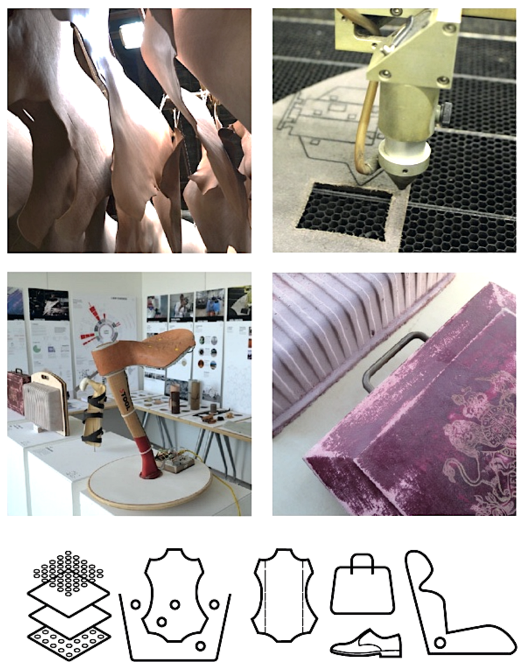
Leather Futures

How leather can be used as a sustainable material

of choice for the future



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Copyright statement

Abstract

The purpose of this research by practice determines how leather can be used as a sustainable material of choice for the future. Using a design-led methodology, this research develops knowledge for guidelines for the sustainable practice in this traditional industry, in order to make leather a material of choice for sustainable future consumer experiences and manufacturing. This investigation updates and re-evaluates old practices of handling leather and presents modern practices using alternative tanning methods, digital manufacturing and upcycling leather wastes into bonded collagenic fibres which address the end-of-life directive in the automotive industry. Finding knowledge gaps through the literature review, this research proposes leather as an eco-informed material choice (Ashby 2009) and it introduces new practices to the catalogue of working with leather (Waterer 1946; Amberg 2018).

Leather has a future; it is still a material of choice for high-end design applications including vehicle interiors, upholstery and luxury products. It has unique properties including particularly that of aging gracefully and longevity. It can be soft and luxurious, yet tough enough for self-supporting structures. There is a huge quantity of animal skins and leather produced every year across the world. A rational use of resources suggests that there are considerable environmental benefits by using this material efficiently. This study proposes new ways to use leather which otherwise goes to waste. This includes new systems that I have devised to use leather waste and offcuts, which currently are discarded into landfill or are being incinerated.

My methods address the future of leather by undertaking detailed observations of practice through fieldwork in the UK, Italy and Japan. Also, by prototyping circular practices using leather through hands-on investigation in a design laboratory and tannery environment.

My findings identified collaborative communities which were drawn out in three areas: an actor network map, a leather processing diagram with closed loops and an atlas of locations of leather making. I produced a framework and an accompanying glossary to inform future practice with leather, including composite fabrication and digital manufacturing. In the practice part of this research, several artefacts have been created, demonstrating a potential process for undertaking 'circular' product design. A body of findings resulting from this research were categorised and presented in guidelines aimed at supporting future practice. Physical leather samples and upcycled

composite materials from leather shaving waste tested the validity of the guidelines. Here, the studies demonstrate circular systems for production and reclaiming production by-products, through experiment and prototyping.

An outcome of this research highlights the relevance of leather as a material for the circular economy – this is communicated through a handbook that illustrates terms and processes, which it is hoped will inspire makers and users.

The value of this research for design practice is in its exploration of sustainable manufacturing methods and uses of leather, exemplified by providing samples, as well as the creation of the illustrated handbook. For the academic community, its consideration lies in developing design and reframing the position of leather and its by-products in the circular economy, which unlocks value from the reuse, repair, remanufacture, retrieval and recycling of materials and products.

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Author's Declarations

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.

Friedemann Schaber May 2022

Definitions

BLC	British Leather Confederation, more recently Eurofins BLC
CAD	Computer-aided design
CEO	Chief executive officer
COTANCE	Confederation of National Associations of Tanners and Dressers of the European Community
FAO	Food and Agriculture Organisation of the United Nations
FILK	Forschungsinstitut für Leder und Kunststoffbahnen
ICLT	Institute for Creative Leather Technologies
ILM	International Leather Maker
ICS	Intelligent Connected Smart Materials
IULTCS	International Union of Leather Technologists and Chemists Societies
IOM3	Institute of Materials, Minerals and Mining
LCA	Life-cycle assessment
LWG	Leather Working Group
SATRA	British Boot, Shoe and Allied Trades Research Association
SEM	Scanning Electron Microscope
SDG	Sustainable Development Goals
SLTC	Society for Leather Technologists and Chemists
PLA	Polylactic acid
PU	Polyurethane

PVA	Polyvinyl acetate
UK	United Kingdom
UNIC	Concerie Italiane, Italian Tanners' Association
UNIDO	United Nations Industrial Development Organization

Chapter 1

Introduction

1.1 Background and Motivation

Leather is a natural, sustainable material. When properly sourced and made, it has unique properties. This research sets out to explore – through observations and making – innovative uses of leather.

The East Midlands of England makes up an industrial region with a long tradition of leather processing and the making of footwear. This has provided a supportive environment to undertake the prototyping of the artefacts developed in the course of this work, which will showcase new possibilities.

At the same time, the research interrogates the transfer of knowledge within the communities of practice associated with particular types of leather. Leather comes in many forms, and as such, has a huge range of properties including strength, flexibility and finishes. These properties depend on the type of animal and the many ways of tanning and preparing it, which have developed throughout history and which continue to evolve.

This work probes the interplay between craft traditions and innovation, and demonstrates processes of bringing a new product to market. Working closely with a cluster of leather manufacturers, the research aims to shed light on the contribution of design and networks of practitioners to give a future to the British leather industry and prospective practitioners. My motivation also includes the ambition to make better use of waste leather material.

1.2 The Aims and Objectives

The first aim of the thesis is to develop a systematic and contextual study of leather material. Its application and intersection with the automotive industry are examined through case studies and practice exploration. The second aim is to present future design capabilities for leather within the circular economy. It does this by referring to the potential of upcycling and recycling, identifying the gaps in understanding, and by studying and evaluating the technology of leather making.

The objectives are grouped in the three following themes that relate to:

Circularity;

Sustainable future materials,

Manufacturing and use.

Manufacturing has been investigated by reviewing leather craft and the processing of the leather in an artisan and industrial scale. Locations of leather manufacturing were surveyed through visits to understand the supply chain that Northampton and Walsall-based leather goods manufacturers depend on.

Prototypes were made that utilise recent technologies and digital manufacturing techniques such as laser cutting. Also, some techniques of textile and paper making were adopted with the objective of applying these techniques to leather making. These include forming, laminating, upcycling and sandblasting.

To understand the social and cultural history of the material use, a rich repository of artefacts has been found and interrogated in collections. The artefacts tell us how leather has been widely used for body protection, including clothing and footwear, and for transport through many applications. However, leather has gradually been replaced with rubber polymers, which are derived from fossil fuels and are of environmental concern.

