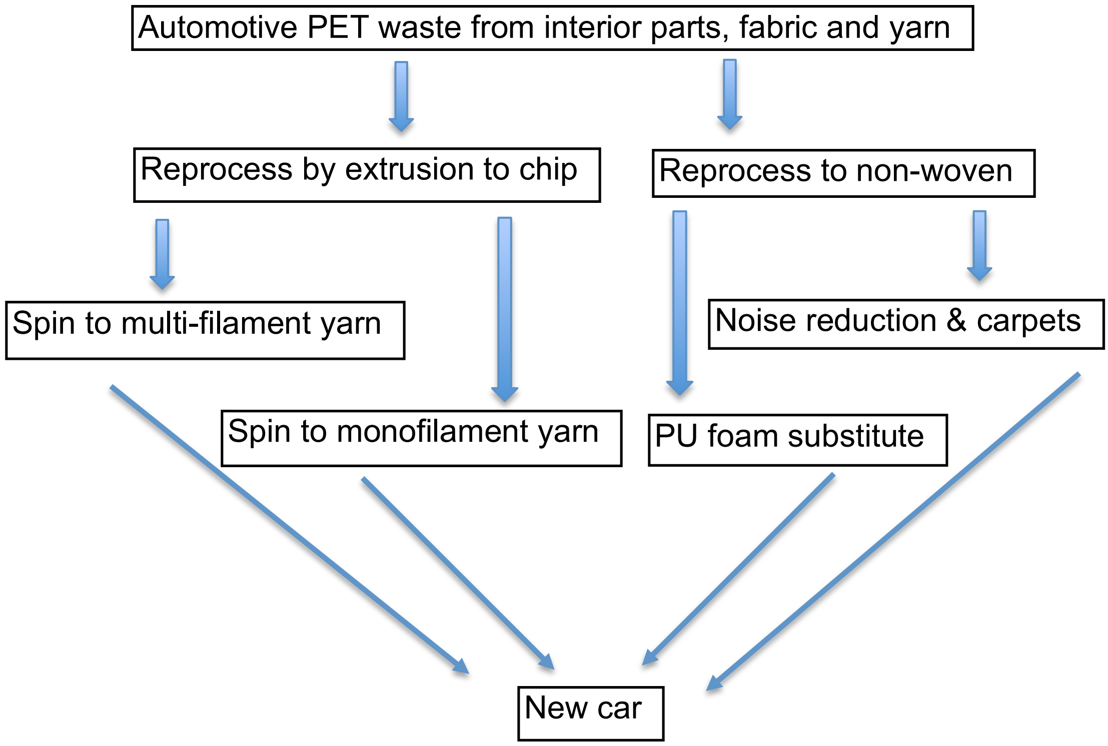

Figure 17: Reuse of waste polyester diagram, produced from the sketched diagram made at the Antex meeting.
Sheila Clark, 2012.

Non-woven textile waste was found in some non-visible areas in the Fiesta, inside the door panels to reduce noise, and as backing for the parcel shelf: these were composed of mixed fibre waste. In keeping with the aims of the project I needed to ensure that the material I would employ was 100 per cent polyester.

Spacer fabric foam replacement

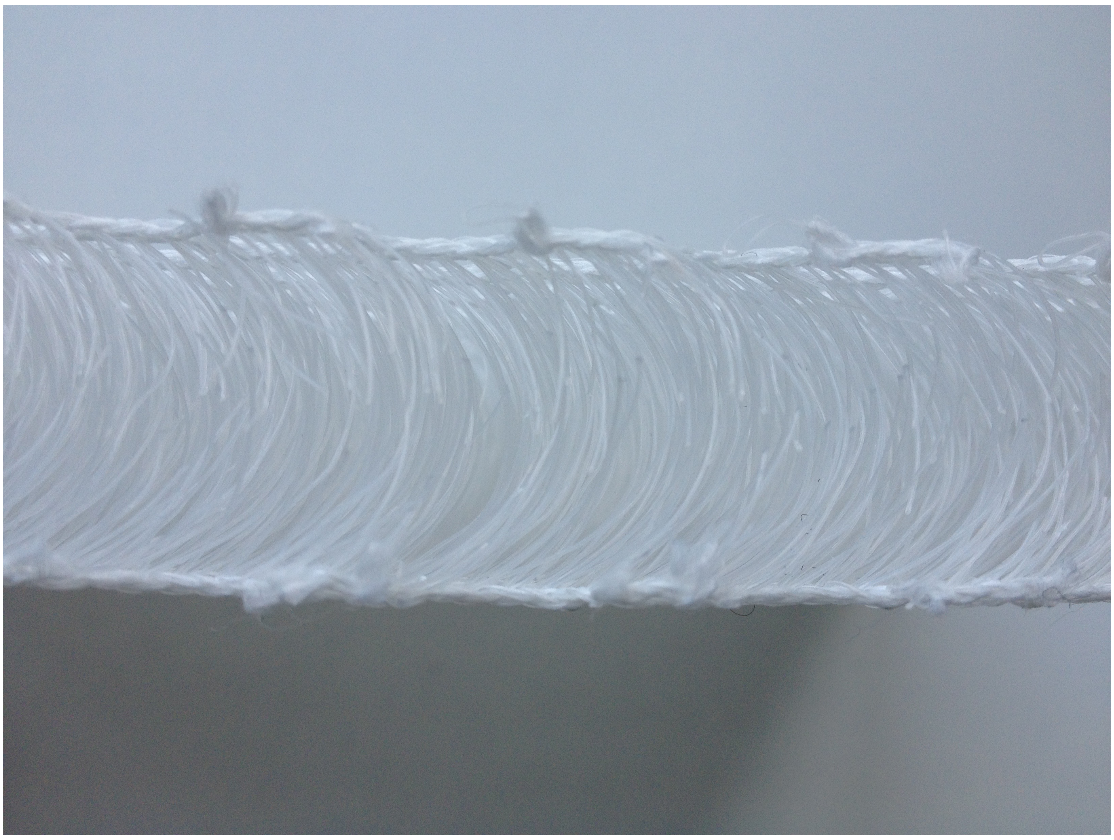

Figure 18: Spacer fabric.
Sheila Clark, 2016.

Spacer fabrics are mainly constructed by double needle bar warp knitting. This method of knitting requires each course to have a separate supply of thread, which makes it possible to determine a specified distance between the two face sides of the one-piece textile. As a substitute for the polyurethane foam a 4mm spacer fabric with commensurate compression was used, which was supplied by Ames. The inclusion of spacer fabric would have additional performance properties that can be perceived as beneficial, such as breathability and lightness.

The depth between the two face sides of a spacer textile consists of threads that are under tension but independent of each other (Figure 18). This construction allows flow of air between the threads, along with a reduction in the density of the textile. In comparison to polyurethane foam the relevant mass is reduced which offers a lighter foam solution, however it is more expensive. Increase in cost of a material if it provides a significant weight reduction in the vehicle can make it viable for use.

As air is able to easily permeate through the spacer this affords benefits in relation to comfort and wellbeing. I visited the manufacturing facilities of Baltex in Derbyshire on the 11 April 2012 to witness at first hand the process of knitting spacer fabrics and to discuss the collaborative research they were involved with. This four-year project was with the University of Bolton[37] and QOL Design and Development.[38] The output, in 2013, was 'Airospring' cushions made using spacer fabrics, developed by Baltex. These independent seat inserts are intended to distribute weight thereby relieving pressure and by maximising air flow support blood circulation, for wheelchair users in particular. The spacers used are layered with each piece up to a depth of 20mm: Baltex have the facility to create spacers of between 3mm and 20mm in thickness.

Compression is recoverable and resilient due to the pile threads that pass between both sides of the textile. This can be engineered through yarn use, construction and variable depth to be specific to requirements dependent on end use, although Fung and Hardcastle (2001, p. 85)) comment that the speed of recovery from pressure is not as fast as with conventional foam backing.

Comparable spacer fabrics are manufactured by Ames. As described one with a depth of 2mm was bonded in the finishing process to the woven textile fabric. I had planned to use a thicker spacer of 20mm in trimming the Fiesta seat on the squab area. I had a meeting with Ford on 29 May 2015 to discuss trimming a seat with these materials. In preparation I had mounted pieces of the fabrics to demonstrate them individually and how I envisaged they would sequentially be layered in the trimming process.

At the meeting there were representatives from colour and material design and the trimming department. At this stage I was assuming that in order to prove the concept of using these materials in combination would require having a seat trimmed with them. Two main points came from the conversation: first that the materials could be suggestive of a new form language, and second that the trimming team had experienced difficulty using high depth spacers in existing seat cushioning.

Reflecting on these points, I recalled the discussions at my re-entrance examination in 2014 from which it had been agreed that the individual parts I had created were more impactful as stand-alone pieces, which would be lost if they were installed in the Fiesta interior.

I questioned my thinking, which had sought to use the materials in a conventional manner. My awareness throughout the making processes had been about how to

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[37] The University of Bolton is known for the development of technical and medical textiles.
[38] QOL (Quality of Life) Design is registered with Innovate UK, which replaces the earlier organization the Technology Strategy Board (TSB). QOL's focus is on the development of products in relation to healthcare.

communicate the fact that some of the materials used were recycled from waste in a positive manner. I decided to revert my focus to the materials themselves, showing them as a concept that suggested a seating form. This would make visible the layers of material construction over a supporting framework. In order to understand the combination of materials used in a Fiesta seat I had deconstructed beneath the surface textile skin to expose what was hidden beneath. To layer the materials, keeping them visible would be in keeping with the deconstructed reveal of the Fiesta seat.

For exhibition purposes in June/July 2015 I displayed the layered textile and spacer draped over a curved fibreglass form. I considered this an unresolved conclusion, so I continued to pursue an avenue that had not, as yet, been successful in order to complete the intended output. For a pattern template I used a simple flat seat area and back with a curve in the dorsal region from which I made a toile for the foam replacement. This I scanned, amended and refined into a DXF file[39], which I sent to Ames production facilities in Turkey. There had been equipment problems and an inability to read the computer files from Ford with previous attempts to recreate the seat squab foam as a shaped spacer. This now allowed the opportunity for a spacer to be made specifically to the curved seat form.

High-distance spacer fabrics can adapt to a curved form if the angle is not too steep. The spacer I had made at Ames was engineered to fit the curvature of the form by not having the internal pile yarns at specified points. Ames spacer machine can be programmed from a DXF file to do exactly this, which, during knitting effectively ensured that stitch areas are not engaged or dropped (Figure 19).

[39] DXF file, is a CAD data file for enabling data interoperability between AutoCAD and other programmes. It stands for Drawing Interchange Format or Drawing Exchange Format. https://www.coreldraw.com/en/pages/dxf-file/

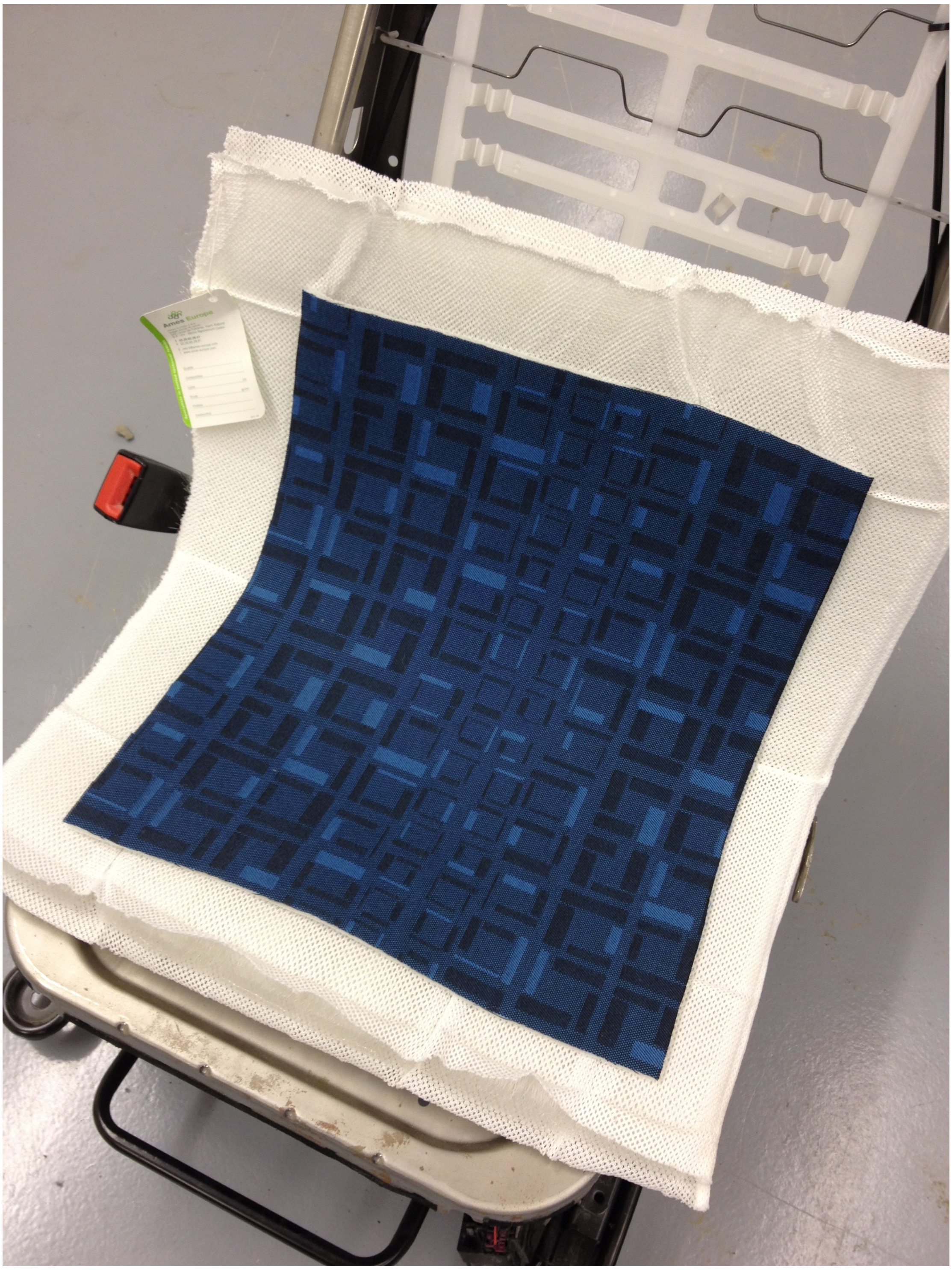

Figure 19: Scarf deco fabric placed on shaped spacer fabric on Fiesta car seat frame. Sheila Clark, 2015.

Further practical outputs: child's car seat cover

I purchased an ordinary child's car seat with cover, which I took apart and used as a template to remake with textiles I had developed. The original cover was made of 100 per cent polyester for the face fabric, wadding and trims. I made two prototypes: the first using black recycled polyester fabric with silver ions, and an alternative version using TechDesign as the face textile. Both fabrics were already supported with the spacer foam replacement lamination, which would be equivalent to the wadding that was used in the original. For the trims I used the excess fabric from the selvedge edges that was not foam backed (Figure 20).

Figure 20: Child's car seat cover made with TechDesign fabric.
Sheila Clark, 2015.

The intention was to demonstrate the use of recycled materials that could also be recycled at the end of life and also to include the anti-bacterial element that, at the time, I thought would be beneficial from a wellbeing perspective.

Chapter Conclusions

In planning and conducting this project I worked with established industry systems, processes and products. I adapted aspects of these in order to develop seat textile face fabric and under-skin foam replacement concepts. Within the parameters of the resources available I developed what could be perceived as applicable materials for such use today. However, through the processes involved in the project I became aware of the complexity of the established systems that are in place and how in changing one part of the seat I then had to consider further material and manufacturing aspects.

The face textile I produced is of a quality equal to that which is currently employed for textiles in the automotive industry. However, it would need to be proved that the foam backing using spacer fabric conformed to the necessary performance requirements. In designing the seat foam replacement one-piece spacer prototype I did not have sufficient technical and digital knowledge to successfully engineer the spacer to replicate the existing foam form. In attempting to achieve what I had intended I realised that I needed to think about the problem differently: the materials capabilities were directing me towards and indicating that a new form language was required. Ultimately, this would result in re-designing the entire seat shape: redesign to suit the materials. This was an important indication of the near-impossibility of making significant changes to one part of the materials, manufacturing and aesthetics without considering the implications for the whole system.

The invisible performance attributes of the prototype textiles that I made and employed extend to the origin of the materials used: that is, waste-derived. Visually there is no apparent distinction between existing automotive polyester seating fabrics and those I had made. This emerged as a key question for the material producers and the automotive industry's attitude to sustainability: how can the fact that the materials or products are 'sustainable' be represented both visually and positively?

The knowledge and expertise of staff in each of the respective companies that I worked with guided my decisions regarding yarn construction, applying weave structures to my designs, technical considerations and planning. Through working with industry I could direct and steer the project within their existing capabilities. By linking with established systems, which I adapted to fulfil the projects aims, I was able to produce face textiles that are equal in performance to current automotive qualities, using waste. Through this collaboration I was able to address the production volumes necessary for automotive companies, thereby proving the concept within a specific timeframe. The resulting textiles are visually uniform without irregularities, which the industry demands. I was able to control the making within the criteria used by industry. The support from industry and interest in my work was positive and encouraged my approach.

The disadvantages in this approach can also be viewed as advantageous in other respects, in that I had to work with the existing systems and capabilities of the companies involved, Antex, Guilford and Ames. I had limited control over timing because my project had to be accommodated within their commercial production schedules. Creatively it was quite restrictive due to the technical considerations of making the textiles perform appropriately and in relation to the expectation of appearance. With the pattern or design of the textile I could be more creative. However, in designing for a seat cover the repeat needed to be a small-scale design in order for it to work well in the Fiesta interior and reduce waste in the trimming: a larger-scale design would require placement on the seat areas which would increase the amount of fabric being wasted. I was restricted in the number of designs I could take through to production because of the warp length and time considerations. Regarding the seat foam replacement, I could not achieve the right spacer fabric that would equate to the original seat foam with the company I was working with: they had technical problems with the equipment, which had been relocated to Turkey from the Netherlands. In the end it resolved itself as I decided to ‘suggest’ a seat form instead of replicating the original, as I realised that the seat needed to be reconsidered and designed to suit the materials.