The objectives of my research are as follows:

- To understand future use by exploring current and future trends. Focussing on product, automotive and interior design;
- To examine the creative use of the leather by looking at the broader cultural context of leather making in Italy and Japan in comparison to the UK;
- To understand the perception of leather alternatives such as natural fibres and vegan leather imitations;

- To explore new ways to use low grade leathers and waste leather fibres and off-cuts;
- To investigate the potential for recycling, for example, by shredding and reforming offcuts and waste from leathergoods manufacture.

1.3 Research Question

My main research question asks, “How can leather be used as a sustainable material of choice for the future?” Important sub-questions are how can design thinking create an impact and make an ageing industry like leather relevant once more? Following Nidderer’s (2016) concept of Experiential Knowledge, this research investigates how emerging technologies will affect practices from the designer and the user perspective. This led me to experiment with digital techniques, composite fabrication and alternative methods of tanning.

The key questions explored here are: can leathers be produced to respond to increasing or changing usage? Is there a future for leather in the circular economy? What can the leather industry do to avoid becoming just another good that can easily be substituted, such as a textile with other fabrics? As for sustainable communities working with leather, can we empower communities through ‘making’ and participating in the leather value chain? The research illustrates the need for the UK to exploit its creative capabilities – as identified by The Cox Review of Creativity in Business (2005). There is a lack of interrogation of how emerging technology affects leather practices from the perspective of designer and the user.

1.4 Interconnected Thematic Issues

One of the key perspectives is sustainability. I argue that it is an eco-informed material choice, as leather comes from a renewable natural fibre, which mankind has worked with for millennia. One should also bear in mind that, on current projections, animal husbandry and meat consumption will continue around the world for a very long time. This implies that large quantities of skin suitable for leather production will continue to be produced globally and a rational use of resources argues that this should be used efficiently. Leather products are generally long-lived, but one should note that if skins are not utilised, the waste will rot or decay, producing, carbon dioxide and other pollutants.

This relates to the theory of the Circular Economy and innovation for sustainable development. The process of Design Thinking and some of the associated concepts, such as collaboration, visualisation and an emphasis on creative research tools, have been used during the creative exploration of leather.

Over the course of developing my key perspective, I found it helpful to draw information from literature, exhibitions, presentations in congress, workshops and so forth. In addition to the concepts relating to the *circular economy*, I noted that there is a lively discourse about new materials in design, the experiences that people have with, and through, the materials of a product and the fundamentals of materials. However, there was not much informed debate on leather design. I also realised that leather is a complex material with many issues, but with unique aesthetics and performance properties that – when responsibly processed – will positively address changing user demand, and the growing concern for leather's sustainability credentials.

So, this leads me on to the question of tanning – the treatment by which raw animal skins are converted into stable and durable leathers. A major effect of tanning is to cause the natural fibres to chemically cross-link and form stable bonds. The protein collagen is the major component of these fibres within skin. Various tanning substances can be used in the form of plant based tannins, synthetic chemicals and metal salts. Most commonly used is a solution of chromium sulphate, which was found to offer a fast and versatile tanning reaction. However, these tanning agents have been frequently held responsible for the negative environmental impact of leather production alongside other chemicals, in the form of effluent. There is the legacy of previously used forms of toxic chromium salts in a hexavalent form, or Cr(VI). The scientific discourse points out that the environmental impact of chromium salts nowadays used in the form of chromium three Cr(III) is low and can be managed efficiently (Covington 2020: 599). However, the removal of chromium from tanning waste remains complex and it hinders biodegradation, for example, the composting of shoes. In the automotive industry, a replacement of chrome tanning methods has taken place. Of note here are the 'wet white' and 'wet green' tanning technologies. These leather innovations and their relation to my own material explorations/artefacts are discussed in a comparative table in Chapter 5. There is a wide interest to explore alternative tanning technologies and to consider biodegradability with an emphasis on ecologically friendly processes. Traditional vegetable tanning agents exist and have been used for centuries. Extracts from distilled natural and plant based phenolic tannins are products of the biosphere and they suit the model of the *circular economy*. Part of my work has been to identify design applications of new or rediscovered replacement vegetable tanning agents from plant matter, which can be recovered from other processes. These new agents have the dual benefit of both reducing the environmental impact of tanning and of making use of waste streams from other industries. My examples are from forestry, farming and the beverage industry in the form of tree bark, spent tea, coffee ground, cider apple pulp and hop. In addition, they can create new types of leather with different and attractive properties, when used in conjunction with other tanning methods, as retannins.

More specific areas of tanning are covered in the glossary (Appendix II), i.e. alternative tannages, chrome tanning, olive tannage, vegetable tanning, wet white or synthetic tanning, titanium tannage and aluminium tannage.

The focus of my practice and writing has been on re-defining leather, considering environmental social and technical contexts. I will argue that leather has a future if we enhance its inherent sustainable properties, develop the communities that work with the material, and apply new technologies. As guidance, leather has been defined [British Standards Institution 2015] as: Hide or skin with its original fibrous structure more or less intact, tanned to be imputrescible. The hair or wool may or may not have been removed. It is also made from a hide or skin that has been split into layers or segmented either before or after tanning.

1.5 Structure of Thesis

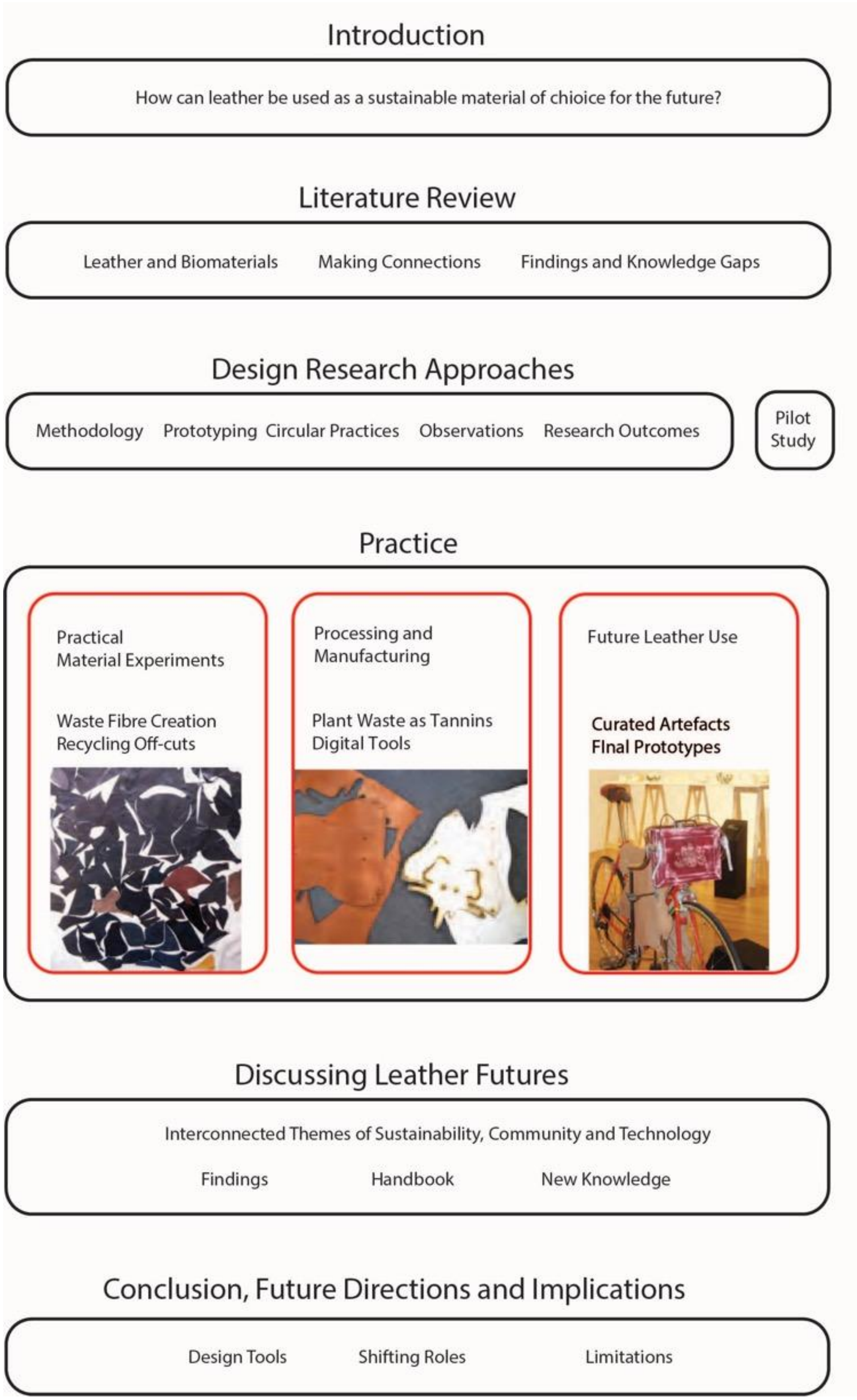


Figure 1.1 Illustrating the Structure of Thesis.

1.6 Structure of Practice Component

This section is presented in a thematic order [Figure 1.2]. It consists of three parts:

Firstly, practical materials experiments; this includes the creation of bonded fibres from leather waste, also recycling of leather off-cuts, furthermore trials to achieve deep 3D relief effects.

Figure 1.2 Illustrating the Structure of the Practice Component.

The second part is sustainable processing and manufacturing, explored were plant waste as tannins. Also, digital tools for fabrication.

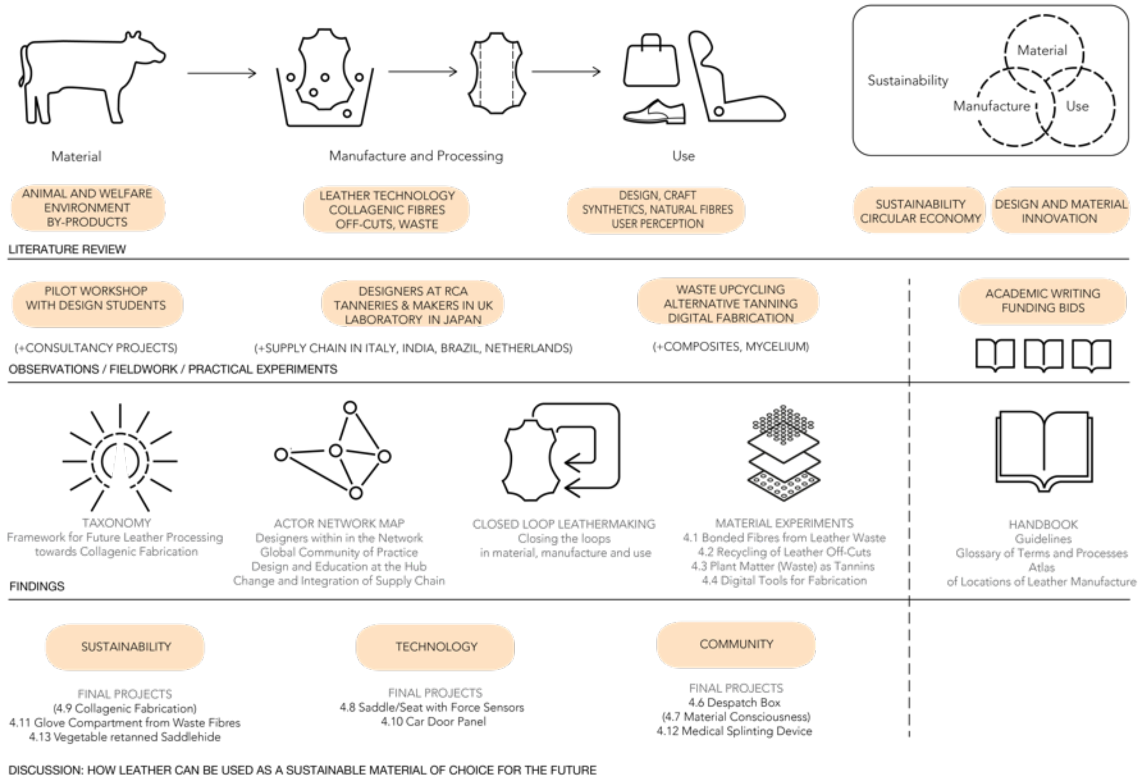


Figure 1.3 Illustrating the Interconnected Structure of the Thesis and Practice Components.

The final section on sustainable future leather use presents final projects.

Artefacts made from leather and collagenic fibres developed in practice, which led to a curated display of artefacts as part of my practice. These include experiments, swatch books, models and prototypes. There are also handbooks, tableaus and photographic output. The experiments that were unsuccessful have also been recorded.

The items for the design briefs have been specifically selected to interrogate how the material, manufacture and use of leather can be innovated under the headings of sustainability and the circular economy. Each of the projects were positioned strategically within the framework of the sustainable development goals in terms of its triple bottom line. The projects utilising the wastes aimed to highlight the sustainable development, sustainable production, and consumption.