The advantages of the approach that I took was, that I achieved with the textile’s face fabric and its foam replacement what I intended and set out to do. The performance is as commensurate (although this has not been tested) as possible with that of existing seat fabric and supporting foam backing used by the automotive industry. By meeting industry standards in using recycled polyester I had made a textile that the industry could believe in. By working in this way I was able to work with technicians who had extensive expertise and experience in this area. In addition the facilities allowed me to produce a large quantity of fabric, have it finished and adhered to the spacer foam replacement.

Unique insights

Working with Guilford Europe at their manufacturing plant in Derby gave me insight into the scale of their volume of production: approximately 400,000 metres a week (*Manufacturing Today,* 2016.*)* and the scale of their operations to produce uniform fabrics at a specified amount, on time: they are penalised by the automotive companies if they deliver late. This includes financial penalties and the possibility of being barred from receiving further orders. Prior to each contract being finalised the specified textile is trialled, which involves producing a warp length at full capacity. This process is timed with the textile checked by representatives from the automotive company. This trial run is then scrapped, becoming waste before full production begins.

When my fabrics were being woven the tuners were amused that I was working with brightly coloured yarns: the other looms were weaving only black fabrics, which they told me was the core business for them, indicating the limitations of colours and designs selected for production by the automotive companies.

Action research

As I was involved and active in the research project I had to make decisions quickly within the project space. All the details from planning the material, yarn type and structure, colour selection, woven structure and design were ‘fixed’ in advance. It was only when I received the lengths of fabrics and sample pieces and began to deconstruct a Fiesta seat that I realised I had been focusing on one aspect of the seat: the surface covering and supporting foam backing. This project space then expanded to consider the whole seat and all its component material parts, which at this stage combined with the view that the materials themselves were the focus and in standing alone had more potential for consideration than if they were hidden from view in a complete seating package.

This was the first project to be completed. Concurrent with this work I was planning, researching and negotiating materials and industry support for the other main projects, which involved me making early decisions on colour, materials and design. The next project to be described, ‘Renewable Textiles’ was informed by the textiles aspect of this project. There was a cross over between all the projects as the pace and available space at which they developed evolved.

This project highlighted the detail involved in producing a ‘sustainable’ material solution for a product. Each individual element must be considered in relation to the whole outcome. In this instance of a car seat fabric and foam replacement it was evident that the under-skin materials need to support the concept of the surface material to allow the recycling system to be simple and effective. If only one part is considered and other materials are included in the matrix of the complete product then end-of-life recycling becomes more complex and expensive.

Chapter 6: Renewable textiles for composting

Summary

As an alternative to using synthetics in a singular stream to facilitate recycling McDonough and Braungart (2002) advocate the use of natural materials that would be compostable to create ‘products that, when their useful life is over, do not become useless waste but can be tossed on the ground to decompose and become food for plants and animals and nutrients for the soil;’ (McDonough and Braungart, 2002, p. 91).[40]

I used this concept as a starting point from which to explore and demonstrate its viability and potential through practice. My intention was to use solely natural materials for seat textile and foam replacement that would be compostable at the end of life. I endeavoured to work with fibres that are locally produced within Europe, in order to reduce the amount of transportation required.

My initial focus was on the face textile. From my research into the potential of different animal and plant fibres I chose to focus on wool. Other natural fibres do not meet the lowest performance requirements for automotive textiles. Wool has properties that meet some of these criteria (Fung and Hardcastle, 2001, p. 45), which are discussed next.

Wool

Historically, wool was used in the textiles for passenger seat covers in carriages: this use continued in the first automobiles that were constructed following similar methods. Wool is more expensive than polyester, and therefore is used only for high-end models in an automotive seating context (Mukhopadhyay and Patridge, 1999, p. 8, Fung and Hardcastle, 2001, p. 13).

Due to its hygroscopic nature, wool absorbs moisture, perspiration and water vapour, therefore giving better thermal comfort than synthetic fibres (p. 208). In textiles used

[40] This would be through managed industrial composting systems of which there are two types. Composting piles are termed ‘feedstock’. ‘Windrow composting’ employs machines to encourage aeration by turning the pile. Alternatively, ‘aerated static composting’ uses fans to attain aeration by forcing air through the feedstock, which does not need turning. Ideal conditions that include temperature, moisture, oxygen and the carbon-to-nitrogen ratio are monitored. When the ideal conditions are met microbes thrive and the temperature increases. The combination of heat and microbe activity assists in breaking down the feedstock. Once this is completed it is screened for residual contaminants, resulting in organic compost.

in aircraft this function helps to regulate air humidity in the cabin (Lantal, 2017). Its resistance to abrasion is, in general terms, lower than that of textiles which are 100 per cent polyester, although this depends on the construction of the textile and yarn (Fung and Hardcastle, 2001, p.13). Wool is usually blended with a synthetic fibre to improve its resistance to wear. Lantal and Botany Weaving are both companies that separately supply fabric for the airline industry that ranges from 100 per cent wool to wool blended with polyamide (Botany Weaving, 2017; Lantal, 2017). Lantal's wool blend standard fabric ranges from 89 per cent to 95 per cent wool content, the remaining content being polyamide: it weighs 350g/m^2-500g/m^2. A lower-weight version is available, 'wool blend light', woven using a finer yarn count and composed of 90 per cent wool and 10 per cent polyamide: this ranges in weight from 330g/m^2-340g/m^2 (Lantal, 2017).

Lantal markets a textile for use in airline seating that is derived wholly from renewable material resources. Composed of 60 per cent wool/40 per cent viscose called Climatex Lifeguard FR (also available in the ratio of 50 per cent wool/50 per cent viscose) it is described as 'fully biodegradable' (Lantal, 2017). Produced by Rohner Textiles (a subsidiary of Lantal) Climatex Lifecycle was the result of a project, instigated in 1991 by DesignTex,[41] to create a more 'environmentally responsible' textile: McDonough and Braungart advised on the process (Larson, 2007). The original materials used were wool and ramie (*Boehmeria nivea (L.) Gaud.- Beaup.),* which belongs to the nettle family (*urticaceae*) and is native to eastern Asia (Kozlowski, Baraniecki and Barriga-Bedoya, 2005, p. 70). The viscose element of Climatex Lifeguard FR has been developed by Lenzing[42] whose viscose fibre derives from European white beech.

Ramie is acknowledged as the toughest of all the bast fibres (Kalita, Gogoi and Kalita*,* 2013): its use in textiles has been traced as far back as the fabric used to wrap ancient Egyptian mummies (5000-3000BC) (Kozlowski, Baraniecki and Barriga-Bedoya, 2005, p.70). Ramie was first cultivated mainly in China, India, Indonesia, Algeria and the Congo (Kalita, Gogoi and Kalita, 2013). It was introduced into Europe in 1733, and was cultivated in the Netherlands (from1808-1809). However, according to Karpowiczowa, (1954) as cited by Kozlowski, Baraniecki and Barriga-Bedoya (2005, p.70), the first record of its cultivation was in 1786 in Bologna, Italy. In 1942, the difficulty of decorticating the ramie plant to obtain the fibres whilst avoiding making them 'brittle and tender' was a challenge (*Textile Research Journal,* 1942).

[41] DesignTex is the textile division of the commercial furniture manufacturer Steelcase. https://www.steelcase.com/discover/brands/designtex/

[42] Lenzing, http://www.lenzing-fibers.com/en/lenzing-viscose/

Kalita, Gogoi and Kalita (2013) state that ramie's use for textiles has, in part, been restricted owing to the complexity of the degumming process and a lack of experience of its mechanical preparation. They perceive that its inherent properties of strength and resistance to bacterial growth, alongside its environmental attributes, support its suitability for blending with other fibres.

Formed from the Swiss company Gessner, the innovative Climatex brand conserves material resources by following McDonough and Braugart's 'Cradle-to-Cradle' philosophy. Climatex Dualcycle fabrics consist of Cradura, wool and Redesigned Lenzing FR. Cradura (the name is derives from Cradle to Cradle and Durability) is a polymer fibre made from fibre production waste, fishing nets recovered from the ocean and recycled carpet. Instead of blending the synthetic fibre with natural fibres into a yarn, the patented method of weaving employs the benefits of each in the fabric. The woven structure is described as a 'textile lock', which makes separating each of the materials at the end of life simple: they can be either recycled or composted. The cellulosic (Lenzing FR) element of the textile can be dissolved with sodium bisulphate also known as sodium hydrogen sulphate (NaHSO4). This chemical process removes, or 'unlocks', the link holding the wool and Cradura yarns in place. In practice the textiles would need to be used in products designed to allow this process to be employed at the end of life, which would require forward planning for appropriate systems to be in place,[43] (Climatex, 2017).

For automotive application, wool is usually blended with polyester (Fung and Hardcastle, 2001, p. 48). Schoeller's Travel Tex range of 70 per cent wool/ 30 per cent polyester blends for weaving forms part of their stock provision. Developed for the transport industry and used in trains, buses and aircraft it is also suitable for automotive use. As discussed in Chapter 3, the transport industries have similar but different requirements for their textiles, which are determined by testing. In conjunction they develop bespoke articles for specific automotive projects (Schoeller, 2017).

Schoeller collaborated with the Swiss automobile company Rinspeed on a 'sustainable automobile – down to the very last fibre' (Rinspeed, 2017). The resulting concept car, known as iChange, an electrically powered vehicle that is capable of adapting its form in relation to the number of passengers, was shown at the 79th

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43 This is a process similar to that used for devoré, in which part of the fabric is 'burnt out' using acid to create a pattern or reduce a pile, as in velvet. In this case by 'burning out' the cellulosic element, which is holding the other yarns in place, these will be released and separate. However, it is important to note that the complete product in which the material is used would need to be considered from the outset with this end-of-life process in mind. As an experiment to prove the concept it is successful.

Geneva Motor Show in 2009. It can be transformed from a single-seat sports car into one that accommodates up to three people by releasing the compressed rear end, which duly expands, at the push of a button. Pure wool was used in the interior to support the sustainable concept. Developed by Schoeller the fibre, subsequently described as ‘high-tech wool’, was spun through new processes with the inclusion of ‘Coldblack’ treatment (Schoeller, 2017). Applied in finishing, this technology reflects heat away from the textile surface in variable degrees upwards from ultra-violet (UV) protection factor (UPF) 30, depending on the structure, density and material employed. This reduces heat accumulation and safeguards against UV light rays: wool has a low resistance to UV light (Fung and Hardcastle, 2001, p. 11 Table 1.4). In the context of the car interior this fibre was used in the roof lining to provide a ‘comfortable interior climate’.

Wool: background

Wool is an annually renewable fibre resource shorn from the fleece of sheep. In Britain there are over 60 varieties, each producing a different fibre quality. These qualities range from fine and medium to coarse, determined not only by breeding but also by the protection the animal requires in relation to regional weather. Thicker coarser wool fibre derives mainly from mountain or hill sheep. Those farmed in the lowlands tend to have finer, softer fibres. Merino wool is produced in the southern hemisphere, Australia being a main provider: the fine wool fibres there have a low micron value,[44] and it is thus valued more highly, particularly for apparel (British Wool Marketing Board, 2010, p.9).

Wool: properties

The inherent properties of wool satisfy the criteria required for the interior of vehicles. It has a high resistance to ultra violet (UV) light and is flame retardant, due to a high water and nitrogen presence. Its tensile strength makes it resistant to wear, resulting in a durable appearance. After scouring,[45] the residual lanolin or oil content discourages the adherence of dirt, also protecting it from staining. It does not encourage bacterial growth. Wool fibre has a natural elasticity, allowing it to recover its original form after compression or stretching, and it therefore produces resilience in a textile (Campaign for Wool, 2017). The individual fibre structure allows it to absorb moisture and release it, providing thermal comfort (Fung and Hardcastle,

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[44] The micron (micrometer, one millionth of a metre) is used to measure the diameter of an individual wool fibre.
[45] Scouring: the process of removing the majority of impurities from the fleece. It is the first stage of processing during which the fleece is also washed.

2001, p. 13). However, its hygroscopic nature increases its weight: the resulting release of moisture requires a ventilated environment to allow it to disperse. It naturally responds to body temperature, self-regulating to cool in hot conditions and warm in cold, therefore functioning efficiently in varied climatic conditions. It is resistant to static electricity due to its moisture content, unlike synthetics. Additionally, it is hypoallergenic (Campaign for Wool, 2017).

Wool: sustainable credentials

Wool naturally decomposes within a few years: its high nitrogen content is beneficial to plant growth. It is a renewable resource (Campaign for Wool, 2017).

When I visited Ford's technical site to see at first hand their in-house testing facilities, I raised the possibility of using wool. It was not viewed favourably partially due to its odour, which is enhanced in the warmth of an enclosed environment, one of the conditions under which Ford tests materials.

Factors that contributed to my decision to use wool as the main material for this project are:

- The inherent performance properties of the fibre
- The technical 100 per cent wool yarn developments by Schoeller for transport use - trains, buses and aircraft - transferable use from the airline industry demonstrates feasibility
- Its sustainability credentials through being a renewable resource that is compostable

My involvement on the advisory panel in the early stages of the Campaign for Wool in 2011 enabled my connection with Laxtons, a specialist yarn producer in Guiseley, near Leeds, Yorkshire, working with British wool (Laxtons, 2017). I visited the Laxtons mill on 27 July 2011 to discuss the potential for Laxtons to provide yarn for weaving the textiles for this project, in order to demonstrate local material provision. At this time their spinning capabilities could only produce a yarn that was thicker than I required (Nm 2/7[46]). Using this yarn would result in a heavy cloth that would be counter-productive in an automotive context in which lightweight materials are critical to reducing fuel use, and therefore not supporting sustainable objectives.

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[46] Nm or new metric is a system for measuring the number of kilometers per kilogram in any given yarn. It describes the thickness or diameter of the yarn.

The spinning group Schoeller were also involved with the Campaign for Wool at this time, and were keen to promote the potential for the use of wool in automotive interiors. Following discussions, Schoeller was interested in supporting my project with the provision of yarns. The initial offer involved their Travel Tex blended yarn, a quality approved for automotive seat upholstery end use, which was available from stock. However, they had in development a 100 per cent virgin wool yarn for the same end use. In comparison to the quantities that would be required for industrial sampling purposes mine were small. In keeping with my project aims I chose to use the Travel Tex Nm 2/28 100 per cent wool development yarn (not a stock quality). It was available for my use solely in black: colours dyed specifically for customers are confined to their use. The yarn has very high light-fastness critical to performance in the context of a vehicle, due to its exposure to daylight (Schoeller, 2011).

At the time I intended to employ a colour palette that was the same as I had used in the Mono project: the resulting fabrics would work visually alongside the other materials within the Fiesta interior. The projects were running concurrently. However, it was not feasible to request bespoke dyeing for this purpose. As an alternative, Schoeller offered their stock-supported quality Sport Loden (Nm 2/28, 100 per cent pure new wool), available in a wide range of shades. Engineered as a knitting yarn, it has less twist than weaving yarns: nevertheless, it is not unusual for a yarn such as this to be employed for weft purposes.

Schoeller provided 27.71kg net weight of Travel Tex in black, for warp use, and 16 shades of Sport Loden totalling 22.33kg net, for weft use. These yarns were stored ready for use.

I contacted and visited weaving mills within the UK that might support the project by demonstrating a manufacturing level of production. On the occasion that I visited Laxtons I also visited Camira Fabrics Ltd (28 July 2011) at their design studio in Mirfield, near Leeds. Camira manufactures both woven and knitted textiles and leather and vinyl for applications in the contract, transport, healthcare and education interiors. Camira was established in 2006 with ‘sustainability and innovation’ at the core of their business philosophy (Camira, 2017). This initial meeting, although unscheduled, was extremely informative and positive. Following my introduction of the project aims they expressed their interest in supporting it by collaborating with weaving and yarn requirements.

Camira's transport seat covering range includes (as previously mentioned) leather, vinyl, and Trevira CS[47] chenille, polyester, closed loop recycled polyester and 'high wool content' moquette[48] fabrics - for example their Fusion fabric (Camira, 2017 and Trevira, 2017). The wool content in the moquettes ranges from 53 per cent to 37.4 per cent. Each quality is combined with variable percentages of polyester, nylon, cotton and viscose.

Nettle fibre

Camira produces a contract textile commercially that resulted from the company's involvement (from 2005) with a study that took place between 2004 and 2008, the Sustainable Technology in Nettle Growing, (STING) project by De Montfort University, Leicester, funded by the UK government's Department for the Environment, Food & Rural Affairs (Department for the Environment, Food & Rural Affairs, 2004-2008 and Harwood and Edom, 2012, pp. 107-119). Harwood and Edom (2012, p. 115) state that the project stemmed from the discovery that fibre from the common stinging nettle (*Urtica dioica L.),* when blended with wool, increases the fire retardancy properties of the yarn. Camira's Nettle Aztec and Nettle Traveller blended yarns have a ratio of 83 per cent virgin wool/17 per cent nettle, whilst their Nettle Nomad is 75 per cent wool/25 per cent nettle. The STING project studied the cultivation of the nettle plant and the potential for extracting nettle fibre for industrial spinning. However, the yield was found to be lower (4-7 per cent) than other bast fibre crops such as flax (20-30 per cent), jute and hemp, although Harwood and Edom (2012, p. 110) note that in a more recent (2008) study carried out in Italy the amount harvested was higher in the hotter and drier region in the centre of this country (Bacci, Baronti, Predieri and di Viriglio, 2008, pp. 480-484). In conclusion, they suggest that as a renewable fibre nettle has the potential to be an alternative resource: '[…] collaboration between scientists and engineers on the STING project has finally enabled the mechanical processing and extraction of fibre to be optimised' (Harwood and Edom. 2012, p. 117).