The projects address different needs that respond to the UN Sustainable Development Goals, including that of sustainable manufacture and consumption. Firstly, the creation of products from bonded fibres (car door panels and glove compartments) are to demonstrate the fact that value from leather shaving waste can be generated, leading to artefacts that can substitute synthetics and possibly to offer industry solutions with performance properties inherent in collagen that are biodegradable – potential binders that are natural such as mycelium. Furthermore, plant matter waste can be a feedstock for leathermaking in the form of tanning extracts, substituting problematic chemicals (chromium salts) with nutrients from the biosphere in accordance with the model of the circular economy. Vegetable tanning is suited for micro tannery operations, supporting sustainable rural communities by offering local processing and value to their by-products, that can complete the circle from food to leather. Digital fabrication, in its intent, was to maximise cutting yields through nesting and tessellation, reshoring manufacture back to the UK. Digital scanning, engraving and cutting tools for manufacture are of interest to digitally skilled makers as it allows for personalisation and customisation opportunities, and thus sustaining artisan communities (SDG 11). The Despatch Box was intended to illustrate an idea of product longevity and potential repair. Here, product longevity is a key aspect of sustainability and is intended to encourage consumers to prolong the lifetime of products, therefore has a part to play in minimising environmental sustainability impacts (McLaren et al. 2015). Both the medical splinting device and saddle seat with force sensors facilitate the intrinsic property of the leather, in that it is bio compatible, breathable and hypo allergenic, with potential to integrate sensing capabilities. Both also relate to sustainable development of good health and wellbeing.

To summarise, the research described here has consisted of original research and practical work, creating new products and treatments for leather, extensive research into methods employed around the world, supported by numerous visits to centres of excellence in the leather industry, and wide reading into both processes for treating leather and into the theory and methodology of design. The literature review summarising this last element forms the next chapter.

Chapter 2

Literature Review

The literature review chapter discusses the interconnectivity of the material, the leather making processes, the community and the environment and its usages. This directly influences my practice and shaped the material forms, that offer applications and are impacting the environment. A review will be undertaken in the form of consulting literature, trade fairs, policy documents, scientific output, historic and contemporaneous documents and artefacts.

2.1 Leather and Biomaterials

Well-made leather is extremely durable, and, moreover, has the property of ageing gracefully and even becoming more attractive with use and maintenance – unlike almost all man-made synthetic materials. These are properties that give well designed products made of leather long life and enduring value – they are often inherently less disposable than items made from synthetic materials. These are properties which, in themselves make a contribution sustainability.

According to the European Community Regulation (2009), raw hides and skins are by-product of the meat industry, which are stabilized by the crosslinking of their protein fibre structures into leather through a process called "tanning".

Vincent (2005) shows how structural biomaterials such as skin function, and if properly handled leather can be both renewable and sustainable. It has unique performance properties that mankind has used for body protection and comfort, as well as for a huge range of functional objects. Existing products include crafted footwear, luggage, containers, luxury goods and automotive applications. From the outset, this chapter offers a review of the literature on leather technology and natural materials, and its relationship to design practice and sustainability.

This chapter consists of three sections:

1. Leather and Biomaterials;

2. Making Connections;

3. Findings and Knowledge Gaps.

Firstly, current issues relating to natural fibres and man-made materials are highlighted in the context of sustainability (Papanek 1984) and the circular economy (Stahel 2019; Capra 1982; McDonough and Braungart 2002). Secondly, craft, design, network and practices of working with leather (Waterer 1946; UNIDO 2010; Amberg 2017a, 2018) are discussed. Following from this,-the chapter identifies the knowledge gaps found in the areas of materials, in manufacturing and applications.

The conclusion section discusses how the findings of this literature review underpin the scope and practice of my research, in which the focus is placed on the issues relating to new materials in design (Stattmann 2000; Franklin and Till 2018), eco-informed material choices (Ashby 2009) and scientific and technological fundamentals in leather (Heidemann 1993; Covington 2009).

Leather technology comprises the processing of animal skins with the stabilisation of collagen fibres through tanning. Like other biomaterials, it also has an environmental impact, resulting from its source as a by-product from the meat industry, its processing and use. Principally, the material originates from cow, pig, goat and sheep reared for meat consumption. The debate around issues of leather, from industrial farming, the energy supply for the production of meat, and animal welfare has been summarised by Brugnoli (2012) and Mittloehner (2018). Furthermore, both the issues of establishing the framework for sustainable leather manufacture (Buljan and Kráľ, 2019) and of transforming the livestock sector through the sustainable development goals (The Food and Agriculture Organization of the United Nations (FAO), 2018) have comprehensively been addressed.

Their research examines emissions from agriculture and livestock, taking pasture grazing into consideration, and whether emissions could be attributed to slaughterhouse by-products, including skins. Livestock is a major contributor to global greenhouse emissions (5.1 %), mainly in the form of methane [see Figure 2.1]. Research has been undertaken to describe a method for calculating the environmental footprint of leather (COTANCE, 2018), which led to EU-approved product environmental footprint category rules. On this topic, the scope of this literature review is limited to core concepts such as life cycles, circularity and socially responsive practices.

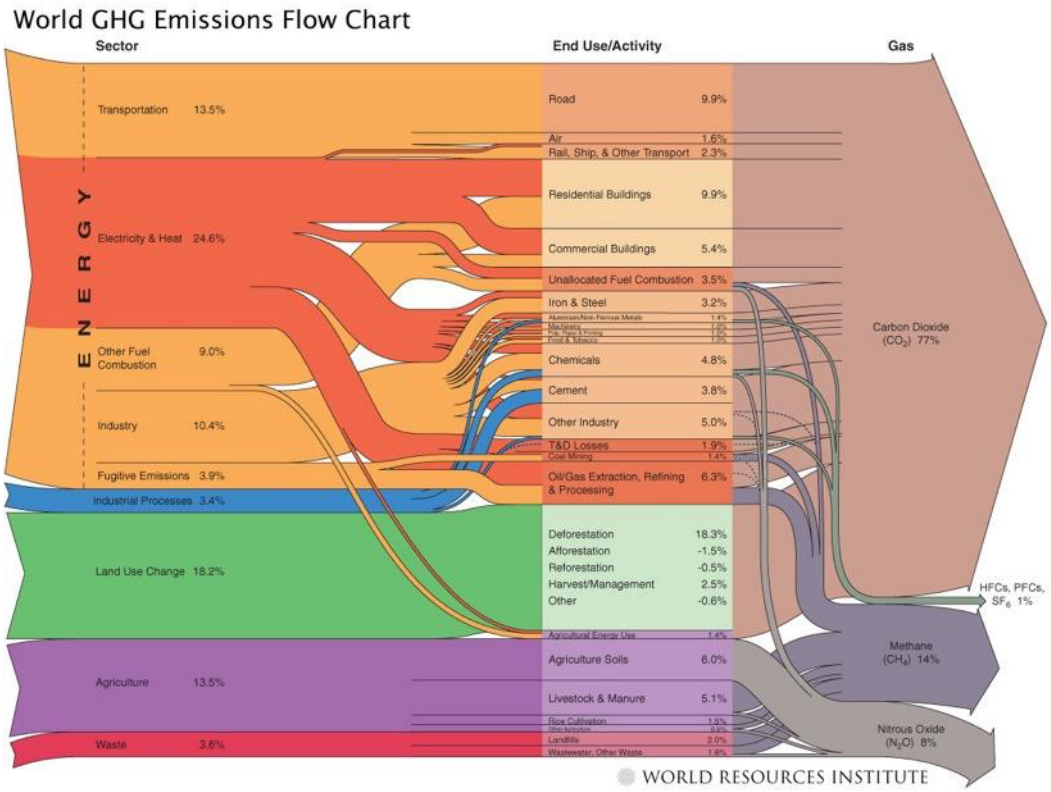


Figure 2.1 Global Green House Gasses Emissions Flow Chart
(Source: World Resources Institute, 2000).