Nettle is a bast fibre plant with the fibres located on the exterior of the stem. Removing the fibres has traditionally been achieved manually following either dew (in the field and reliant on appropriate weather circumstances) or water (immersion after

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[47] Trevira CS is polyester that is chemically constructed to be inherently flame retardant without surface treatment.
[48] Moquette is a woven pile fabric that is notably used for seat coverings in London Transport's underground trains.

harvesting in containers) retting[49] to facilitate the removal of the fibres. Fibre has been extracted from nettle stalks for centuries for textile uses. Nepal has a long history of using the Allo, or Giant Himalayan Nettle (*Girandinia diversifolia*) in woven textiles (Dunsmore, 1993, p. 59). Between 1940 and 1945 the UK government attempted to use the fibre for making paper, and as an alternative to cotton (Harwood and Edom, 2012, p. 108). The fibre was also considered as an alternative to flax for reinforcing plastics used in the manufacture of aircraft by the Department of Scientific and Industrial Research in 1940.

I visited Camira again on 8 August 2011 to discuss my project, their capabilities and the ways they could support my work. Along with these discussions I visited their manufacturing plant in Meltham, Yorkshire, where the weaving takes place.

Further communication ensued by email; one visit to Mirfield took place on 2 February 2012, and meetings were held at their London showroom in January 2014, when the project was reinstated after a period of 12 months. I specified the use of the Schoeller black Travel Tex 100 per cent wool yarn for the warp. The weft yarns for the main design and supporting plain fabric would be selected from those used in their Nettle Aztec textile: 83 per cent wool/17 per cent nettle available in eight colours (Camira, 2017). I had originally sent colours to be match-dyed to my colour palette however this was not possible and the best option was to work with what Camira had available.

My rationale for this combination of yarns was as follows: the warp wool yarn had proven suitability for use in automotive fabrics, and in addition, employing the wool/nettle blend yarn in the weft would increase fire retardancy. The point of difference from the fabrics in Camira's range was the inclusion of the finer count automotive quality wool yarn. This adjustment in conjunction with the selected weave structure would give the fabric a closer set and it would be lighter in weight. The textile would be compostable, derived from renewable resources in accordance with the project aims.

In designing the textiles I developed a series of graphic patterns that were inspired by Art Deco printed textiles, molecular structures and snow crystals. By continuing the theme from the Mono project designs it was intended that these fabrics would complement each other in the Fiesta interior. At this stage it was still envisaged that the seats would be trimmed accordingly and installed in the car.

[49] Retting: soaking or technically 'rotting' plant fibres causing natural chemicals to break down the pectins that keep the stem intact thereby facilitating the release of the fibres.

I selected five of my designs for conversion into the weave programme: ScotWeave: Repeat Deco (Figure 21), Repeat Snow (Figure 22), Spots and Crosses) (Figure 23, Spots and Line (Figure 24) and Stripes (not shown).

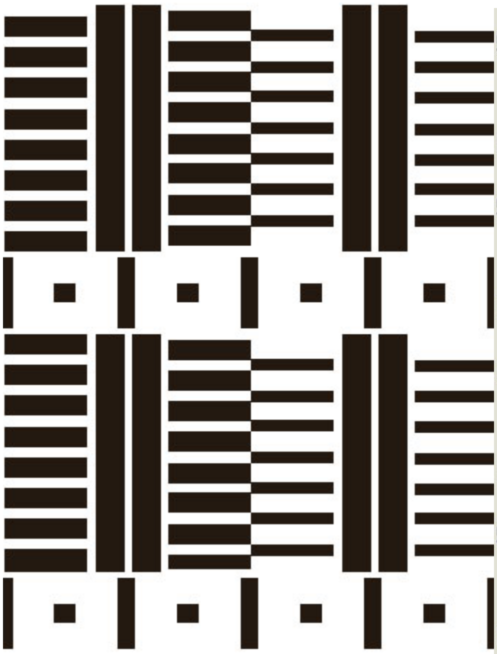

Figure 21: Repeat Deco design.
Sheila Clark, 2014.

Figure 22: Repeat snow design.
Sheila Clark, 2014.

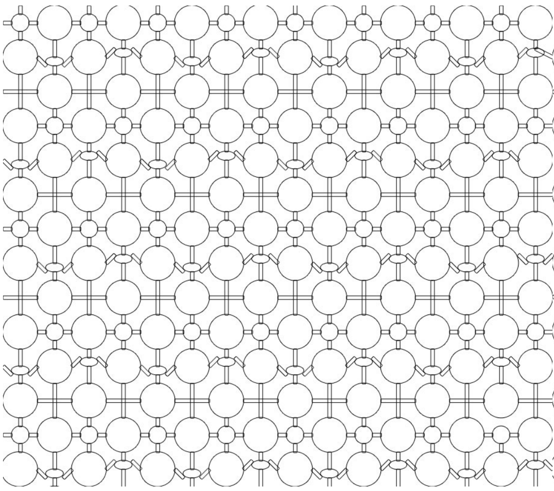

Figure 23: Spots and crosses design.
Sheila Clark, 2014.

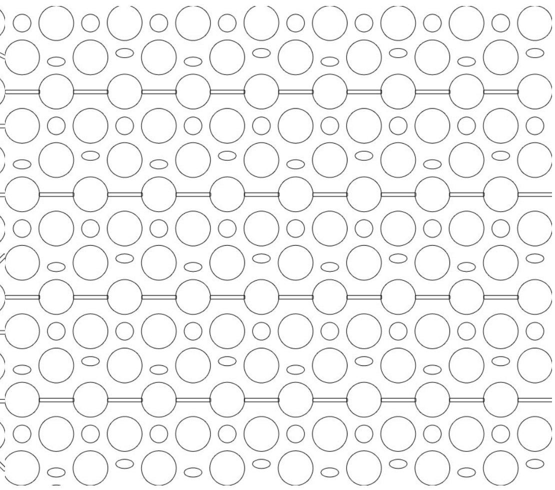

Figure 24: Spots and line design.
Sheila Clark, 2014.

The inclusion of a horizontal stripe design would enable the utilisation of the Schoeller Sport Loden wool yarn in a variety of weft colour combinations as sample pieces. The designs were prepared in Photoshop and put into the Scotweave programme at Camira. I had previously chosen the weave structure from fabric

archives, which facilitated this process.[50] As in my previous project it was critical that the fabric would not have long floats to avoid snagging. Weave simulations of the main design, Scarf Deco were forwarded to me for consideration and approval.
The Schoeller yarns were sent to Camira on 12 August 2014. On 14 January 2015 the warp yarns were split onto several cones, the warp was made and immediately put into the loom ready for weaving. This unscheduled use of the loom at the manufacturing facility meant that the weaving had to be conducted promptly. It was important that I was present whilst this happened: I needed to direct the amount woven of each design and colourway and the weft sequence and ideally record the process.

On Monday 19 January 2015, the fabrics were woven under my instruction. Camira's requirement that this was completed urgently resulted in the number of designs that were woven being compromised. I prioritised the main design and colourway with an accompanying plain, sufficient for trimming one Fiesta seat. This involved altering the scale of the design, as well as colour placing whilst testing on the loom (Figure 21). Alternative structures and scale of design were trialled in the Repeat Deco design (Figure 25) with Repeat Snow (Figure 26) sampled in one colour. It was intended that the Schoeller weft yarns would be woven later, but this was not possible because Camira's production schedule meant that the loom was needed for manufacturing.

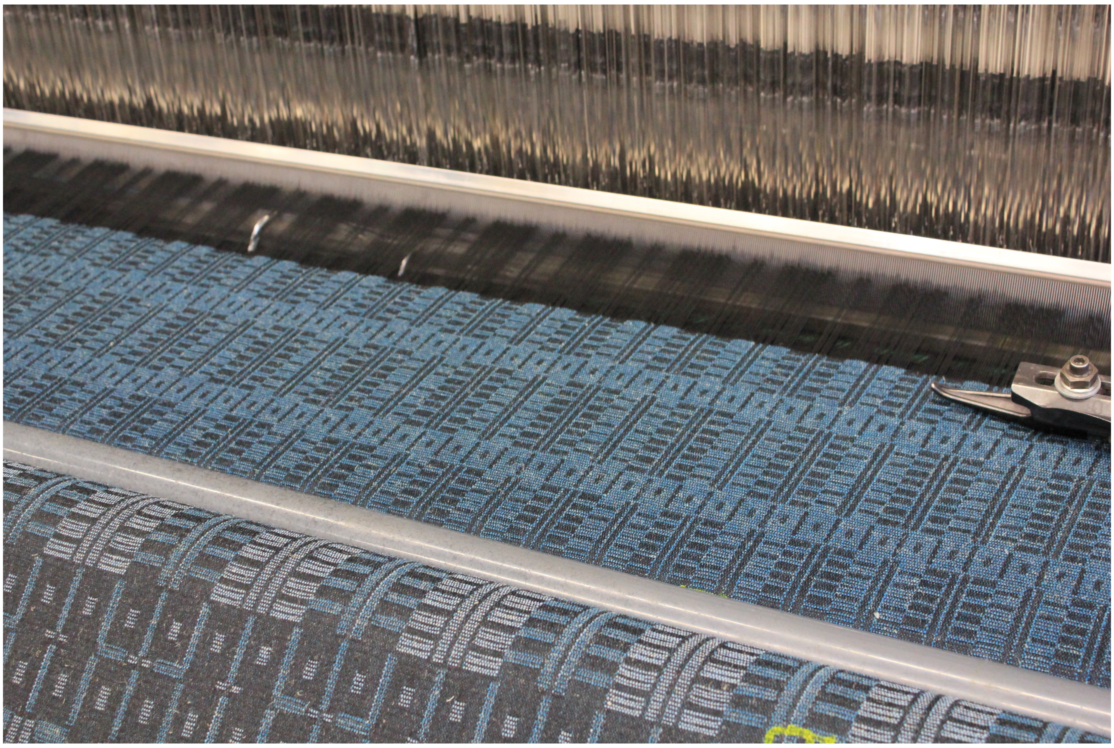

Figure 25: Altering the scale of the main design at the weaving stage, on the loom.
Sheila Clark, 2015.

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[50] My instructions for converting the design to Scotweave were followed by the designer at Camira: although I requested to do so onsite myself this was neither possible nor practical.

Figure 26: Repeat snow design being woven.
Sheila Clark, 2015.

When the weaving was complete, the loom-state fabric length was finished, which entails washing, steaming and pressing. This process allows the fibres to settle and shrink closer into the fabric structure. The resulting textile is no longer coarse to handle, and has a softer touch. It retains a slightly irregular surface appearance that indicates the nettle fibre content with the wool.

Wool felt

My intention to trim one of the original Fiesta seats remained throughout the stages of this project. Along with the face textile, a foam replacement made from natural material was needed. In line with the use of wool for the textile, due to its many benefits (as described earlier in this chapter), I investigated using different forms of non-woven wool. Felt covered in tallow or ewe's milk, to make them waterproof, was used by the Mongols to roof wagons in the fourteenth century (Laufer, 1930). The use of pressed wool felt in contemporary vehicles is more common in engineering applications, such as brake pads. Non-wovens are utilised for vibration-dampening purposes, as well as for carpets, parcel shelves and other applications and are often made from recycled mixed textile waste fibres (Figure 27) (Fung and Hardcastle, 2001, pp. 105-106).

Figure 27: Non-woven from mixed textile waste fibres.
Sheila Clark, 2015.

Felt is one of the oldest methods of textile fabrication (Laufer, 1930, p.1 and Mullins, 2009, p. 27) involving a combination of heat, friction, pressure and water supported by the properties of the wool fibre. Described by Mullins (2009, p. 10) the crimp and elastic nature of the fibres are augmented by heat and dampness. The protein, mostly keratin, structure of an individual wool fibre is encased by the epidermis, which is overlaid with scales that interlock during the felt-making process. In conjunction, the fibre contracts in these conditions, assisting the procedure. Wool felt can be produced in varying densities and thicknesses from different fleece fibres. Pressed wool felt is more compacted and less visibly fibrous.

The early machines for felt-making were modelled on processes used in hand-crafted felt, described as the 'plate hardening method' (Mullins, 2009, pp. 22-23). Following this, mechanical needle punching was introduced, similarly inspired by previous methods. It is used to produce both wool felt and nonwovens, which can include or exclusively contain plant and synthetic fibres in their composition. Synthetic fibres can additionally be heat-bonded to support adhesion in the process. These industrial processes allow large volumes of felt fabrics to be produced that are consistent and uniform in appearance (p. 7).

Following visits to trade fairs (Techtextil[51], Frankfurt and Index[52], Geneva) and

[51] Techtextil Europe a trade fair for technical textiles and nonwovens is held biennially.

contacting with the Wool Marketing Board I sourced a variety of commercially available wool felt samples. These included soft-, medium- and hard-pressed felt for use in engineering and technical applications, as well as needled felt from different wool fibres.

I envisaged that I would use a combination of these and in layering them strategically replicate the function of the foams that had been used in the Fiesta seat. Over the frame I intended to place recovered wool fibre that is loosely commingled, which could be built up and formed into a supporting cushion. This would be followed with a stitched layer of needled felt: British wool fibre from the Swaledale[53] breed on a jute scrim that would contain the previous looser foundation of fibres. The next layer would be constructed from 3mm thick industrial hard-pressed felt and finally trimmed with the wool/nettle textile. However, I was concerned that the weight of the combined wool felts would unbalance the sustainability credentials of the project.

The vertical 'tier one'[54] supplier Johnson Controls worked in conjunction with the mattress manufacturer Harrison Spinks to develop the 'ComfortThin' automotive seat in 2012 (available for use in models from 2015) (Johnson Controls, 2012). Polyurethane foam used in the seat back was substituted by 'Posturfil and PosturfilHD pocket spring technology'. This seating concept reduces the space occupied by the seats with comparable comfort for the occupant: each of the springs is individually responsive to pressure (Spink Springs, 2017).

Chapter Conclusions

I conducted this project in a similar way to that of the previous project, Mono synthetic in that I linked with a manufacturer to produce the textiles. A significant difference was that Camira's products that involve natural materials are designed for contract furnishing solutions. The performance requirements are high, but not as stringent in all aspects as those for automotive textiles. The tests are similarly concerned with wear and tear, and fire retardancy but do not include tests such as fogging, for example.

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52 Index, a trade fair for nonwovens, is held every three years.

53 The Swaledale breed was developed by farmers on the North Yorkshire and Westmoreland borders, UK in 1920. It is a hardy, hill breed with a fleece that has a medium to harsh handle: the fibre is resilient and mainly used in carpets. The sheep are mainly white with some black on the head.

54 The 'tier one' supplier is at the top of the chain supplying the automotive industry with completed parts ready to be fitted to the vehicles. Johnson Controls supply seating systems. A 'tier two' supplier, such as Guilford, engineer textiles, which are then supplied up the chain to the tier one supplier.

My rationale for following a similar model was to access the use of industrial manufacturing facilities, capabilities and technical support. I sought to work with this division of Camira because of their experience in using natural materials and their approach to the use of sustainable materials in particular their use of wool, flax and nettle as a result of their involvement in the STING project.

Initially, I envisaged that I would be able to develop my own yarn for my project which I would then have woven. However, when I became fully aware of the complexity of systems involved in doing this I had to compromise, which led to me questioning my contribution to the innovation. I adapted the fabric produced by Camira only by changing the warp yarn, using Schoeller Travel Tex and by using my own design. This demonstrates a tension between what I thought I would be able to do in theory and what I was able to actually achieve in practice. It was action research, in which I myself instigated the project. I took decisions in response to the situation that developed during the design stage, the weave structure planning and the actual manufacturing process. It was necessary to compromise as the circumstances evolved.

Camira was keen to support my project through the provision of yarns and weaving, and in the discussions that we had prior to the actual making. I was drawn to the company by their approach to sustainability through the exploration of the use of natural fibres. What I found of particular interest was that they allowed the irregularities of the natural yarns to remain visibly present in the resulting fabrics. This evidence, or partial evidence, of the story behind the materials used embraces a different visual language, in which imperfection is accepted and allowed: it does not impact on performance.

To address the idea that there may be patterns in the company's attitude to sustainability I would observe that addressing one product component does not necessarily have an impact on the whole product, although it must be noted that as a textile producer this is the extent of its remit. Similarly, my realisation that if the fibre, yarn and final textile are sustainable in some respect when they are applied to a product such as a car seat, the other materials employed may negate this unless there is careful dismantling at the end of life. I would describe this as 'partial sustainability', in which the entirety and complexity of the overall end of life and origin of the materials used in the product have been partially or individually considered and addressed. The whole set of systems should be addressed, including the overall environmental impact from obtaining the material, manufacturing the material and product, alongside a consideration of how at the end of life the materials within the product will be recycled, or composted. This involves preparatory planning on how the product will be dismantled into component material parts and how the materials will be separated, in addition to establishing a set of systems and the communication of information to ensure that these conditions are followed. It seems that ‘partial’ sustainability is more easily achievable, which has become evident through my projects. When I focused my efforts on the textiles and then tried to apply them to the seat form I realised that I had to consider the complete set of materials, processes and systems that are involved in the manufacturing and material input of the whole product: that is, the car seat.

Advantages and disadvantages of the approach

As with the previous project, it was advantageous to work with industry and to be able to access the equipment and facilities such as finishing, as well as technical support and the knowledge, skills and expertise of individuals within the company. I was directing the project within the capabilities that exist in industry today, linking with systems and adapting them. In doing this I was able to develop a textile with a high performance specification, although this was different to that which accepted by the automotive industry. By using wool in combination with nettle this increased the fire retardancy properties of the fabric. This led to a similar conclusion, that in using these more sustainable materials a new form language for the face fabric, as well as the overall material usage, would need to be considered and accepted by the consumer and the automotive industry. The project shows a tension between the theory and practice of my design thinking: what I thought I was doing changed as the project progressed. The outcome of the final textile is a means to explore (for myself) and demonstrate (to others) my idea towards a new form language when using these materials.

In working with industrial systems there was a limitation on what I could change and incorporate into the project: for example, I could not develop a new yarn, as I had first imagined. I had limited control over the timing of when the fabric would be woven, and logistically the Schoeller weft yarns were delivered to the studio and could not be accessed on the day of weaving. The series of interconnecting systems in industrial manufacturing became evident as the project developed: the yarn and subsequent textile face fabric of the seat was part of a much wider and deeper set of material considerations when combined into a car seat.

In understanding what I had achieved with this part of the project, beyond what Camira was already producing, I concluded that I had acted and made decisions as the circumstances presented themselves. I had achieved a fabric that demonstrated the concept of using natural materials, which introduced the way in which they would demonstrate this visually through the slight irregularity of the yarn visible in the cloth. This was continued in the foam replacement considerations: that through the nature of the materials a different form was being suggested. If I layered the wool nonwoven material to replicate the density of the polyurethane foam, the relative weight would be increased. I had not considered using springs but I could have incorporated other plant fibres such as coconut waste or a traditional material such as horsehair. This links to the conclusion from the Mono project: that a new form language for the seat would be necessary in using these renewable materials.

Chapter 7: Renewable compostable composites

Summary

I discuss in this chapter my research methods, which were led by design, this time focusing on the competence of renewable materials to replicate existing parts that were made from non-compostable synthetic materials. These renewable materials are of natural, plant origin, sourced within Europe. I approached the tasks from a non-scientific perspective but considered fundamental engineering principles particularly in relation to strength and stiffness.

I made a glove box lid, door panels and rigid formed parts. I followed an iterative design process, initially making small-scale experiments using the chosen materials. From these I determined the most effective materials and methods to create full-scale pieces replicating interior parts of the Fiesta. I considered the importance of working at full scale in order to assess the practicalities of using the materials, aesthetic appearance and overall feasibility from a design perspective.

In creating these replica prototype parts I used craft methods. First I made moulds from the original pieces from the Fiesta parts that I had disassembled, these being the inner door panel and glove-box fascia: this was followed by working with the materials that I had sourced for the tasks. The materials were researched and obtained by linking with industrial suppliers. At meetings with these companies I discussed my aims and intentions in relation to the capability and potential of their respective materials. These discussions showed that there was interest in their products from the automotive industry but this had not yet materialised into material trials. EcoTechnilin was trialling a pre-preg[55] bio-resin-soaked nonwoven flax for flooring applications in vehicles, but this had not been fully developed at this time (2011). Cambridge Biopolymers were not operating at a commercial level in the production of their bio-resin: they were seeking investment. Both companies wanted to supply the automotive industry, as a large-volume business: it has one of the highest expectations of performance through rigorous testing.

Throughout the duration of my projects there were two main considerations: increased evidence of the use of renewable-material-based composites in automotive models and the shift in my intentions as new ideas emerged through the

[55] Pre-preg refers to a fabric that has been pre-impregnated with resin, meaning that it can be placed into a mould without the addition of further resin.

process of making. It was at this stage that I became fully aware of the impact of the inclusion of textiles in all the projects.

The original intention was to fit these prototype material parts into the Fiesta. As the projects progressed it became clear that this goal detracted from the crux of the research, which was to understand, through the process of working with the materials, their potential for rethinking automotive interior solutions. My approach indicated, through experimenting with the materials, that a new form language of automotive architecture and construction would be the way forward.

Kolko (2017) identifies four frameworks for establishing ways of understanding in form language. One is Gestalt, meaning 'unified whole', a term developed by the Berlin school of experimental psychology that refers to theories of visual perception. A second is the golden ratio, which refers to Fibonacci's sequence of numbers that create the golden rectangle, and the Fibonacci spiral, that is found in nature. These two methods of balancing proportions have been proven to produce results that are visually pleasing to humans. Third is the theory of semiotics, the study of signs and signification: signs convey and communicate meaning, and use codes to create value and meaning. The last framework Kolko identifies is visual form language structures, within which he identifies three movements: biomimicry, which involves studying nature and taking inspiration from it, not solely in relation to form but including systems approach and complex problem solving through evolution; industrialisation, which refers to the form and material traits that suggest that a product is technologically advanced, and anthropomorphism, which gives real-life attributes (human or animal) to inanimate objects. This creates a familiarity with the object that reflects the characteristics of the product as well as human values. Salingaros (2014) locates two complementary languages in architecture and urbanism: a pattern language and a form language. The pattern language refers to rules that have been developed over time for the way that people interact with built forms. He defines a form language as geometrical rules for how things are put together; in architecture these relate to different architectural traditions and styles. Saarinen (1985, pp. 182-183) states that in an architectural context in the use of the word '"style" we mean a "form language"'. He continues to argue that the two are distinctly different processes. The search for form leads to form-evolution, which in turn becomes a progression towards style. Style follows the measured evolution of form (p. 184). Gemperle et al. (1998) discuss how when designing in relation to the human body, in my case the seat and car interior panels, a humanistic form language is needed. Humanistic form language involves creating convex and concave form shapes in order to accommodate the human body. While the term 'form language' has clearly many definitions, it is a useful term to capture the overall character of any design approach in some specific field, such as the vehicle interior. It can be thought of as capturing the general aesthetic principles adopted, perhaps by an individual designer or, more typically, within a particular design culture.

The context for my use of these materials was created by looking back at how they had been used historically, specifically in reference to the work of Henry Ford (see Chapter 3) and early material composite research for aircraft components.

The context of renewable fibre composites for transport applications

Henry Ford experimented with using renewable plant material composites for automotive use in the 1940s (Furtado et al. 2014, p. 21). His developments with compressed soybeans, in particular, resulted in a type of plastic formed panels (discussed in Chapter 3). This was superseded by the cheaper and newly developed petrochemical-based plastic alternatives following the Second World War as the project had been abandoned due to the war effort. Concern for the environment has resulted in new regulations which, in conjunction with diminishing reserves of fossil fuels has led to renewed research into the potential of renewable material alternatives (Mohanty, Misra and Drzal, 2002; Pandey et al. 2015). In their research and development report on the use of natural fibre composites for automotive interior components, Ellison and McNaught (2000) state that such practice has been increasingly evident since 1994/5, starting with the use of jute in the door panels of the Mercedes E class. From this period the use of renewable fibres has been considerably more common in mainstream automotive models, as discussed in Chapter 4.

Drzal, Misra and Mohanty (2001) identify two forms of bio-composites, which they describe as ‘partially biodegradable’ and ‘completely biodegradable’. Those that employ a compostable natural fibre, such as bast[56] (kenaf, flax, hemp, ramie and jute), leaf (sisal, henequen, abaca and pineapple leaf), seed (cotton) and fruit (coconut fibre and coir), combined with a thermoplastic such as polypropylene or a thermoset such as polyester, are categorised as “partially biodegradable” types. Drzal, Misra and Mohanty (2002) point out that such material combinations are not adequately ‘eco-friendly’, due to the polymers’ non-compostable properties. They suggest that the use of renewable materials for both the matrix and the reinforcement in composites would be more environmentally beneficial and would ensure that they are identifiable as “completely biodegradable”.

[56] Bast fibres are obtained from the stems of certain dicotyledonous plants.

Employing natural bast fibres offers the potential for locally obtained resources to be used in composites that could support developing countries (Drzal, Misra and Mohanty, 2001; Nyambo et al. 2015, pp. 195-239), in addition reducing transportation and lowering emissions, fuel use and cost. This was evidenced in the Fiat Latin America Style Center project, 2011: *Novo Uno Ecology: influências no desenvolvimento de design* (Novo Uno Ecology: influences on the development of design). The resulting prototype concept car, the Uno Ecology, demonstrated the aims of the project in practical outcomes, the aims of these being to lessen the impact of material use on the environment. Renewable sources of locally sourced materials that were used included sugar cane bagasse: this fibrous matter, which remains after the stalks have been crushed, was used as filler with polypropylene to create interior and exterior panels. Ash from rice husks was also employed as filler in other polypropylene-formed parts. The inclusion of polypropylene as the matrix renders these parts partially biodegradable. Fibre from coconut shells was compressed into seat foam replacement forms, resulting in solutions that are completely biodegradable from a renewable resource. In addition, the natural tannin contained in the coconut fibre prevents the development of both mould and mites.

The international conference 'Natural Fibres '09: Materials for a Low Carbon Future' marked the close of the United Nations-designated International Year of Natural Fibres, 2009. It was held during from 14 to 15 December 2009 at the Institute of Materials, Minerals and Mining (IOM3) in London. Attending this inspired me to investigate the potential of natural fibres by developing prototypes for the Fiesta. The initial task was to recreate the lid of the glove-box compartment, followed by an inner door panel, using renewable plant fibres to reinforce plant-derived resin.

Removing and dismantling these parts from the Fiesta revealed details of the manufacturer, the date and time of production and the material content, impressed on the reverse side of each. I identified that the Tier One supplier Faurecia[57] was the producer[58]. In order to improve my understanding of the manufacturing process of automotive interior plastic components I visited Faurecia Interior Systems facilities in Méru, France (26 April 2011). The discussion centred on using bio-based materials for components of an interior door panel with an emphasis on performance. The first concern expressed by Faurecia was in regard to the ageing of such materials, which poses potential barriers to use. These include the materials' response to variable thermal climatic conditions, deterioration with UV, resistance to sunscreen creams

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[57] Faurecia focus on four areas: automotive seating, interior systems, automotive exteriors and emission control technologies. http://www.faurecia.com/en/about-us

[58] At the Interior Motives conference in 2008 (17–19 June) I had met with the Vice President of Design and reconnected subsequently meeting with a colleague due to his schedule.

and potential odour released during ageing. Secondly, there was the issue of how the surface of the material wears through prolonged use, both visually and functionally, hence its potential resistance to abrasion, friction and scratching, and similarly its ability to withstand impact when knocked, or when the airbag is deployed, is imperative. Critically, the material must be resistant to fire, stable rather than volatile, and must not give out any emissions likely to cause fogging of the windows. New materials are tested before even being considered for use in design (see Table 5, pp. 94-98).

The materials used for the Fiesta interior door panels are acrylonitrile butadiene styrene (ABS), polypropylene (PP) and polyurethane (PUR). ABS is used for its impact resistance and toughness: in the door panel it was placed strategically behind the fascia, providing functionality without exposure to sunlight, which damages it. The outer panel of PP was riveted to the inner panel (ABS) area, which was possible to separate manually.

Selecting the materials

As a reinforcement material in technical performance composites, flax[59] can be traced back to 1939, in its early use as a part in a prototype aircraft wing spar (in the Blenheim bomber) and fuselage (in the Spitfire). Dr N. A. de Bruyne, working at the Aero Research laboratories at Duxford on the development of synthetic resin for aircraft, had used cotton ‘cord’ as the reinforcement material. At the suggestion of Malcolm Gordon this had been substituted with linen or flax fibres. Named Gordon Aerolite, it was described as being ‘[…] almost twice as strong. And is three times as stiff’ as the “Cord” material, additionally performing well when compared with other materials used in aircraft at the time’ (de Bruyne 1939, pp. a, b and c). In outlining the procedures of production, de Bruyne stated that the initial process ‘is to get all the fibres uniformly arranged parallel to one another’. The Aeronautical Research Committee reports details that ‘These fibres are laid only in the longitudinal direction and are not woven or twisted in any way’ (Staff of Mechanical Test Department, Royal Aircraft Establishment, 1937, p. 2; Gordon, 1939, p. 1). Livingstone Smith (1943) comments that natural cellulose fibres are more commonly used to provide strength in reinforced plastics than other high-strength artificial fibres, such as nylon. He refers to data from the Department of Textile Industries at Leeds University regarding the tensile strength of various fibres, noting that flax has the highest, followed by hemp and nettle. Continuing he suggests that if the fibres can be laid in

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[59]Flax (*linum usitatissimum*) is a member of the genus Linum in the family of Linaceae.

the path of the main stresses then the result could be effective. Hill and Hughes (2010) agree that unidirectional composites or those where the fibre is specifically arranged fully utilises the strength and stiffness of natural plant fibres.

Although it was superseded by glass fibre in the late 1940s, flax has more recently been considered a more sustainable possibility (Dissanayake et al. 2009), due to its low environmental impact (Hill and Hughes, 2010, pp. 148-158), renewability and compostable nature (Furtado, et al. 2014, pp. 18-38). Misra et al. (2011) commented that natural fibres are lighter, less expensive, have superior specific strength, require comparatively less energy to produce, are good for the environment, biodegradable and have superior sound abatement characteristics when compared to synthetic glass fibre (Misra et al. 2011). In addition to these positives Ellison and McNaught (2000) refer to the benefits of natural fibres regarding workers' wellbeing during the manufacturing process, in comparison to the use of glass fibre, and their zero toxic emissions when subjected to heat.

In their life cycle analysis comparing the production of flax yarn and glass fibre, Dissanayake et al. (2009) conclude that the production process that uses flax sliver equates to glass fibre mat in terms of energy consumption. When the flax fibre is spun into yarn the energy used in the process makes it a less viable option in relation to energy use. Ellison and McNaught (2000) identified limiting factors in the use of bast fibres such as flax, jute and hemp, which include concern about the reliability of the quality of the supply that can result in technical difficulties, and uncertainty about long-term availability.

Although the parts that I was replicating did not have glass fibre in their composition I was using the flax as a reinforcement to support the bio-derived resin matrix.[60] The interaction between the properties of the fibres and the bio-resin would be critical in the performance of the composite (Hill and Hughes 2010, pp. 148-158). Hill and Hughes identify a potential disadvantage as in water sorption if the fibres become exposed over time, due to damage to the hydrophobic matrix. Natural fibres' hydrophilic affiliation[4] gives them a tendency to swell, which could lower their stability (Alonso and Murias, 2011). Further, the fibres are damaged during mechanical processing, which they suggest could be improved by lessening interference with the fibre. Hamada et al. (2013) acknowledge that natural fibres are not as strong as

[60] A matrix is a substance to which other things are fixed: in this instance the flax provides structural support to the bio-resin matrix, which has an elastic property when thinly layered in isolation. This aids it to be flexible but stable in respect of firmness allowing movement preventing it becoming brittle and snapping.

either carbon or glass fibres: however, they compare well in regard to other characteristics. They consider the main barriers to use are their absorption of water and their inability to bond with the resin matrix.

The core components of almost all natural fibres are cellulose, hemicellulose and lignin. These are present in variable proportions depending on the category of the fibre (Nyambo et al. 2014/2015, pp. 195-239), cellulose being the main ingredient. The individual traits of natural fibres are affected by the attributes of the cellulose content which is reliant on the circumstances during the plant's growth, such as climate, location and phase of development.

Plant derived bio-resin

My early experiments centred on encasing a textile or fibres within a clear resin: this was described as a bio-resin. However, the materials I trialled that were composed of a variety of synthetic and natural fibres reacted in a volatile manner after extracting air in a vacuum chamber. Further investigation revealed that the resin contained only a small percentage of material that could be described as ‘bio’. At this time I was using tray compartments to contain the resin, and the experiments did not consider formed surfaces.

Following these unsuccessful attempts I investigated and sourced a plant-oil-derived bio-resin at Cambridge Biopolymers in Duxford. This company owns patented technology which allows reductive ozonolysis of the plant oil rather than using chemicals to activate polymerisation[61]. Its plant oil sources are rapeseed, soybean and sunflower: high in monounsaturates, these have the optimum fatty content required for this purpose. They are thermoset polymers, which form a rigid matrix that is flexible rather than brittle.

Cambridge Biopolymers’ 80 per cent bio-derived resin is not commercially available, but following discussions the company agreed to support my project by supplying it without charge. It comes in two parts as follows: Bioresin AOG is composed of a mixture of products derived from the oxidisation of vegetable oil that have not been

[61] The ‘bioresin’ technology uses the natural reactivity of ozone to attack the double bonds present in the oil, forming oxygen linkages that can be converted into cross-linkable units. Other resin products made from natural raw materials employ chemicals to epoxidise the double bonds prior to polymerization, but we have found ozone activation is an effective approach, which provides a very clean and effective synthesis whilst generating little or no waste by-products. http://www.cambridge-biopolymers.com/Bioresin.html

fully characterised, but which consist primarily of aldehydic[62] derivatives of alkyl glycerides. This part is proportionately mixed with Bioresin RN (Aqueous), a pre-condensed aldehyde/resorcinol prepared as a 90 per cent w/w aqueous solution. When thoroughly mixed, the catalyst, sodium hydroxide NaOH (caustic soda) can be added, which activates the chemical process for curing.

Bio-resin and bio-plastics

Biopolymers from renewable resources, like petroleum-derived plastics, can be divided into two groups, thermoset and thermoplastic. Thermosets are acquired from naturally occurring oils from agricultural crop sources, such as linseed, soybean, castor, peanut, palm or rapeseed, amongst others. Thermoplastics can be subdivided into the following types: those using polylactic acid (PLA), deriving from sources such as corn or sugarcane, and polyhydroxyalkanoates (PHAs), created by the fermentation of bacteria and thermoplastic starch made from corn, potato or wheat (Gagauz 2015). Misra et al. (2011) identify PLA, PHAs and bio-based polytrimethylene terephthalate (PTT) as bio-plastics from renewable origins. They separate plastics derived from cellulosic resources and those from protein sources, such as 'soy/corn/wheat', and use the term 'bio-resin' to describe those obtained from vegetable oils. There are three recognised categories of wholly organic polymers: polylactic acid (PLA), polyhydroxbutyrate and polyfurfuyl alcohol.