In spite of these environmental costs, it will be appreciated that the world-wide production of meat for consumption is still increasing. As a by-product of this, animal skins form a resource which already contain a significant embodied environmental cost. This suggests that to convert these skins into leathers which have a large range of uses and impressive longevity, is a more responsible use of this resource than disposing of it as waste and landfill, where it will rot and generate a range of pollutants.

With regard to the processes for handling the raw skins and their conversion into leather, expertise in leather and collagenic materials are drawn from the research published by a number of leather chemists. For example, Covington (2009) and Covington and Wise (2018) shed light on the fundamentals of leather, through the science of collagen that forms the fibre bundles which make up the structure of skin. Heidemann (1993:290-430), a proponent of modern leather manufacture, translates scientific knowledge into the processing that occurs in the laboratory and tannery. This includes tanning with metal salts, such as chromium, zirconium and aluminium; the tanning with glutaraldehydes; and the practical and theoretical aspects of vegetable tanning. Through these experiments, he addresses the rationale as to why leather is made in a particular way, thus arguing that the tanning agent and degree of tanning are the most important factors influencing the properties of leather.

McDonough and Braungart (2002) scrutinise the impact of such industrial processes in their *Cradle to Cradle* approach, and argue for a radical shift in our wasteful use of resources. This can be done by mirroring the regenerative productivity of nature, with special consideration for design and biodegradability. In doing so, the leather industry, supply and value chains can be impacted. Covington (2007) and Germann (2008), outline our understanding of the 'Ecological Tannage', and discuss the issues relating to chrome tanning and its exclusion from automotive products. The diminished uses due to the end-of life-directive that the automotive industry is facing, with demands on resources and recyclability. Chrome tanned leather upholstery and trim is found to have issues mainly with current recycling systems and disposal issues. Therefore, alternative tanning methods are explored and offered to automotive manufacturers and leather goods industries. More recently, dos Santos (2016) demonstrates the potential of a new route in vegetable tanning with leather, through the depolymerization of condensed tannin, as found in mimosa and other plants.

From a design perspective, leather has been considered as a potentially recyclable material with an abundant supply, lending itself to a sustainable future (Franklin and Till 2018:14). Stattmann (2000) asks: What will happen when material research addresses the concept of regenerative raw materials? She then classifies biodegradable composites as 'nature tech' materials. Here, the terms *bionics* and *biomimetics* focus on understanding biological systems and adapting them to industrial ones; intelligent natural systems are being interpreted and imitated in industrial processes, thereby offering new solutions. The challenges in this field include having a tactile interface, achieving maximum durability and the recycling properties. There is a continuous output of research concerning new materials in design (Howes and Laughlin 2012; Franklin and Till 2018; Solanki 2018), materials experience (Karana *et al*. 2014 & 2015), and fundamentals of materials and design (Nordin, Hopf and Motte 2013). I discovered a gap in research concerning design with natural fibres and structural biomaterials; it does not yet comprehensively interrogate leather, or collect and connect individual case studies (Thompson 2013, Solanki 2018). Whilst there is design research presented for leather alternatives on a plant, bacteria and mycelium basis (Hijosa, 2014

Ivanova 2015, Montalti 2017), there is still scope to systematically order and present key concepts and processes in the leather trade, for consideration by design research.

2.1.1 The Context of Sustainability and Sustainable Design

The key concepts that inform this review are environmental issues and system thinking with regard to manufacturing (Stahel 2019; Capra 1982; Webster and MacArthur 2017); wasteful linear processes using harmful chemicals (McDonough and Braungart 2002 & 2007), together with ecological, economic and social elements of sustainability (Papanek 1984). Sustainability is defined here as "the endurance of systems and processes" (Brundtland and Khalid 1987; Magee *et al*. 2013), which aims for sustainable development goals, such as economic development, social development and environmental protection. Furthermore, a responsible and proactive decision-making and innovation are called for maintaining a balance between ecological resilience and economic prosperity as well as minimising negative impacts.

Stahel (1981 & 2019) first proposed a circular economy, illustrating loops in a model of life-cycles [Figure 2.2] and its impact on job creation, economic competitiveness, resource saving and waste prevention. Today, these factors are commonly referred to as the three pillars of sustainable development.

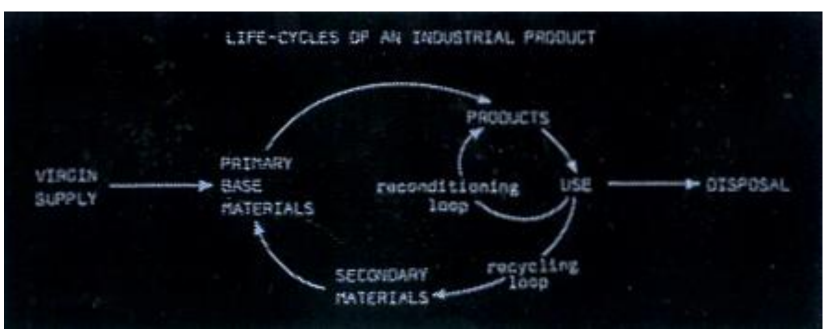


Figure 2.2 Walter Stahel's Model of Life-Cycles (1981).

Alongside Stahel, the chemist Braungart promoted material recycling as a loop – *cradle to cradle*, also as a reaction to the linear processes of *cradle to grave*. Stahel and Braungart aligned their position to be as though they were deviating from the mainstream (Product-Life Institute, 1982-2017).

The United Nations' Sustainable Development Goals press for change through collaborative approaches by scientists, businesses and researchers from varied backgrounds, to address "wicked problems" and bring forth systemic change. Design thinking approaches have been prescribed by Kelley and Brown from IDEO (Brown, 2009) which is based on a *human centred design* approach that emphasises collaboration across disciplines to address systemic challenges. This format has been tested widely, through facilitated workshops. I have first-hand experience through taking part in "innovating for sustainable development workshops" (Imperial and Reading Universities, 2018) and through design contests (Acumen 2019; Rockefeller Foundation 2020).

The research sets out to interrogate how leather can be used as a sustainable material of choice for the future; in this section of the literature review the key concepts of sustainability and sustainable design and their sectors will be defined through contemporary terms and by referring to literature that has been found of relevance. The definitions that have been provided in the literature are highlighting diverse perspectives and evolving theories/practice. The concluding section provides direction and orientation for this research. Examples in literature and practice highlight the complexity of sustainable design. Increasingly, the literature engages with systems thinking and I have found this useful to understand and tackle systemic issues related to leather material, its processing and use.