The term bio-plastic can be used to signify materials '[…] that are either biodegradable, derived from both renewable and non-renewable resources, or materials that are non-biodegradable and derived from renewable resources' (Misra et al. 2011). The combination of different bio-plastics is also possible in the engineering of attributes for specific uses. Therefore whether it is compostable is dependent on the specifics of the bio-plastic. Similar to all 'sustainable' claims regarding materials I found it difficult to establish whether the material is wholly or partially sustainable: in what true sense can it be described as sustainable? This was a recurring concern in the research – the need to establish examples of 'greenwashing' – i.e. on digging deeper into the available information it becomes evident that aspects of the material are not sustainable. Establishing the truth about such claims when the overall picture was considered I realised that the whole scenario, from obtaining the material, processing it, production systems, products that use the material and end-of-life composting, needs to be in place and transparent to fully support the claims. I found the respective terms 'bio-resin' and 'bio-plastic' confusing: initially, I assumed that these materials were all compostable;

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[62] Aldehyde is an organic compound.

when I researched further I concluded that many could be best described as bio-derived.

Misra et al*.* (2011) suggest that the aim is to utilise the maximum of bio-derived materials from renewable resources to create a sustainable future through a reduction in the use of petroleum sources. In reference to bio-based plastic they comment that the competence of the material should be commensurate with that of petroleum-derived plastics: additionally, they should be cost effective. This sets a high benchmark for the use of such materials especially with regard to cost, competence and appearance; is it possible that differences in such materials could be accepted? If the bio-derived resin from Cambridge Biopolymers was used on an industrial scale the cost would be commensurate with synthetic resins, but only when it is produced in large volumes: in early-stage production this is not viable. As discussed, a composite engineered from renewable resources may not be compostable: for example, if the renewable resource-derived plastic is not able to biodegrade. However, the shift from reliance on petroleum-derived plastics to those from renewable resources could be considered a positive advance. Compostable bio-plastics degrade mainly through the enzymatic action of microorganisms to carbon dioxide, methane, inorganic compounds or biomass in a specified period of time. Alternatively, others can undergo microbially induced chain scission leading to mineralisation, which also includes photodegradation, oxidation and hydrolysis. (Misra et al. 2011). Bio-based plastics that are not compostable are made from a base of bioethanol obtained from corn or sugar cane. These are bio-based polyolefins, such as bio-nylons, bio-polyethylene and bio-polypropylene (Evans 2011, cited in Misra et al*.* 2011).

Craft methods and processes of construction

There were two main factors that contributed to my decision to make the formed panels by hand. My meeting with Faurecia had made me aware of the complexity involved in incorporating the use of new materials into the established production chain of injection-moulded, engineered parts. It was apparent that using an untested material would not be viable, as it would potentially contaminate the moulds. From my own experimentation with the bio-resin I realised that it would require considerable testing before industrial prototyping. Secondly, as the material was not commercially available I was reliant on obtaining batches that would not be sufficient for use in an industrial context.

In March 2008 I visited the Geneva Motor Show, where the Morgan Motor Company was showcasing LIFECar, a fully operational prototype concept car that combined luxury brand association with sustainable objectives. These extended to the use of materials, focusing on reducing the amount used and lowering weight. The output tested the association of high-end products with indulgent material consumption by advocating excellence in craft making, integrity of material use and the synergy between these and the production process. The project was conducted in partnership with Cranfield University, Riversimple, Oxford University, QinetiQ, OSCar and BOC Linde (Humphries, 2013).

I visited the production facilities at the Morgan Motor Company in 2010[63] to witness the craft manufacturing processes that they employ and to discuss their use of materials. The company has a strong philosophy of sustainable practice through low-volume production that continues in the tradition of coach-building. Morgan cars are not scrapped but built for longevity from quality materials that age with use in a similar manner to an antique artefact. The Morgan customer is investing in being part of a distinctive and iconic brand, and is therefore willing to pay for quality, craft production processes and sustainable materials in the vehicle they buy. This low-volume production allows slow processes to be used: the materials employed are high end, which results in an expensive, niche vehicle.

For my research projects I specifically selected an ordinary, small, family car – the Fiesta – in order to address the challenges associated with mass production and sustainable products. If the production of Morgan cars were scaled up to the level of Ford's mass production it would be difficult for them to maintain the consistent level of craftsmanship, quality of finish and material usage. This is evidenced historically in the evolution of car production: the shift from craft processes to mass production in order to fulfil product demand from the consumer and to reduce costs and maximise profit was discussed in Chapter 3. What I found particularly interesting on my visit was to see the processes that are associated more with traditional coach-building and early automotive production. These are comparable with the methods I used to make the inner door panel and glove-box lids.

From a materials perspective Morgan endeavours to achieve low weight without the use of plastics. Three core materials are used: ash wood, aluminium and leather. The frame is constructed from lightweight ash, which is effective in dampening vibration. Three or four thin layers are bonded with polyurethane glue, placed over a mould and vacuum-bagged for two hours. As the glue dries the material forms

[63] Date of Morgan visit: 12 January 2010.

around the shape of the mould. Alternatively, the ash/glue layers are clamped into a jig to shape them until set. The aluminium panels are beaten to shape by hand: this lightweight metal can be formed more easily than steel. Additionally, it can be recycled. Leather is used in the interior trim. The vehicle is also assembled and crafted by hand.

I used the original polypropylene fascia of the glove-box lid as a template to make a male and female mould using Jesmonite (a water-based casting material) with non-woven fibreglass as the reinforcement material. The surface of the resulting mould mirrored exactly the textured surface of the original part. At the same time as making this mould I continued with small-scale experiments with the bio-resin. To make these I had crafted an abstract, low-relief, curved edge form in carving foam. This was cast in plaster, creating male and female moulds to use as templates to experiment with permanently shaping different materials. This would demonstrate the behaviour and capabilities of materials when shaped into or over forms: my experience relates more to two-dimensional working.

From these tests I realised that the thick consistency and sticky nature of the material would not be conducive to pouring and drawing it through the limited cavity between the two mould faces. Using this method would also be problematic in terms of controlling the placement of any reinforcement material, which was necessary due to the flexible nature of the bio-resin when cured. I had noted the tendency for the bio-resin to bend when applied in thin layers when experimenting with the material. I considered that by increasing the scale at which I was working whilst aiming to retain the depth of the original piece, it would be necessary to reinforce the bio-resin. From these conjectures I decided that I would have more control over the outcome of the piece if I laid the mould by hand. As reinforcement material I used loosely woven jute[64] (genus *Corchorus*) from an imported used coffee bean sack, which would strengthen the bio-resin with a minimum of interference with the resulting thickness of the piece.

Both faces of the mould were highly waxed and polished to facilitate the release of the part. At the first attempt to recreate the part, I overcomplicated the process by the addition of aluminium powder and small amount of ground cocoa shell waste in the matrix. These were readily absorbed into the bio-resin, which coagulated making it dry and less malleable. When making the small-scale experiments the use of aluminium powder had acted to alter the surface colour of the piece from dark brown

[64] Jute (genus *Corchorus*) is a bast fibre.

to an aged silver appearance, after light sanding. Adding cocoa shell to the bio-resin made it comparable to a hard, cork-like material (Figures 28 and 29).

Figure 28: Bio-resin and cocoa shell.
Sheila Clark: 2014.

Figure 29: Detail of bio-resin and cocoa shell.
Sheila Clark: 2014.

The laid-up mould was vacuum-bagged for four hours: the vacuum created pressure and compressed the materials, thus helping the bonding process, and pushed them firmly into the mould. After this process the mould was removed and left to cure at room temperature for three days as a cautionary measure to ensure that it was entirely cured. Removing the part from the mould was problematic, as it resisted being released. When finally removed, the face side had suffered some damage, which I considered to be the result of packing the bio-resin with fillers, which had absorbed moisture in the bio-resin and made it too dry. Sanding the surface to reveal silver colouration from the addition of aluminium powder was counterproductive, as it removed the surface detailing. Adding these materials resulted in a colour resembling milky chocolate (Figure 30).

Figure 30: Glove-box lid made with bio-resin, aluminium powder, and ground cocoa shell; seen partially sanded in lower left part.
Sheila Clark, 2012.

On reflection, I considered that it was unnecessary to add materials for aesthetic purposes. The task was to successfully recreate the glove-box lid using natural materials: by adding non-essential ingredients I had moved away from demonstrating the purest example of the materials performance and representation.

The rear of the piece was markedly ridged where the thick plastic of the vacuum bag had creased when the air was extracted. I attempted to sand these away, but the fibrous jute cloth prevented this and caused deterioration. A second and third attempt was made: with each of these I hoped that I would be able to achieve a perfect replica of the original. For each attempt I followed the same procedure as follows.

In preparation, pieces of loosely woven jute fabric from a waste coffee sack were cut into strips, rectangles, squares and triangles to be readily available as reinforcement material. An initial gel coat of the bio-resin was applied to the surface of the mould: this would be the face of the glove-box lid. The bio-resin was thixotropic on the mould face and pooled in areas as it followed the contours. In applying the gel coat this was difficult to control: I did not want to disrupt the surface bio-resin or interfere with the material as it began to set. This first coat was followed in stages, layering the bio-resin-saturated jute pieces, which had been stippled with a resin-soaked paintbrush to remove excess air. The bio-resin was mixed in small batches as the working time had to be a balance between the material becoming too congealed to work with and alternatively being too slow to cure.

I continued layering in this way until the mould was sufficiently layered with the materials, which I assessed purely from previous attempts and common sense. At this stage I placed the two (male and female) faces of the moulds together, sandwiching the bio-resin between them. I hoped that this would produce a piece that had both surfaces suitable for installing over the glove-box. The ridges resulting from the vacuum bagging that physically were present on the back of previous trials would prevent it being adhered to the other part of the glove-box.

Working with the bio-resin required precautionary safety goggles and protective overalls; I used disposable plastic gloves to enable me to work quickly, as the mixture is very sticky and adherent. No respiratory mask was needed: the odour is sweet but not toxic. The brushes were cleaned in water and reused later when fully dry.

In comparison to the textile projects this was hands-on craft making. By contrast I was establishing and setting the criteria within which I would work, with little experience of mould-making or resin-casting. I was personally controlling the fabrication of the pieces. However, using craft processes presented problems in terms of controlling the materials in relation to both the resin and the textile support. Hand-moulding plastic is a very different process to machine-moulding plastic parts. I have detailed the methods I followed to indicate the difficulty I experienced in having complete command of the materials. There were limitations on the process, method and materials. Thwaites (2009) toaster project explored how a cheap, everyday item is reliant on a series of large, complex supply chains that are not seen by the consumer (Fairs, 2009; Thwaite, 2009). The problems he encountered dealt with some of the same issues that I was faced with, especially the relation between small, apparently unproblematic components and massive, sophisticated supply chains and manufacturing systems.

The male and female moulds I had made were suitable for pouring resin between the two faces when they are sandwiched together. This would not be feasible as the bio-resin was too sticky to draw through the mould. Additionally, the substrate was in textile form, which would be disrupted in such a process. Retrospectively, I recognise the textile would need to be mixed into the bio-resin, in the form of short fibres not a fabric, before being drawn through the male and female moulds, by an efficient process, for the best result. One of the glove box lids I made is illustrated below (Figure 31).

Figure 31: Glove-box lid made with bio-resin and woven jute coffee sack.
Sheila Clark, 2014.

Interior door panel: making the moulds

The manufacturer's interior door panel was composed of two parts riveted together: the outer was made from polypropylene (PP) and the inner from a mixture of ABS and PP. The two parts were separated manually, as each part needed to be recreated independently. The first stage was to prepare appropriate moulds.

With the significant increase in the size of the parts in comparison to the glove-box lid, the moulds needed to be lightweight to make manoeuvring them manageable. Jesmonite, which had been used to make the glove-box lid moulds, would be too heavy. In addition, the moulds would be used a limited number of times, so they could be less robust.

I had visited the Bronze Age sculpture casting foundry[65] previously (10 May, 2011) as they were experimenting with the same bio-resin, and I was aware of their experience of casting large-scale sculptural work. I asked their advice on making moulds for these panels, and they kindly agreed to guide me step by step through the process of fibreglass polyester resin mould-making. I worked independently on each panel to make the moulds, following the process as instructed by staff at Bronze Age: they allowed me to work at their premises.

Each original part was laid on a wooden board and a wall of Plasticine modelling putty was built slowly around the respective panel. This barrier projected beyond the exterior parts by a margin of approximately eight centimetres, forming a ledge. It was smoothed out so that there was no distinction or gap between the panel and putty at the point where they touched. The next stage was to make a silicon jacket from each panel. Its ability to pick up detail would replicate the surface impression and the non-stick nature of silicon would allow easy release following the making of the bio-resin part. Four layers of silicon were applied to ensure against tearing: it had inevitably pooled in areas as it slipped from the steeper curves. The putty edge was also covered with raised markers, placed at intervals: these would later act as guides. The process involved some skill to ensure that there were no air pockets: the silicon has to be 'twirled' in spiral drools onto the surface with the fingers, then it naturally spreads, settles and sets.

The next stage was to make a strong support to encase the silicon jacket: fibreglass and polyester resin were used for this. Working with these materials required respiratory apparatus, protective clothing, good ventilation, disposable gloves, brushes and pots. Fibreglass sheets were cut into shapes in preparation for use: the resin was mixed in batches as once the catalyst has been added the synthetic resin begins to cure and working time is limited. The fibreglass pieces were saturated with resin, placed over the silicon and stippled to remove air. When the layers were sufficiently built up wooden supports were added to strengthen the mould.
Ironically in contrast to the material aims of my projects, the materials that I used in making the moulds required significant protective apparatus and clothing due to their toxicity.

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[65] Bronze Age Sculpture Casting Foundry "for all moulding, casting, repairs, restoration, patination services, based in Limehouse, London" www.bronzeage.co.uk

Making the door panels

The larger scale of the door panels in comparison to the glove-box lid required a denser, stronger and thicker support material. From the experiments I had conducted I considered that the open weave of the jute coffee sack would not be a sufficiently robust reinforcement to support the bio-resin. From my investigations, the material samples I had gathered and my experiments I decided to use flax-needled felt.

Component materials - Non-woven flax

The company EcoTechnilin, established in 1990 by two flax co-operatives in northern France, produce non-woven needle-punched flax matting (Fibrimat, see Chapter 4, p.83). European linen is cultivated in a coastal band across the western regions of the continent, where it thrives on the damp atmosphere and soil composition (Masters of Linen, 2010). The combined experience of growing, harvesting, retting and scutching the fibre in preparation for further use are factors that contribute to it remaining localised.

The flax matting is constructed by first carding the fibres and then cross-lapping these sheets of loosely laid fibres into several layers, depending on the desired density. Finally, the layered fibres are linked by the mechanical process of needle punching, which produces a uniform felt.

I visited EcoTechnilin's research and development facility near Ely, Cambridge on 13 April 2011, after I had requested samples of their materials following the Automotive Interiors Expo, Stuttgart, which I visited from 22 to 24 June 2010. EcoTechnilin's other products include natural (flax, jute, kenaf) and glass fibres, combined with thermoplastic binders such as polypropylene and polyester in the mat. These are used for thermo-compressing parts: the mats are heated until the plastic binder begins to melt, at which point they are compressed between cold tools. As the temperature lowers, the plastic element sets as it cools, holding the mat into the form of the tool. At the time of my visit EcoTechnilin were developing bio-resin-impregnated flax mat that could be easily transported and thermo-formed, - FibriPreg flax/bio-resin pre-preg: this is now commercially available.

Constructing the outer part

In making the outer and inner door panels I followed the same procedure for the glove-box lid, with the exception that I used 3mm non-woven flax as the reinforcement material. The flax matting was cut into a variety of shapes in preparation for soaking with the bio-resin, which was mixed in larger batches. First the gel coat was applied directly to the silicon surface, followed by layers of flax mat generously soaked in bio-resin, which were stippled to remove air.

The outer part was the first panel created: it was made at the Bronze Age premises. This part was not vacuum bagged because I did not want any ridging on the reverse surface that might prevent the inner and outer sections being joined: this had occurred with the glove-box lid. It was left to cure for several days before being removed from the mould. Using silicon enabled the part to be released easily. The surface detail of the original panel had been replicated in detail; however it had some small surface flaws. It was transported to the RCA. Ideally, it would have been fitted to the inner panel and door soon after fabrication: this would have prevented it from warping. It fixed into this distorted shape and become insufficiently flexible to readjust.

Constructing the inner part

The inner panel was made at the RCA using the same method of layering the mould (Figure 32). When sufficient material had been applied, the piece was inserted into a vacuum bag: the pump removed all the air from inside it, at the same time creating pressure that compressed the materials firmly into the mould. This did result in ridging on the back of the panel. However, the surface was in good condition and the part retained its shape.

Figure 32: Making the inner door panel.
Sheila Clark, 2013.

The Fiesta was transported to The Dove Company[66] in Norfolk, where there was available workshop space to house it. The company specialises in design engineering, manufacturing components for automotive interior and exterior prototypes and production. At this time I still envisaged that the parts I had made would be fitted into the Fiesta, which they would be able to assist with.

At my first meeting with Dove I explained that the interior door panels I had made needed to be fitted to the Fiesta door. I was aware that this would involve adjustments behind the panels to secure the parts, but I was not willing to compromise on the visual appearance of the panels. As we discussed the best way to fit the panels, they were handled, which resulted in the outer panel breaking into two pieces. This was a result of a weak point arising from the layering up of the non-woven flax during fabrication. The appearance of the parts was assessed critically, with the feedback that they did not look professional. In addition they advised that it would not be possible to join and fit them to the Fiesta door without modification to the rear surfaces, which had ridges resulting from the vacuum bagging and use of a

[66] The Dove Company: “Extensive experience in design engineering, from traditional general pattern making to full size interior and exterior mock-ups and show cars.” “Our production area offers prototypes, rapid prototyping and production runs.”
http://www.doveco.com/www.doveco.com/Welcome.html

single mould. There was insufficient space to accommodate the panel into the space available in the door cavity.

The surface detail of the door panels I had made show fibre content in the resin. From a design perspective I like the subtle visibility of the flax reinforcement: it suggests the natural material content. This is used as a design feature at Camira in their Sting and Nomad fabric ranges (discussed in Chapter 6). In these fabrics the creation of an irregular surface appearance by the use of non-uniform fibre is reminiscent of craft making: a way of indicating the textiles origin is natural and has a sustainable concept. The fashion designer Rei Kawakubo (Comme des Garçons) describes her view of imperfection, and how the looms are manipulated to achieve fabrics that are imperfect. 'The machines that make the fabrics are more and more making uniform, flawless textures. I like it when something is *off* - not perfect. Hand weaving is the best way to achieve this. Since it isn't always possible, we loosen a screw of the machines here and there so they can't do exactly what they're supposed to do.' (Kawakubo, quoted in Koren, 1984, p. 117)

After considering the available options I decided to use the original outer panel with the bio-resin inner panel. This panel was visually in poor condition: it had been used as the template for making the mould and been marked by the process and materials. I made the decision to have it painted alongside other interior parts: these would then act as markers, delineating the parts I had remade inside the Fiesta and linking them through a unified colour. I discussed and considered paint options in a meeting at the design studio and manufacturing facility of Mankiewicz Gebr. & Company.[67] The company agreed to provide its Nextel automotive interior soft touch paint, which is stock supported. I selected a specific shade of blue to coordinate with the exterior paint colour of the Fiesta and the textiles I had fabricated. The parts were sent to Germany to be professionally painted (Figure 33).

[67] Mankiewicz Gebr. & Co. (GmbH & Co. KG), based in Hamburg, Germany: "…leading manufacturers of high-quality coating systems for the general industry, aviation and automotive markets worldwide." http://www.mankiewicz.com/english/company/

Figure 33: Painted outer door panel with Nextel paint and bio-resin inner door panel. Sheila Clark: 2015.

Prior to fitting to the door, the rear of the bio-resin inner panel was sanded to remove excess material, allowing it to fit into the cavity. In areas where the bio-resin had gravitationally pooled it was too thick. This was in part due to the craft process used to make the panel and inexperience in using the material. The edges were trimmed neatly and the two panels assembled together, secured with filler and glue and then fitted to the door. The original compressed part housing the door-opening device, which had been covered with the same textile used by Ford for the Fiesta seats, was recovered with wool/nettle fabric backed with industrial wool felt (Chapter 6) (Figures 34 and 35).

Figure 34: My door panel fitted to original Fiesta door, mounted on stand.

Sheila Clark, 2015.

Figure 35: Detail of door panel showing nettle/wool fabric inclusion.

Sheila Clark, 2015.

Summary

In order to create the door panel prototypes I had to add processes to enable the part to be fitted into the Fiesta door. This resulted from the craft or hand processes I had used to make the part and the behaviour of the materials, in conjunction with the scale of the piece. I was fitting these materials into an existing form: on reflection I would redesign the part to suit the materials. It was not until I reached this point in the prototyping process that I fully realised that I was designing in reverse. Using biomaterials when making early trials I perceived that they had the potential to recreate the intended Fiesta parts. This iterative design process led to me recreate the inner door parts at full scale, but on reflection I could have focused on redesigning the surface of the panels to better suit the material. This I would eventually achieve with lower relief in the surfaces that would allow the resin to not be gravitationally pulled over the steep surfaces, resulting in a more consistent depth to the cured panel.

There were similar limitations in the process, method and material as in the making of the glove box lid. However, the increase in scale of the respective parts posed a different set of criteria of making.

Renewable material forms: Biotex

Composites Evolution[68] develops products that are engineered for high-performance composite applications from renewable resources (see also Chapter 4). The products include yarns, fabrics and pre-consolidated sheets. As an alternative to glass-fibre reinforced composites, the use of natural fibres lessens weight, has a reduced environmental impact and diminishes vibration.

The material that I selected to work with is composed of flax fibres that are commingled with polylactic acid (PLA). The fibres are either aligned or slightly twisted, facilitating their saturation with the matrix during thermo-setting. The PLA forms a net-like structure around the fibres, containing them. In addition, the placement of the fibres improves their effectiveness by 50 per cent in comparison to using standard yarn twisting. These yarns are then woven into two available constructions – 4x4 Hopsack 510gsm or 2x2 Twill 420gsm. The fabrics are intended

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[68] Composites Evolution “supplies innovative, sustainable materials to the composites industry. The “materials are used to enhance performance, reduce weight and improve environmental impact in a variety of market sectors, including automotive.” The “…products include fibres, resins and intermediates based on natural and bio-derived materials.” http://compositesevolution.com

for the production of fibre-reinforced thermoplastic composite parts. A combination of pressure and heat melts the PLA, which saturates the flax, combining the two materials. On cooling the textile construction will set firm and stiff permanently.

I first visited Composites Evolution on 12 January 2012 to understand more about the capabilities of the material and the potential for experimenting with it. They sent me sample pieces of Flax/PLA in both 2x2 twill and 4x4 hopsack woven structures to work with.

Composites Evolution's Biotex fabric needs to be sandwiched in layers prior to applying heat and pressure in order to provide the required density and strength. A temperature of up to 200ºC is necessary to activate or agitate the molecules melting the PLA content. The equipment that I used in trialling was an Adkins MK.6 flat platen heat transfer press: 380mm x 510mm, in the Textiles workshop at the RCA. The tool allows the pressure to be varied, accommodating different thicknesses between the plates. Temperature can be adjusted by individual degrees to a maximum of 200ºC. Additionally, a timer controls the duration the materials are in the press. My initial tests explored layering both different woven structures of the Biotex, varying the temperature and pressure for different durations.

This method was effective, and worked well with small-sized (approximately 20 x 16cm) pieces of the Biotex fabric. I found that placing the fabric individually in the press before layering gave the best adhesion when cooled, although this was an awkward procedure. It entailed turning each face of the textile in the press to ensure the PLA was melted, then quickly sandwiching it together.

Following these flat lamination tests I considered that I could try using the plaster Pobble[69] moulds to form the Biotex. These male and female moulds fit flush together but could be used to sustain pressure over the heat-pressed sandwich of Biotex. By layering up by hand, whilst the materials retained a high level of heat and the PLA was still unstable and semi-melted, it was possible to place the sandwich of layers between the moulds and manually apply pressure for a short period of time. This forced the textiles into the shape whilst the PLA set and fixed the shape and adhered the layers.

I found this method worked effectively, but with two problems. First the scale of the form was too small to accommodate the tendency of the excess of fabric outside the

[69] 'Pobble' is the name I gave the forms as they resemble the appearance of both a cobblestone or pebble.

curved area to drape. On cooling this resulted in ridges forming at the edges where it was not sufficiently contained under pressure between the moulds. The woven fabric would be more suited to draping over a lesser gradient of curvature. I considered that the material would work better when used in the low-relief interior parts of the Fiesta.

Biotex is neutral beige in colour, the natural state of the material composition, which limits its decorative application (Figure 36). It can be dyed in fabric form at a low temperature: if the temperature is too high it could potentially activate the melting state of the PLA content. The results are restricted to a solid colour, which darkens considerably when heat set, and has a glossy appearance.

Figure 36: Biotex formed in pobble mould.
Sheila Clark, 2014.

In the early stages of the project I carried out numerous weaving trials with various different weft yarns to explore their performance in a textile. I consistently used a cotton warp. I had used a weave structure, satin, that brings the weft yarns to the surface of the cloth, covering all the warp threads. I experimented with using a variety of these fabric samples to laminate the top surface of the Biotex layers. There was no addition of PLA in the fabrics I had made, but they still adhered well. The structure of the Biotex yarn facilitated this, the flax fibres being encased within the 'net' construction of PLA fibre. The fibre compositions of the fabrics that I laminated to the Biotex included wool (washed, milled and felted) (Figure 37), metal content (copper and silver) and polypropylene (Figure 38). As the Biotex foundation fabrics have low shrinkage it was possible to achieve good adhesion and negligible distortion of the face laminations.

Figure 37: Biotex with wool face woven textile, formed in pobble mould.
Sheila Clark, 2014.

Figure 38: Biotex with PP and metal face woven textile, formed in pobble mould.
Sheila Clark, 2014.

When I received the fabrics I had developed with Camira I trialled them in a similar way, as the face adhered to the Biotex textile, both flat and formed Figure 39). By adding the surface textile, which has better fire retardancy due to its nettle content, I imagined the combination would be used to create visible interior panels in the vehicle interior. I envisaged that I would be able to make a larger formed panel. However, this was not logistically possible due to the limitations of my craft process and lack of appropriate male and female metal moulds. In an ideal scenario I would have had aluminium male and female moulds of the interior part and an autoclave in which to thermoset the textile combination.

Figure 39: Biotex with Repeat Deco face textile, formed in pobble mould.
Sheila Clark, 2015.

Summary

The experiments that I made using Biotex have the potential to be further developed, possibly with an automotive company and Composites Evolution. I was encouraged by the results I achieved and their potential for lightweight interior face panels. I was disappointed that I was not able to produce a finished part at full scale. However, the samples I made indicated it would be possible with the correct tooling and equipment.

Chapter Conclusions

The interior panels within a vehicle are composed of surfaces that are not flat, but curved in low relief providing function as well as contributing to the styling or visual identity of the car. Surfaces such as the seats are built to create form using a series of materials. It was important to consider both of these in my practice as they represent what is visible in a vehicle. From my experience and knowledge base I veered towards the use of textiles, yarn and fibre, which I used to produce prototypes that were sustainable. This allowed me to explore what this meant in practice and how this could be achieved, what problems, hurdles and understanding would there be.

It was important to me that the scope of the projects extended beyond focusing solely on textiles, and are understood beyond textile trim solutions, but are seen from the perspective that the material contributes to sustainable objectives and form language in whatever way it is used. However, it became apparent to me, particularly in the projects described in this chapter that the use of textiles can contribute to many aspects of the interior. This can be visible or hidden inside the panels that hide electronics and the controls of the car.

Bio-resin: limitations of the process, material and method

In an ideal scenario I would have had access to the appropriate moulds and been familiar with the processes involved in making large scale and smaller scale moulds and parts. As this was not the case I had to learn different skills to those I am more used to employing. Using hand-lay-up methods meant this project became craft-making, which does not and cannot fully explore the potential of the materials for industrial manufacturing. I was more able to control these processes on a small-scale but less so when I scaled up to that of the door panel, which posed further challenges that I was less equipped to deal with.

The process of hand laying a mould in contrast to injection moulding between moulds are very different processes. Hand weaving and industrial weaving are similar processes, apart from the speed of production, that indicate the way a fibre and yarn will behave in a comparable way.

However, these methods were useful in suggesting the capabilities of the material and allowed me to consider how it could be used in an automotive interior. Using the material in this way posed questions that relate to the use of such materials and the perception of ‘how’ an interior surface ‘should’ look in a vehicle. This debate regarding expectation of perfection, flawless surfaces, timeless ageing that is linked with perceived engineering and performance of the vehicle. At Dove for example to produce something that is not flawless is not acceptable to the automotive industry. However, if the craft methods used by Morgan and Comme des Garçons for example, display an element of imperfection this can be seen as premium as it suggests the highly prized slow and skilled craft approach.

If the material were used in injection moulding the resin would be mixed with chopped fibre to facilitate the process. However, in the processes I used it was appropriate to employ cut textile pieces to reinforce the resin.

I fixed early to solution conjectures, in order to explore the pros and cons of the materials and processes. Additionally, it was critical to work at full scale to appraise the behaviour and capabilities of the materials. I recognise that there are more efficient methods of trialling materials other than craft making, but these processes were a way to progress the practice.

Biotex: limitations of the process, material and method

The material has great potential for use in the automotive industry, as evidenced by its use at JLR. However, it is not visible in the interior. The experiments that I made with the addition of the wool/nettle fabric I developed at Camira have the potential for further development. This could be in collaboration with an automotive company, Composites Evolution and a weaving mill such as Camira. Creating a product that is low weight and is inherently resistant to fire, a result of the materials used, could be a potential solution for visible surfaces in the interior of the vehicle.

I was inspired by the relative success of the pieces using a low tech, craft approach in the heating and moulding of them. It was disappointing that I could not produce a full scale interior panel but the work I did produce indicated proof of concept that with the correct tooling and equipment can be further explored.

Looking back there is evidence of historic plant material discoveries that still can be pertinent today to support a sustainable approach to manufacture through the use of renewable plant based materials.

However, there are concerns over quality, consistency, ability to supply and cost. The appropriate systems need to be in place to provide the correct composting conditions and process at the end of life. The part needs to be easily disassembled which needs consideration in the design process, including manufacturing.

Chapter 8: Conclusions

The changing landscape of sustainability and the automobile

In this chapter I reflect on key aspects of the research, set in the changing landscape and understanding of sustainability and of the automotive industries, and I summarise the main challenges. I examine the nature of my own work as research, the methods I used and their limitations. Lastly, I set out ideas for future work that following this research, and my reflection on it seems to me to be important avenues for exploration.

My understanding of the nature of sustainability has significantly evolved in relation to both thinking and practice throughout the duration of my PhD. As my research was conducted over a period of years, society's general perception and awareness of sustainability issues has developed and shifted in a continually changing landscape. There has been a move towards a circular economy with automotive manufacturers implementing strategies and systems for the recovery, reuse and recycling of automotive parts and the materials they are made of. This could be in response to end-of-life vehicle directives but also through the recognition that there is a financial as well as an environmental rationale to this practice.

Through my research and practice I came to understand and consider the manufacturing systems that are in place and how interconnected they are: changing one material element can affect the whole set of processes involved. Following this I recognised that changing the materials in products to fit into one recovery stream - biological or technical - requires systems to be created. This concept is evidenced by the key authors on sustainability, including Stahel and Reday-Mulvey (1981), McDonough and Braungart (2001 and 2002), Stahel (2010), Charnley (2015), Webster (2015), Moreno et al. (2016) and The Ellen MacArthur Foundation (2017).

The principal challenges of a shift to sustainable production and consumption for the automotive industry are:

- Establishing material recovery and treatment systems for both the technological and biological cycles that move beyond automotive shredder recovery at the end of life of a vehicle.
- Design for disassembly to facilitate the removal of the parts and the design of the product, keeping material streams separate where possible.

- Ensuring that material supply systems throughout the product chain are transparent and bona fide in their sustainability claims.
- Changes to manufacturer and consumer expectation of uniformity and perfection in products.
- The potential need to re-examine the performance requirements, standards and testing to accommodate different, sustainable material.
- The challenge to manufacturing processes of using different materials.

At an early stage in my research I thought that the interiors of electric vehicles could extend their sustainability credentials further through changes in material usage. Approximately ten years later, the automotive industry is moving towards the reality of autonomous vehicles and potentially Mobility as a Service (MaaS). These are significant changes for an industry that is often criticised for being slow to adopt new possibilities. In the *2017 UK Automotive Sustainability Report* (SMMT) (2017, p. 5) The Society of Motor Manufacturers and Traders expresses the expectation that the automotive industry will change more in the next five years than it has in the last fifty, in part through digitisation and further automation in manufacturing. Is it conceivable that with these new developments the automobile interior can be reappraised towards sustainable material use: what this might require?

I will now discuss the above challenges in more detail.

Appropriate recovery systems

At the outset of my PhD I identified that the materials I would use in the practical work belong to two separate streams: biological for industrial composting and technical or synthetic for recycling. I envisaged that working from a 'materials first' approach would demonstrate how this can be applied in practice in a vehicle. However, I soon realised that in changing one part there was a domino effect that cascaded, for example, from the seat face textile itself onto the next component in the overall product, such as the foams and the supporting frame. When I was faced with the reality of a full-scale vehicle, and the complex nature of all the component parts, it was clear that unless there were established systems to dismantle and recover the materials, replacing individual parts was not sufficient. This was one of the reasons contributing to my decision not to install the parts in the Fiesta: in addition, they were stronger when viewed as individual elements in their own material group. This demonstrates one of the limitations of the research process. As a sole designer working on industrial products it is difficult to tackle all the components that make up a part such as the seat. I realised that working on one element alone, such as the face textile, is ineffectual unless the whole set of design scenarios and material usage within the product are considered, and the appropriate recovery systems are in place, or at least in development. With the knowledge I have now, I understand that taking a 'materials first' approach by fixing the outcome to an existing product initially reduced the potential for innovation. My exploration through practice had to expand in scope beyond the design of the things themselves or the selection of 'sustainable' materials.

Design for disassembly

Several automotive manufacturers including Renault, Ford, Toyota and JLR (Chapter 4) have expanded, and continue to expand, recovery systems for vehicle components, so that the parts can be either reused or recycled. Remanufacturing is an area of growth in the industry because it has value environmentally, financially and from the point of view of consumer satisfaction (SMMT, 2017, p. 24). In an optimum situation, in order to recover biological and technical materials separately, parts need to be designed for recovery with this in mind. There are some combinations that can be recycled many times, one example being the combination of kenaf and polypropylene (Chapter 4), but this does not optimise the use of the potential recovery systems of each respective material: it limits it. However, automotive companies do not necessarily feel free to innovate radically. They are constrained by the conservatism of their customers and perhaps constrained even more by that of their own marketing and sales divisions. Matsumoto, Chinen and Endo in their comparison study of U.S and Japanese consumer perceptions of remanufactured automotive parts found that they were more widely accepted in the U.S than in Japan. This was in part due to there being less awareness of remanufactured automotive alternators and starters in Japanese consumers, who were also less convinced of the cost benefits of remanufacturing and perceived higher associated risks particularly in relation to the quality of the product. The U.S. consumers were more cost aware making them more accepting of remanufactured parts. This illustrates a potential cultural barrier to their use in Japanese markets. Three suggestions are made to overcome this perception from the consumers: firstly, to increase consumers' knowledge of remanufactured automotive parts, secondly, to increase their perception in relation to their benefits, and thirdly to lower their concerns about quality associated risks (Matsumoto, Chinen and Endo, 2016, pp. 966, 975 and 976).