2.1.2 Sustainability Definitions

In the following section the key themes sustainability, sustainable design and development (SD) will defined, and their sectors reviewed.

Sustainability

The key concepts that inform this review are environmental issues and system thinking with regard to manufacturing (Stahel 2019; Capra 1982; Webster and MacArthur 2017); wasteful linear processes using harmful chemicals (McDonough and Braungart 2002 & 2007), together with ecological, economic and social elements of sustainability (Papanek 1984). Sustainability is defined here as “the endurance of systems and processes” (Brundtland and Khalid 1987; Magee et al. 2013), which aims for sustainable development goals, such as economic development, social development and environmental protection. Furthermore, a responsible and proactive decision-making and innovation are called for maintaining a balance between ecological resilience and economic prosperity as well as minimising negative impacts.

This has been defined by the Brundtlandt commission (1987) as the endurance of systems and processes. It allows for co-existence and growth that is not on the expense of future generations. As such, it is an aim for sustainable development goals, such as economic development, social development and environmental protection. Magee et al (2013) further define this as a “Responsible and proactive decision-making and innovation that minimizes negative impact and maintains balance between ecological resilience, economic prosperity, political justice and cultural vibrancy to ensure a desirable planet for all species now and in the future.”

Sustainable Development

“Synonymously used with sustainability, the famous Brundtland report defines sustainable development as the “development that meets the needs of present generation without compromising the ability of future generations to meet their own needs” Keeble (1988, p. 20).

Sustainable Design

McLennan, J. F. (2004), in his ‘Philosophy of Sustainable Design’ calls for physical objects, the built environment, and services to comply with the principles of ecological sustainability. It is worth noting patterns of trends in social innovation (Manzini 1989 & 2016); slow design which relates to a social aspect of sustainability (Fuad-Luke 2009), and eco design (Papanek 1984), which offers a discussion on impending issues such as textiles, natural fibres and the reduction of poverty. In more recent years, Thackara (2005) advocated sustainable design – that is, economical, ecological and social responsibility – through appropriate technologies. With current research in engineering and service design, for example, Rao (2009) looks at sustainable design in a different context and presents examples of project-based learning in India, with lessons on promoting sustainable development. (Schaber 2012)

In the following section, five main sectors in which sustainability and sustainable design (SD) is involved, will be considered and reviewed.

Circular Economy (CE)

Stahel (1981 & 2019) first proposed a circular economy, illustrating loops in a model of life-cycles [Figure 2.2] and its impact on job creation, economic competitiveness, resource saving and waste prevention. Today, these factors are commonly referred to as the three pillars of sustainable development.

Alongside Stahel, the chemist Braungart promoted material recycling as a loop – cradle to cradle, also as a reaction to the linear processes of cradle to grave. Stahel and Braungart aligned their position to be as though they were deviating from the mainstream (Product-Life Institute, 1982-2017). The cradle to cradle approach mirrors the regenerative productivity of nature, with special consideration for design and biodegradability. In the context of the leather industry, trials of such practices have been adopted in the process of the supply and value chain, by way of obtaining a similar certification to that of cradle to cradle (Buljan and Kráľ 2019).

Based on a UKRI Circular Economy Workshop transcript (2019), the transition to a circular economy requires systems-wide thinking and co-ordinated action across business, the government and society. In order to “overcome the barriers to transformation” (Circular Economy White Paper, 2019), it requires “fundamental understanding on interactions between systems – environmental, economic, social, cultural, legal and regulatory, technological and behavioral” for specific resource flows. In this context, it is for biomaterials (i.e. leather), and seeking solutions, including the use of new designs, new business models, changing consumer expectations and “game-changing materials and technologies that unlock value from the reuse, repair, remanufacture, retrieval and recycling of products, components and materials.” The opportunity of designing for the circular economy has been highlighted by Charter (2018), with practice-based research in understanding material flows across design disciplines. Earley et al. (2016) and Earley (2017) offer a textile design practice perspective, applying circularity principles within a sustainability framework and by presenting case studies drawn from textile researchers.

United Nations' Sustainable Development Goals

The United Nations' Sustainable Development Goals press for change through collaborative approaches by scientists, businesses and researchers from varied backgrounds, to address "wicked problems" and bring forth systemic change. Design thinking approaches have been prescribed by Kelley and Brown from IDEO (Brown, 2009) which is based on a human centred design approach that emphasises collaboration across disciplines to address systemic challenges. This format has been tested widely, through facilitated workshops. I have first-hand experience through taking part in "innovating for sustainable development workshops" (Imperial and Reading Universities, 2018) and through design contests (Acumen 2019; Rockefeller Foundation 2020).

Triple Bottom Line Model and Approaches to Integrated Sustainability

An approach to integrated sustainability is Elkington's (1997) model of the triple bottom line whereby the environmental, social and financial factors are considered.

The Bio Paradigm of Design

Eco-informed material choices (Ashby 2009) highlight how design decisions impact manufacturability by studying the complexities of material specifications, manufacturing limitations, assembly limitations, and end of life cycle management. Ashby has developed a comprehensive database of natural and man-made materials, which offers diagrams of structural properties and is marketed as CES EduPack. Ashby (2009: 240) offers a definition of 'sustainable materials being part of a natural ecosystem and its closed-loop cycle', and makes a brief reference to leather being one of select sustainable materials as it qualifies as renewable from the carbon cycle of the natural world. However, he considers that only very few of the materials used today would qualify as 'truly renewable' because renewables such as trees, are themselves a "diminishing source with the operations of cutting, drying, chemical treatments and transportation which all have some non-renewable consequences".

The Quantified Sustainable Development Space

Quantified methods that are of relevance include the carbon foot printing (Carbon Trust), also, the water footprint of leather. Relevant consumer goods and footwear are of industry standards, such as the HIGGS Index, cradle to cradle certification and the life cycle analysis (LCA).

Having discussed the main definitions concerning sustainability, in particular, its subset circular economy, I discuss below the future direction for sustainable material, manufacturing and use of leather.

2.1.3 Direction and Orientation

Here I propose the idea that Sustainable Development is a relative concept and provide a personal view on the intent of this work to highlight new strategies for further test and development.

Weetman's (2021) concepts of circular economy have been applied to this investigation in terms of design for durability and recovery, end of use, recirculation, process recovery and reuse of the materials that are ultimately biodegradable. It would mean that it is necessary to come up with an intervention to the existing value chain including systemic changes. My research highlights those systemic changes which need to be considered in areas of a closed looped leather processing and utilising waste streams, for example, shaving wastes.

It is worth emphasising that a key part of my work is to highlight the need to explore leather alternatives by understanding the leather sector generally and the way networks of technical and design experts deploy and share knowledge to advance practice. Anticipated new products from collagen may include collagens formed into films, or scaffolds for tissue engineering. As Covington (2009) speculates, there is an emerging market for alternative materials from plant fibres or mycelium. Thus, it is possible to consider that the leather industry could play a role in the development of such natural fibres, which have already been experimented with in the use of pineapple fibres. It is also interesting to note that the footwear companies based in the Midlands, which are the social and cultural fabric of their communities, emphasise this as a core attribute of their brands' sustainable narrative.