Material supply systems

When investigating and sourcing materials, both prior to and whilst conducting the projects, I was often misled by the material marketing that emphasised its sustainable credentials, which, when I investigated further I found to be only part of the bigger picture. Tracing every detail of a materials journey is complex and problematic, as this information is not necessarily transparent or available. My realisation that every material has some impact on the environment, from land use, mining and obtaining it, manufacturing processes, water treatments and transportation to end-of-life handling made me question the approach I had taken and the choices I had made. However, as a designer/maker my process is to explore the problem and solution spaces by committing early to potential or partial solutions and through the manipulation of the materials. In future designing, the complete material life cycle and its impact should be explored before committing to using it. But unless materials suppliers and manufacturers provide evidence to enable those using them to fully understand what has been involved in obtaining or creating them, this is difficult. This practice has been adopted where the provider wants to be transparent and show traceability, describing the chain of events that bring a material to the designer or customer, which is often accredited by certification bodies. The automotive industry is working with its supply chains to improve the environmental performance of their suppliers and those that, in turn, supply them (SMMT, 2017, p. 15). As the industry is at the top of the tiers of supply and manufacturing chains, this makes them authoritative in influencing systems change towards a circular economy. Materials systems include the source, the extraction/acquisition, the agricultural and land impact and societal considerations and impact. Suppliers of parts and materials need automotive customers, because the volumes they order are so high: because of this they follow directives from the automotive industry.

In the product, the material content should be transparent to enable consumers to understand how to dispose of it at the end of life; for vehicles in Europe the responsibility lies with the manufacturer. (When I took apart the Fiesta all the parts were labelled with their material content and manufacturing information, allowing them to be traced back in the event of a fault). However systems beyond this need to be in place, not only for recovering materials after the vehicle has been shredded, but to go further in material recovery, as described in a circular economy (Chapter 4), to optimise the use of materials. Designers need to be aware of and understand these systems so that they can design to facilitate their uptake through their practice. As Moreno et al. (2016) indicate, through the consideration of a whole set of systems designers become ‘systems thinkers’. Designers can subsequently make informed decisions about which circular approach to adopt in relation to the business model, and by considering the cultural and social context influence consumer perceptions.

Changes to manufacturer and consumer expectation of uniformity and perfection in products

One of the issues faced in making the prototype textiles and panels was how to communicate that they were sustainable. This, in turn, raised the question of challenging consumer and manufacturer expectations of the visual appearance of products: the aesthetics of sustainability affected by not only customer expectations but also perceived customer expectations. The natural brown colour of the bio-resin and the partially seen non-woven flax in the door panel visibly exposes the identity or nature of the material: it looks ‘natural’. The fabric that I made using nettle and wool evidences the use of renewable materials, in this case the visible fibrous nettle yarn. By contrast the textiles created in the Mono project are undistinguishable from virgin polyester fabric: they do not visibly demonstrate that they are made from recycled material. This poses questions about how to communicate that a product is ‘sustainable’. Would consumers and manufacturers accept an alternative visual identity in products, one that is not uniform but is imperfect and inconsistent? Henry Ford’s development of Fordite, which used waste straw, rubber base, sulphur, silica and other ingredients, came about partly out of necessity due to the expense of using wood but also because it was difficult to create absolute precision with wood (Ford, 1926, p. 63). Uniformity, perfection and newness are consumer preferences, as subliminally this reflects the engineering and performance of the product. It is also aspirational, suggesting and reflecting the status of the consumer. Chapman (2005, p.30) suggests that material consumption is more than the aspiration to acquire new things; it is an individual’s journey towards the desired self. The acquisition of new products is an external representation of their existence and development.

As shown in the table of testing that automotive materials are put through (Chapter 5, pp. 97-101), the intention is that they should show minimal signs of wear and tear throughout the lifespan of the vehicle, which in 2016 was on average 14.1 years (SMMT, 2017, p.23). Change in the visual appearance of a material is seen as damage or degradation, that can result in a product being replaced, as it no longer looks ‘new’ – ‘cosmetic obsolescence’ (Bridgens and Lilley, 2017, p. 2). Bridgens and Lilley (p. 6) suggest that there is possibly more acceptance of the way a natural material ages, for example the patinas on metal and antique wood, but man-made materials are expected to remain perfect. Chapman suggests that by allowing consumers to develop some degree of empathy with the products they own, this encourages empathic feelings towards that particular brand (2005, p. 184).

It is clear that the aesthetics of automotive materials cannot be considered separately from the sources, supply chains and manufacturing methods: the whole set of systems surrounding production, sales and marketing. The aesthetics of materials are presented and framed by sales and marketing as well as continually shifting cultural expectations and trends.

The potential need to re-examine the performance requirements, standards and testing to accommodate different yet sustainable materials

In addition to challenging the expectations and perceived customer and industry expectations that the material's visual appearance should look 'perfect' and 'always new'; the use of different yet sustainable materials could require new testing standards to accommodate them in a vehicle. The table of testing (Chapter 5, Table 5, pp. 97-101) illustrates the numerous tests that materials must pass, with the OEMs specifying similar, yet undisclosed, performance results. This standardisation of requirements across the world does not allow for regional variations of material use and requires every vehicle to function in the most extreme climate conditions: it can be construed as a potential barrier to using different materials. If there were to be a shift to MaaS it would provide further opportunity for the reconditioning, repair and replacement of parts. These facilities could be situated regionally and potentially make use of local materials.

However, if the lifespan of a service vehicle were extended to 20 plus years it would need refitting periodically; again an opportunity for reconditioning, repair and replacement, but this could also be an opportunity for a radical redesign of the vehicle architecture to be modular and able to adapt and accommodate different configurations. The automobile architecture is constrained by the necessity to accommodate the human form in conjunction with protecting the individuals within it, whilst travelling at speed. Theoretically, autonomous vehicles could reduce accidents through digitally controlling the car, which offers potential for new vehicle architectures and interior configurations to be considered.

The challenge to manufacturing process of using different materials

The vast volumes of production required for automotive manufacturing requires a significant investment in equipment, testing, and employee skill and knowledge. From my experience, in particular with Guilford, the established systems can adapt to some degree but the infrastructure is embedded, as I experienced at Faurecia. Changing these whole sets of systems to accommodate different materials is not economically simple. However, there is the potential for a whole system design approach towards finding solutions. Whole system design intends to join together social, economic and environmental situations into an entire design system (Charnley and Lemon, 2010, p. 156). This is a complex area, which is multi-faceted and composed of a mix of products, services and systems. However whole system design encourages a wider view and approach to the problem. It proposes that the focus extends beyond the investigation of one aspect in isolation, but instead recognises that the interconnectedness of things makes a complex structure that needs to be addressed as a whole (pp. 158-159). Charnely and Lemon (p. 158) note that solutions to complex problems cannot be visualised and that the process towards finding answers can be messy, unstructured and context specific. They suggest that to deal with such complexity, every level of the system in which the problem is embedded needs to be addressed (p.159). For the purposes of their automotive case study it was decided by the design team that the 'system' was limited to the six companies involved in the design and manufacture of the car, which set boundaries on the system used (p. 161). My growing awareness throughout my research has been in the number of stakeholders involved in the design and eventual manufacture of a vehicle which extends far beyond design and manufacturing but includes the source of all materials, processes of manufacturing right to end of life treatments. In their conclusion they note that one of the biggest challenges is to encourage designers, developers, engineers, planners, strategists and government officials to consider the whole, see the wider view and the interconnections that are involved (p. 177).

Churchman (1967) responded to a seminar by professor Horst Rittel in which he had used the term 'wicked problem' to refer to a class of social system problems that are ill-considered, where the information is confusing and where there are many stakeholders with conflicting interests, and the consequences in the whole system are confusing. The term describes the problem as mischievous, as attempts to solve the problem can result in it becoming worse. Rittel and Webber (1972, p. 155) suggest that there are no 'solutions' to social problems in the sense of definitive and objective answers: in fact every 'wicked problem' can be considered to be a symptom of another problem (p. 165). To understand the problem and its resolution one has to understand the relationship between the problem and solution, as they are present together: one cannot be understood without consideration of the other (p. 161). This resonates with design problems and the situations I faced in my research. When I tried to find a possible solution I uncovered and encountered more problems as my understanding of the complexity of different facets of the problem deepened.

The relationship between craft-based design and industrial manufacture: key insights

Craft-based design enables visible evidence of the hand or human interaction and this can be intentional. Uniformity, perfection and an ‘always new’ appearance are part of manufacturer and consumer expectations and the intention in industrial design, which subliminally reflects perceptions of the product’s engineering and performance. Kolko (2017) states that industrialisation refers to the form and material features of a product which suggest that it is technically progressive.

Mass production is volume-focused and quick to realise products; in contrast craft making is slow, and the volume of outputs is low. What might be sustainable on a small scale may not translate to an industrial scale. For example, if a locally sourced material is used, such as coconut fibre in Brazil (Fiat Unologica) and it is not available in sufficient quantities to export, then a more local alternative will need to be sought in other countries for the same output. For example, Ford is using local plant oil sources: soy, castor, etc., in some parts. A practice such as this could challenge global manufacturing, in which the same standard of material performance and an identical aesthetic are required, wherever the vehicle might be. Henry Ford advocated the use of local materials, as this reduced transportation costs, in comparison to the cost of using less regional materials: today this would include fuel use. In 1939, at the New York World’s Fair, Ford unveiled his soybean protein fibre, which could be locally grown and produced, unlike cotton, that needed to be transported across a long distance (Boyer, 1942, pp. 2-3, in Wik, 1972, pp. 150-151). Though there are universal aesthetics in automotive brands, there is some local sourcing and variation to account for cultural differences.

Khan, Pitts and Williams (2016) investigates the cultural values and individual preferences of automotive users for human machine interface design features and functionalities. They studied UK and Indian users and found that there were different expectations between the groups that suggested that culture has an influence on the perception of vehicle user interface technology. In conclusion they note that an understanding of cultural bias can affect design localisation and support development strategies (p. 45). They suggest that the automotive manufacturers focus, in the main, on Western preferences: however, as they seek to expand their markets into new regions they need to consider the role of culture in relation to their customers and how that affects their choices, perceptions and attitudes to user interfaces in a vehicle, which would contribute to improving design localisation (p. 46). Da Silveira, Fogliatto and Fendyur (2013) suggest that mass customisation is a growing phenomenon that has grown from a niche competitive approach towards becoming a widely adopted strategy. This is in part due to consumer needs and the growing range of methods and technologies that can support diversity cost effectively. This growing trend can be seen in fashion products and in areas of the automotive industry, where customers can personalise or even contribute to the design of their products. Such an approach could support cultural preferences and shift the trend from global designing in the mainstream automotive sector, potentially making it easier for the industry to accept local sourcing along with localised design variation.

Reflections on my processes

By visiting materials-focused trade fairs I gathered what I perceived to be appropriate materials at the time. This allowed me to experience a wide range of products at first hand: to touch them, gain information about them from the supplier or manufacturer and to request samples of them. In conjunction I was able to establish a connection with the provider or representative through conversations about their material. This also gave me the opportunity to discuss my project with them and the suitability of their material in relation to my intentions. Attending automotive and aircraft interiors trade fairs also demonstrated what trends were developing in these industries and how they were engaging with material innovation with regard to sustainable objectives in their prototypes and commercial vehicles. This was a way of trying to frame the problem and solution with tangible materials and information.
Following the delivery of the Fiesta a meeting was held with the Colour and Trim designers and a member of the Product Development Group at Ford in Dunton on 17 May 2010 to discuss the project. Three outcomes resulted from the meeting.

- To realise the concepts as close to industry standards as possible by working with manufacturers.
- The opportunity to visit the Materials Testing Lab at Dunton.
- Practical support with, and ideas exchange for, the project.

The limitations of what I could produce within the RCA facilities, in conjunction with my discussions at Ford, encouraged my commitment to working with industrial manufacturers and suppliers where possible. This, I felt, would demonstrate the concepts of material use in a ‘real world’ scenario. My rationale was to make the project credible to the automotive industry, endorsing the validity of my ideas beyond the context of a ‘student’ project.

Action research

Throughout the materials research and assessment phases I continued with small-scale experiments in the studio. This action research helped to further frame the research questions within the parameters of craft-based manipulation.

By setting the way in which materials would be disposed of, which I established through background reading and research, the projects began to emerge as potential solutions in relation to the automotive interior. Focusing in this way was also influenced by the meeting I had with Guilford Textiles. From this meeting with a key industrial supplier of automotive textiles I realised that in order to work with a manufacturer (as discussed at Ford) I had to work within their systems and with their capabilities. This in turn set up a chain of events, processes and procedures that deconstructed the concept of the textile into its component parts, these being material origin, followed by fibre, yarn and woven finished textile. The next stage involved negotiating with one of Guilford's yarn suppliers, which meant working within a different system, set of procedures, people, places and resources.

On reflection I now understand that my decision to commit early to working with Guilford was the way I could explore the problem and solution within the parameters I had, at the time, loosely set.

The 'Mono' project started when I connected with Guilford to produce a surface textile, which was quickly established following meetings and my discussions with the design and technical team. Managing the project involved interacting with a chain of suppliers and working within their capabilities, which framed the project. Working within the industry, and specifically with individuals employed at Guilford, allowed me to draw on their respective expertise to execute each aspect of the project, which involved fibre, yarn construction, digital design translation to weave software, fabric construction, actual weaving, finishing and adhering to the spacer fabric. I was actively involved in each stage of this process, making decisions and, for example, learning the weave software programme to enable me to translate my designs into woven textiles.

I felt that this collaboration ensured that the results would be successful in terms of replicating a surface textile and supporting foam using one synthetic material derived from waste that can be recycled.

Problem framing

Early in the research I committed to remaking interior parts of a Fiesta vehicle at full scale, using materials that were sustainable. On reflection this illustrates that, at that time, I was looking at the surface, styling and visible components of the vehicle. The way in which I looked at the problem shifted as the research developed. I realised that in building ideas from the materials as a basis to explore sustainability, and by attempting to apply these ideas directly to existing aspects of the vehicle, I was jumping ahead. On reflection I recognise that I was attempting to build bridges between my materials research and development in conjunction with solutions for automotive interiors. Cross (2001, pp. 89-90), describes this process as a way to consider and connect the problem and solution spaces, which Schön identified as 'problem setting'.

Reflecting on my process I recognise that it was iterative: in managing the three main projects at intermittent parallels I continuously appraised each in relation to the other at every stage. As I imagined the practical work would be incorporated into the Fiesta interior they had to visually relate to each other, which I achieved through colour and pattern. As the exterior was blue I worked in a monochromatic palette of various blues in order to visually link the separate parts when they were installed in the Fiesta: I was not intending to replicate the full interior.

In my research and practice I was fully engaged in the process of experimenting with different material configurations and developing scenarios, which I envisaged could be applied to the Fiesta interior. However, I found it difficult to relate the work I was creating and the development of my ideas in connection to the Fiesta. This problem in positioning the practical work I was making myself and with industry to create made it difficult to justify having the Fiesta installed in the lab at Imperial College: as there was no evidence of progression with the Fiesta. I needed to be offsite to work with industry to create the textiles and the parts: I needed expert help with the tasks I had taken on.

A slow realisation of creative understanding was when I fully embraced the fact that the real crux of my research and practice was in the parts or elements I was making that could be applied to a vehicle interior: the detailed unpicking of each part and remaking of it using a sustainable matrix of materials. These parts that I was making, albeit in tandem with each other, would not work coherently if fitted into the Fiesta interior. This raised the following question: how could the work be assessed if it was fitted inside the interior of the car? This developed into further questions, as follows:

- If the user was seated inside on the seat made from sustainable materials, how could the other parts be viewed and assessed?
- If I succeeded in replicating parts to match existing standards for automotive interiors, what would be the distinction in user experience and awareness of the shift in material use?
- The interior would not demonstrate a coherent design aesthetic.
- Central to the practice were materials, and their visibility would be hidden from view or examination, particularly in the seat concepts.

At my re-entry exam in 2013[70] I exhibited an array of materials, textiles and parts I had completed. The examiners raised the question of how, if they were fitted to the interior of the Fiesta, would the examiners be able to view the work as a whole? The work/ artefacts they considered were stronger standing alone. This resulted in a significant shift in my perception of what I was doing in my research: it resonated with me and felt appropriate to the way the work was evolving. In fact, it was liberating: the journey I had taken in negotiating the Fiesta, its delivery to Imperial, and space in the IDEA Lab[71] at Imperial, arranging for it to be installed and lifted to the first-floor space there was followed by competing with other users for space to work and the logistics involved in taking apart the Fiesta interior, which, when combined, created a complex set of parameters and spaces within which I was operating.
I can now understand that my doctoral work would have been very different if I not negotiated and worked with these spaces of exploration. In fact, my continual questioning of myself that I was not approaching my research or working in the 'correct' way caused constant uncertainty. This was exemplified when I had to justify the bio-resin panels I had made remaining in their original state and existing with imperfections: the company I was working with to fit the panels had, through experience, an expectation of uniformity in appearance, pure surface and no imperfections. The outer panel was broken at this meeting, which seemed to confirm their scepticism of the material I had used: it was an uncomfortable point for me.

The main theme in my research methods is that the problem, solution and question developed from my engagement with the practice. Committing early to partial solution or solution conjectures allowed me to explore the problem and solution spaces simultaneously. What I thought I was doing changed through the emerging process of design. As the work evolved I recognised that what I had initially perceived as my design brief was not fixed because the work changed my thinking

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70 This followed a period of absence due to breaking my arm.