To highlight the separate perspectives and evolving theories/practice, there are clear signs that, in the not-too-distant future, it will be possible to set up leather manufacturing in such a way that nothing deriving from it will be wasted. Instead, everything will be reused in other sectors, including agriculture and construction.

2.1.4 A Circular Economy and the Potential for Leather

The *cradle to cradle* approach mirrors the regenerative productivity of nature, with special consideration for design and biodegradability. In the context of the leather industry, trials of such practice have been adopted in the process of the supply and value chain, by way of obtaining a similar certification to that of *cradle to cradle* (Buljan and Kráľ 2019).

Based on a UKRI Circular Economy Workshop transcript (2019), the transition to a circular economy requires systems-wide thinking and co-ordinated action across business, the government and society. In order to "overcome the barriers to transformation" (Circular Economy White Paper, 2019), it requires "fundamental understanding on interactions between systems – environmental, economic, social, cultural, legal and regulatory, technological and behavioral" for specific resource flows. In this context, it is for biomaterials (i.e. leather), and seeking solutions, including the use of new designs, new business models, changing consumer expectations and "game-changing materials and technologies that unlock value from the reuse, repair, remanufacture, retrieval and recycling of products, components and materials." The opportunity of designing for the circular economy has been highlighted by Charter (2018), with practice-based research in understanding material flows across design disciplines. Earley *et al*. (2016) and Earley (2017) offer a textile design practice perspective, applying circularity principles within a sustainability framework and by presenting case studies drawn from textile researchers.

The *Leather Naturally* industry forum has a thorough tight discussion of its objectives and targeting methods with determination to promote leather internationally (Redwood 2020). The group advocates for leather as a by-product of the meat industry, emphasising the social benefits of producing leather in developing countries. Costello (2020) and Redwood (2018: 8) argue that they have "enough clarity to be able to say that responsibly manufactured leather is sustainable and have communicated this with the aid of circular models and infographics", which illustrate bovines play a part in the long-term storage of carbon dioxides [see Figure 2.3 below]. Life cycles featuring leather are emerging at conferences (IUTC 2019, SLTC 2020) and in literature by chemical suppliers (Smit & Zoon 2019).

New academic research by Omoloso and Wise (2019) investigated sustainability in the whole leather supply chain, from raw materials to the marketing of finished products, and sought to create a way in which sustainability can be identified and measured in the leather industry. To achieve this, it considers environmental issues, such as harmful chemicals, but also economic and social elements.

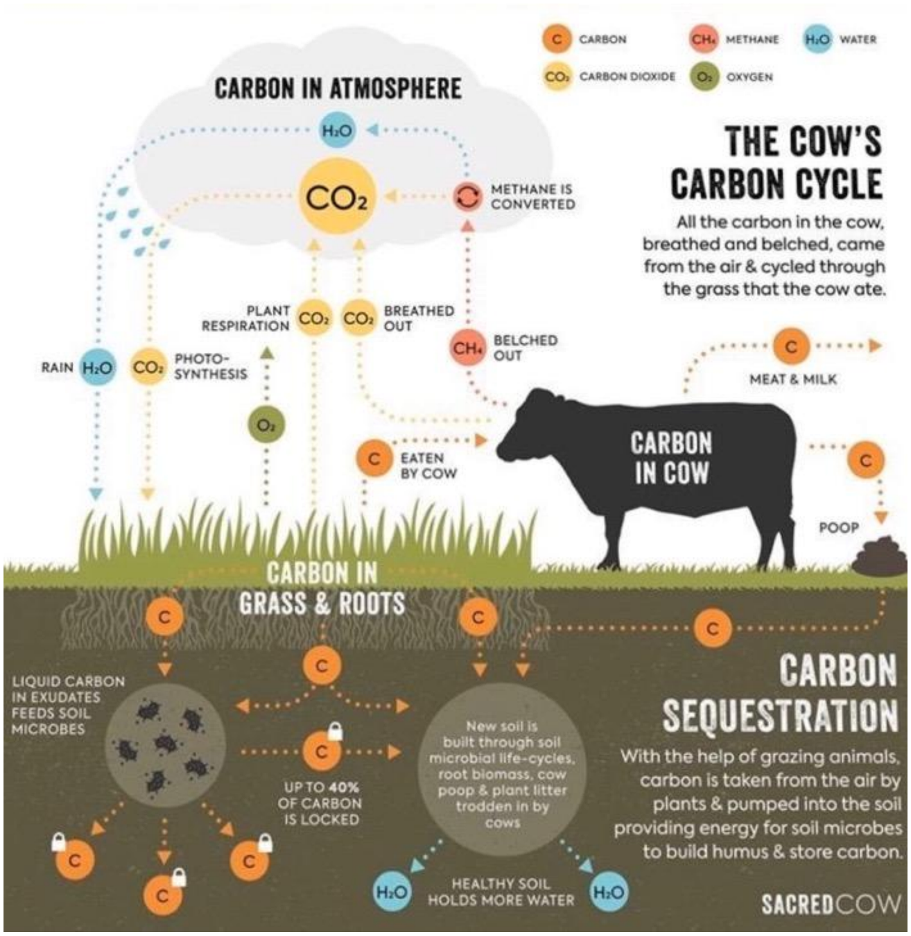


Figure 2.3 Bovine Carbon Sequestration (Source: Nutrition Media, LLC, 2019).

2.1.5 From Waste to a Raw Material

Daniels and Landmann (2013) reviewed how leather waste is currently dealt with, including the treatment of effluent and sludges, and solids from manufacture to composting. In a UK context, there is waste conversion to energy in a thermal processing plant (Scottish Leather 2015), and the associated certification of 'low carbon leather'. An international perspective provides the 'Tannery of the Year' books (Daniels, published annually since 2009), highlighting how dewatered blocks of waste leather go into landfills, being resold for fertiliser and other practices.

As for the end of life for footwear, new models of collection and recycling have emerged. Namely, a redistribution model established by the shoe manufacturer Clarks. I:COLLECT is a shoe collection service supported by brands and retailers (Ico-Spirit 2020). SOEX is a shoe-recycling enterprise, which separates rubber leather and textiles, and transforms them into secondary raw materials (Soex 2020).

According to Covington (2020: 628), there are two areas of demand advocated when addressing sustainability in leather: "the carbon and water footprint of leather" and "competition from other materials." Regarding competition from other materials, he highlights aspects such as the economics of production and the availability of rawstock of adequate quality. He then offers solutions for the disposal of tanned waste, and recovering the main components of collagen and widely used chromium, through chemistry. Furthermore, he discusses 'new methods of tanning with reduced waste of harmful chemicals. The technologists refer several tanning methods as "wet white" or "syntan" as an alternative to wet blue tannage with chromium (see Glossary for the definitions of the terminologies referred here). He also offers a rethink of processing by using fewer chemicals, for example, through unprocessed or green splitting and fleshing of hides. Closed loop processing is being proposed through the use of fresh rather than salted hides. Finally, enzymatic, rather than chemical processing has been demonstrated by his research.