71 IDEA Lab – Innovation Design Engineering Lab. This was instigated and arranged in principle by Dr Paul Ewing with Professor Miles Pennington.

about what the brief should be. This connects with Cross's idea of bridge-building between problem and solution: the problem and solution developing together as the understanding of the task deepens. The problem is framed by this cyclical process and iterative way of working. Having an iterative 'conversation' with the things I made and reflecting on them helped to connect and evaluate my thought processes and the things I had made. My thought processes and actions were adaptive as the work, thinking and evaluation developed.

Evaluation and reflection on my practice was done through laying out the samples and grouping them, which enabled me to see connections and themes emerging in the work. This was followed by mapping them out, assessing them, which facilitated decisions on further action. The work was an external representation of my thought processes. These 'conversations' with the work I had made allowed me to communicate my ideas not only to myself but also to others. In turn this encouraged verbal exchanges and new ideas and approaches in order to develop the practice further.

I now recognise that the experiments and the problems associated with applying these to the existing Fiesta interior form were directing me to conclude that a new form language from the materials upwards could provide the innovation and communicate the sustainable use of materials implicitly. My understanding of the complexity of the problems developed as I began to take apart the existing interior parts of the Fiesta, along with sampling and material gathering.

Craft making and industrial manufacturing

The main projects were conducted in two distinct ways, through craft processes and industrial manufacturing. Hand-making allowed me to explore the use of materials that are not currently used in automotive parts production, whilst working with industrial textile processes and adapting them to incorporate waste, or, separately, renewable materials, meant I could achieve volume production and, in the case of the 'Mono' project, match industry standards as closely as possible.

By working with industrial manufacturers, and in attempting to (such as with Faurecia whom I approached to trial the bio-resin, described in Chapter 7) I experienced at first hand the systems that are in place and learnt that through changing one element within these will affect the entire supply chain. This has been a key point of understanding in my research: that in trying to use materials that are considered more sustainable within existing industrial systems, with their capabilities, their expectations of performance and their required uniformity of product, I could only introduce materials that are as close as possible to those already used, as in the 'Mono' project. This risks losing a key potential benefit of craft-based working, the ability to innovate beyond current constraints.

The act of replacing the surface textile, for example, had no relevant impact by itself: I realised that the whole part needed to be considered, each element in relation to the next component. Similarly, in replacing the inner door panel fascia with the bio-resin panel did not take into consideration the complete set of materials necessary for the door to function. In effect, working from the material itself and applying it to an existing interior part exposed the necessity of redesigning the whole with a different set of criteria*. My original objective changed fundamentally during the course of the research*: if sustainable materials and processes cannot be used in the same ways as those currently in use, then the manufacturers' and consumers' expectations will need to be altered to accept a different visual identity for the product.

Identifiable changes in my thinking through the duration of the project were brought about by an awareness of the following:

- The impact of changing one material element on the product.
- The impact that changing a material has on established manufacturing, production and supply systems.
- How the total material content of the whole part needs to be considered to include the hidden under-skin materials.
- How expectations on the visual uniformity of the product influence the material used in the product.
- The importance of prototyping to scale.

Solution and question developing together

Prior to the main projects I produced a range of woven textiles samples and small experiments encasing these in various resins. They established a communication or conversation about the capabilities of the materials I was using, primarily with myself. Alongside these practical trials I was continuously exploring and researching available materials, amassing samples and making connections with suppliers. However, there were restrictions on what I could achieve and further develop with the facilities available.

This led to my realisation that the resources I had available, in terms of materials and equipment, were not sufficient to produce technically advanced and controllable results. What I could do was experiment, and through craft processes I could communicate a sense of my ideas through the evidence of the samples. It was a highly creative point at which the experimentation was not directed to a fixed solution. I was 'sketching' or 'model-making' by creating a representation of a form of the material that I could then manipulate. This can be described as a way of understanding the parameters of the materials themselves: a method of scoping for possibilities with loosely defined criteria in respect of performance, application, feasibility, scale, product and viability. The outputs or results were continually appraised within a shifting understanding of criteria regarding their potential application to automotive interiors in a sustainable way.

Seitamaa-Hakkarainen and Hakkarainen (2001, p. 63), in their study of the differences in approach to weaving design processes between beginners and experts, conclude that the experts were able to work in parallel with the visual and technical aspects of the task, whereas the beginners tended to focus on the visual. I find that there can be a tension between the two areas, one pulling the other, informing the direction of the work, the decorative or visual element being only one aspect of the design process.

In reference to Cross's (2001, p. 82) suggestion that designers are solution-led, rather than problem-led, I find in my own practice that through making and sketching I am able to locate a space that surrounds or embodies elements or aspects that are partial solutions. These external representations, which are tangible forms of my ideas, suggest further practical experimentation. Laying the samples/experiments out allows me to make connections between them, which I can then group or edit out. Cross (2001, pp. 83-84) discusses how 'early solution focusing' gives designers the space to search and describe the problem and solution together, one aiding the understanding of the other. In my practice, sourcing and acquiring material samples is a way that I scope for possibilities within a loosely defined problem space. They act as early partial solutions that can then be manipulated, combined or made into experiments that can further inform potential answers. This process is a way in which I am mapping my ideas or process of thinking, which becomes a way of communication, not only to myself but others, too. These external representations or tangible manifestations of my concepts and thought processes provide evidence of the journey and demonstrate the multi-faceted approach that I adopt. In addition they allow me to visualise the wider picture of potential outcomes as a whole, and 'reflect in action' through iterative evaluation of the materials, processes and samples (Figures 40 and 41).

Figure 40: Laying out the work, a.
Sheila Clark, 2014.

Figure 41: Laying out the work, b.
Sheila Clark, 2014.

The relationship between making and thinking and limitations of the research process

As a designer/maker I use the making of my work as a form of ‘sketching’ and communicating my ideas: mostly to myself through the process, and to others through the work I create. It is a way of evidencing my thinking. The practical work was made using craft procedures and industrial manufacturing, which each have limitations (Figure 42). Early in the research I used craft processes to make small-scale samples, a method of evaluating the materials I had gathered. However, I continued to make the bio-resin parts (the glove box lid and inner door panel) by hand, which demonstrates the limitations of the process and material (discussed in Chapter 7).

Figure 42 : Scarf deco fabric from project Mono and door panel partially seen from project Renewable Compostable Composites; showing craft and industrial processes.
Sheila Clark, 2014.

The nature of the PhD and its distinction from 'normal' designing

The distinction between designing and designing-as-research has been my growth in knowledge, which has evolved through unpicking my processes, the related systems and the rationale of my choices. As a sole designer and researcher I have come to a better understanding that there is a continual shift in the perception of sustainability. In addition, that established systems are able to adapt to some degree and move towards the accommodation of sustainable production. But changing one part of a complex collection of components within a vehicle is insufficient: the whole needs to be considered.

Throughout my research - making the practical work, linking with industry and reading the literature - I have found that I committed to practical solutions early. This became a platform that then raised issues and questions that I would not otherwise have anticipated. Committing to a material, plan and system of manufacture (industrial) or method of making (craft) I set in process a chain of events that formed an arena for the exploration of the deeper issues regarding the complexity of sustainable design and manufacturing. This was particularly true in relation to my material choices, which had an impact on issues of sustainability, whether they were from renewable or recycled sources. By uncovering details beyond product marketing I realise that what on the surface may appear to be 'sustainable' may not be so at a deeper level.

Positioning my research in line with Archer's triad (1995, p. 11)**:**

As discussed in Chapter 2 Archer established a triad in his understanding of the probable relationships between research and practice: research 'about, 'for the purposes of' and 'through' practice.

Research for the purposes of practice – I had to find out a lot about materials, manufacturing and contexts of sustainability, such as a circular economy, in order to do my designing. I also had to find out about existing systems of materials supply, manufacturing and end-of-life treatments to understand how my practice could be positioned in the "real world". I designed, made with craft processes and industrial manufacturing in order to understand the problems I was dealing with. In addition I had conversations and interactions with industry and materials manufacturers and suppliers. This research was supported by reading academic and grey literature.

Research through practice – My designing was exploratory research, which enabled me to think more clearly about the issues, materials, techniques, technical considerations, aesthetics, and their relationship to each other. This was an example of Schön's 'reflection in action' and 'reflection on action'. It also gave me objects which could be the focus of a dialogue with others as well as evidencing my thought processes. Ednie-Brown (2017, pp.135-136) discusses the years during her PhD that she spent looping around something that could not be put into words. Finally, she realised that the critical action was 'in the doing' of the creative projects. Nevertheless I hope this thesis document demonstrates that, in addition to the practice, I have also been able to produce 'insights effectively shared' (Research Excellence Framework, 2017, p. 4).

Research about practice - There are limitations of one-off, craft designing but it can be a powerful means of early stage exploration and possible proof of concept, in relation to material designing for mass-produced industrial purposes. It has been helpful in giving me a better understanding of the context of my work and, through unpicking my thought processes and actions, to consider the relationship between these and industrial manufacturing processes. Aligning my thinking with academic research and sustainable theories provided a platform for the artefacts and prototypes I had produced.

Through doing the work as part of a PhD I have retrospectively gained some insights into how tackling big problems like sustainability turns out to be like a design problem. I have come to better understand the nature of design problems too.

I now see that a small intervention may have big implications and that any conclusions about the small intervention have to also take into account the wider picture. Similarly, the difficulty of altering one thing, without it having repercussions or a knock-on-effect, which is a classic 'wicked problem' phenomenon.

In a "real world' scenario, the reframing and rewriting of the design or research question can be problematic for project management, budgeting and designer-client relations. One of the valuable freedoms of the academic PhD is to be able to radically reorient the question without these consequences happening or being so critical.

Development and realisation of the main aims:

As the research was conducted over a decade it developed through a period of continuously shifting understanding of what sustainable materials could be in the context of large-scale industrial manufacturing. Throughout the project I became aware that all materials have some impact on the environment, especially when they are produced for high-volume demand. Additionally, the complexity of interlinked materials in a vehicle has a huge impact on the end of life recovery of them. Through the research and industry conversations I realised that existing systems need to be changed in order to provide an integrated view of the whole cycle of materials and products as well as considering the influence of all stakeholders. My thinking changed from the idea of using sustainable materials to compete with other less sustainable options on a like-for-like basis, towards instead considering the issues systemically, including alternative aesthetics that can accept non-uniform, subtly changing materials.

My original contributions to knowledge are:

- The artefacts themselves and the material combinations used to create them: textile solutions, formed rigid surface concepts, door panel, suggested seat foam and the glove box lid.
- Adjusting or adapting existing manufacturing systems to create some of the prototypes.
- Working with companies to close the gap between my research and sustainable manufacturing.
- Demonstration, through my practice and associated research, that the 'aesthetic' aspects of sustainable design cannot be neatly separated from the technical issues of manufacturing and the systems within which they operate.

Key points for future designing

Through my research I have become aware that designers need to be aware of and consider the whole set of systems that surround the product they are designing. This involves an understanding and consideration of whole systems when starting from a materials-first perspective. The form language of the materials to be used in any given product needs to be considered throughout the design process, not just in the styling.

Education is needed for early-stage design students on the biological and technical cycles and the need to establish the systems necessary for a circular economy. This view is echoed throughout the work of key authors on sustainable design, such as, Andrews (2015), Charnley (2015), Moreno et al. (2016). In the future I will think more before I make, research the material fully and dig deeper into the chain of events that enable the availability of a material, beyond the suppliers marketing.

Future research recommendations

Follow on work from this research that I would like to investigate, five areas:

- I would like to further develop my work with renewable, plant-sourced and waste materials. Initially, I would like to visit The Henry Ford Museum in Dearborn, Michigan, to explore the archives of Ford's renewable materials and agricultural waste experiments and developments. This would be from a design perspective with a view to further exploring and developing materials for automotive interior applications.
- Something that I am interested in but did not have the space to explore in this research is biomimicry, which is one aspect of a circular economy. Kolko (2017) identifies biomimicry, or 'bionics', as one of the form language 'movements'. He describes it as studying nature and then taking inspiration from it, in relation not only to form but also to a systems approach and complex problem solving through evolution. Benyus (1997) defines it in three ways: nature as model, nature as measure and nature as mentor.

- I am considering applying for a Leverhulme Early Career Fellowship to fund the next stage of my research. This would be to further explore renewable materials and waste for automotive applications. And to investigate biomimicry in relation to such material usage and systems of use.

- I would also like to further explore the potential for using Biotex in combination with my renewable textiles as interior panel solutions. This would be in collaboration with Composites Evolution and Camira.

- I would also like to work within the automotive sector developing sustainable vehicles from a materials perspective, developing new form language for the automobile for future mobility.

To follow on from this research there are six areas that I suggest for investigation by others:

- First, it would be an interesting challenge for vehicle designers and manufacturers to design a new vehicle in which the best use of sustainable materials are considered: this would be by designing the interior surfaces and products to better accommodate the materials capabilities. This could result in a shift towards a change in the architecture of the car. My research has shown that redesigning components is not enough. Projects such as Lotus's Eco Elise, Fiat Brazil's Uno Ecology and Morgan's LIFEcar have explored sustainability, but only within existing expectations of vehicle forms and surfaces. Is it conceivable that the automotive industry and their customers could accept a different aesthetic within the car that visually demonstrates that the materials are sustainable? I believe this could be further investigated as new digital technologies and MaaS direct the next generation of vehicles.

- Second, for vehicle designers and automotive manufacturers to consider the materials within the interior components at the design stage, so that they can be easily disassembled to facilitate their optimum recovery: this would be in either biological or technical streams, as a circular economy advocates. In doing this they would be designing from a 'materials first' approach with awareness of how the materials will be ultimately recovered from the industrial product they have designed.

- Third, for designers and manufacturers to consider local or regional sources of materials for their products. This would take into consideration cultural differences in aesthetics and consumer preferences. Such practice would also distribute the provision of materials and spread the related economy.

- Fourth, to facilitate designer's sustainable material choices; a method to provide transparency of the whole material cycle, from source to end-of-life treatments, needs to be established. This could be provided either from material suppliers and their manufacturers or in the form of an impartial online database. Work has recently begun at the Royal College of Art on Web of Materials, a project that aims to address these questions.

- Fifth, in order to support the development of a circular economy, systems and facilities need to be in place to enable to optimum recovery of materials for reuse, recycling and industrial composting.

- Sixth, that design students are educated in the systems that a move towards a circular economy involves, and how this impacts on their material choices within their designing.

Glossary

Air jet	High pressured air
Air texturising	Several flat individual continuous filament yarns (often partially orientated) are arranged in a creel and run together in the path of an air jet which distorts and intermingles the filaments 'locking' them in place.
Aldehyde	An organic compound
Cellulose	A highly crystalline macromolecule of D-glucose, containing three hydroxyl group that gives natural fibres their hydrophilic characteristic
Colourway	A range of combinations of colours in a design
Count system for yarns	Weight per unit length, which indicates the diameter of the thread
Cushion	Seat bottom
Design repeat	Design that repeats regularly in sequence to make an overall design
Decitex (dtex)	Weight in grams of 10,000m of yarn
DXF file	CAD data file for enabling data interoperability between AutoCAD and other programmes: it stands for Drawing Interchange Format or Drawing Exchange Format
False twist	Twisting of filaments in a continuous multifilament thermoplastic yarn, this is thermally fixed and then untwisted at a lower temperature. The individual filaments due to their heat memory try to assume the twisted dimension, which bulks the yarn.

Filament	Continuous strand of fibre
Finishing	Processes used after weaving to complete the cloth to the necessary requirements, such as scouring, pressing, stentering, brushing, foam lamination and heat stabilising
Footings	Each pick of warp and weft of a woven textile design. If they are not harmonious at the edge or curve of a shape within a design, it will result in floats and less graphic edges to the shapes in the fabric.
Glycolysis	High temperature activates polyurethane into a chemical reaction forming new polyols: these are used to make polyurethanes
Hopsack	Two threads in the warp are visible as two weft threads are visible,
Hydrogenation	Creates gas and oils through heat, pressure and hydrogen
Hydrolysis	Polyols and intermediate chemicals created by reaction of polyurethanes and water
Mace snag tester	A mace snag tester is comprised of metal spheres with protruding conical spikes
Martindale test	Abrasion resistance test
Matrix material	A substance which binds fibre reinforcement in a composite material
Micron	Micrometer, one millionth of a metre is used to measure the diameter of an individual wool fibre
Moquette	A woven pile fabric

New metric (nm)	Yarn count system, which refers to the thickness in diameter of a yarn and indicates the number of kilometres per kilogramme.
Package	A cone or tube on which yarn is wound
Partially orientated yarn	A stage in the process of making synthetic yarn where the fibres are stretched to orientate the molecules
Pre-preg	Fabric that has been pre-impregnated with resin, meaning that it can be placed into a mould without the addition of further resin
Pick	One single weft thread
Pyrolysis	Thermo-chemically separates polyurethane in oxygen free conditions making gas and oils
Redesign	Design again or differently
Retting	Soaking or technically ‘rotting’ plant fibres causing natural chemicals to break down the pectins that keep the stem intact thereby facilitating the release of the fibres
Satin weave	Weave structure in which the weft yarns float for four or five picks over the warp threads
Scotweave	CAD system that allows design to be put into repeat, and applies weave structures, colour and yarn characteristics to enable a realistic simulation of the final fabric prior to weaving
Scouring	Process to remove the majority of impurities from a fleece
Scutch(ing)	Prepare fibrous material, especially retted flax, by beating, crushing or scraping

Selvedge	Edge of woven cloth to prevent it unravelling (usually discarded in industrial contexts)
Spacer fabric	Double needle bar warp knitted fabric
Squab	Seat back
Stentering	Final finishing process that imparts to a fabric dimensional stability and the correct degree of stretch
Tier One supplier	Top of the chain supplier to the automotive industry, supplying completed parts ready to be fitted to vehicles
Tier Two supplier	Supplies components to the Tier One suppliers
Twill	A weave structure in which diagonal parallel ridges are visible in the fabric, the warp threads stretch over and under two or more weft threads

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