New products from collagen are also being discussed, which are formed into films, such as foam scaffolds for tissue engineering, and involve growing fibrous collagenic materials in the lab from cultures. The potential for innovation can be found in the process of making dialdehyde tanning agents from starch matter, and new organic tanning agents from natural plant polyphenols, together with technologies, which will reduce water usage. Covington also anticipates that there is an emerging market for alternative materials from plant fibres or mycelium. Thus, he considers that the leather industry could play a role in the development of such natural fibres.

In the area of degradation of leather, two studies were undertaken for the metal induced degradation of leather (Feyisa 2014) and compostable leather (Miller *et al*. 2017) respectively; the latter showed that it is possible to improve the biodegradability of vegetable tanned leather by partial removal of tannins. The results indicated that it is possible to obtain 93% degradation within 24 days. This demonstrates the possibility that vegetable tanned leather can be biodegraded via the composting method, thus closing the loop. Biodegradability tests will become a routine task in new product development (Smit & Zoon 2019).

2.2 Making Connections

This section investigates literature on materials and prototyping that connect communities. Models of knowledge transfer and networks are applied to the leather industry. There is also application of models of co-design and co-creation, whereby digital fabrication and user participation cut down waste.

2.2.1 Craft

Here, leather craft comprises the making of finished skins into leather goods, either in a cottage industry, studio or factory context. Regarding the design practice community, I was inspired by the work of Rust (2007), which argues for knowledge through making, and strongly demands that the quality from new artefacts should “provoke insights”.

As for the concept of craftsmanship, Waterer (1946) and Amberg (2017a & 2018) provide an overview and practice of working with leather material, whilst highlighting the important role that leather played throughout history for body protection and seating comfort. Waterer presents a catalogue of leather artefacts across “life, art and industry,” whilst Amberg showcases the leather work in a more contemporary light by advocating the use of leather; he further emphasizes the need to have a duty to use the leather “resourcefully and sustainably” and “preserve a rich tradition of leather making.” This provides an invaluable insight into how the craftsmanship evolved to the present time, and the relationship to art and design.

Contrary to McCullough (1996), who defines craft as a new form of handiwork, from Adamson’s (2007) analytical point of view, craft is considered to be “a process, an approach, an attitude, or a habit of action,” and as “a way of doing things,” but not “a classification of objects, institutions or people.” Early on, Pye (1967) debates the relationship between workmanship and design, and craft and art. Referring to Pye’s contribution, Gauntlett (2011), Sennett (2009) and Risatti (2007) further articulate the definitions of material and manual skill, design, workmanship and craftsmanship. Lees-Maffei *et al*. (2004: 207) discuss the relationships between design, craft and art and highlight the Craft Council's exhibitions as a place to "take stock" of the places of "the new craft" within contemporary visual trends, with craft's "conclusive shift from the margins", now to "occupy an integrated position" with fine art, fashion, architecture and industrial design.

It is generally understood that craft evolves and embraces the notion of prototyping. Thus, the scope of craft extends from traditional artisan techniques to digital measuring, netting and cutting, and also the induction and alteration of material properties (Prototype: Craft in the Future Tense, symposium 2010). Charney (2012) offers a review of a practice-focused view on craft, curating The Power of Making exhibition at the V&A.

Golsteijn (2012) provides a relevant literature review of the above, and includes pertinent theoreticians such as Bean and Rosner (2012), Dormer (1997) and Shiner (2012). She concludes that "Craft is traditionally seen as the executing arm of design, or the uncreative counterpart of art." Golsteijn's thesis closely follows Shiner's view that craft, design, and art should be thought of as three overlapping areas rather than exclusive practices, and this author notes that boundaries between these practices have not just blurred, but have almost completely disappeared.

Building on Nicola Wood's practice based PhD thesis (2006) on the transmission of craft knowledge, Wood, Rust and Home (2009) investigate the use of digital media to support independent learning, and address the problems of professional skills learning and transmission of tacit knowledge.

Questions are addressed relating to mass customization in leather products (Myerson 1997; Clements and Porter 2007), post-industrial manufacturing systems (Atkinson *et al*. 2008), stressing the issues of authenticity, authorship and control – traditionally associated with craftsmanship, and control and autonomy in digital craft techniques (Masterton, 2005).

Concerning post-industrial manufacturing, Marshall's investigation was focused on the integration of digital design and production technologies into both art and craft practices. Offered through the use of digital tools, his research demonstrates how the digital manufacturing revolution, aligned with web capabilities, can enable 'user' participation in the design process to create individualized products of personal value and significance. Furthermore, he goes on to discuss how new communities came to exist because of digitally enabled making, and the opportunities this provides for refiguring the relationship between consumers and producers (Marshall 2008).

2.2.2 Designing with Leather

This section reviews craft, design, networks and practices of working with leather (Waterer 1946; UNIDO 2010; Amberg 2018). Expanding the literature review with grey literature and learning from trade fairs, the research was further facilitated through prototypes presented by designers at degree shows and previous SustainRCA shows. For the creative investigation into leather, there are varied explorations of note; for example, changing properties of leather through heat treatment, boiled leather – called *cuir bouilli* (Hasan 2008; Cheshire 2011) – leather as a self-supporting material (Rygalik 2005; Amberg 2005), digital manipulation (Sintobin 2019), and "an exploration of the threshold between animal and material" using sheep intestines and bovine skins (Lohmann 2004). These approaches are exemplary designs, which Atkinson *et al*. (2008) refer to as designing parameters, rather than end products, and which are alluded to in Lohmann's questions around animal usage and consumption.

Through the literature (UNIDO, Business of Fashion) and other statistics (Leatherbiz), I observed a decline in the use of leather in footwear. Contrastingly, design relevant application is rising on a global scale, with altered customer perception and market demand driving this process. Carmakers realize the wider profit margins by offering leather options, through mass customization (Myerson 1997; Clements and Porter 2007). The practice based investigation into laser cutting and engraving will facilitate a better understanding of rapid prototyping and direct digital manufacture of leather products.

Presentations by car designers focus on leather to express 'quality', influencing the design and brand development of their respective employers – carmakers in Britain. Marek Reichmann (Aston Martin) makes the analogy to footwear, as does Mara Ignatius at Lear. As an analogy, Reichmann relates the minimum use of 'shut lines' with a 'seamless' and 'simple' Oxford brogue; speaks of understatement, refinement and 'wearing the badge on the inside'. Adriana Monk, then at Landrover/Jaguar, proposes black imprinted leather in carbon-fiber optic, complemented by 'charred' timber, inspired by sports equipment and contemporary sculptures, thus reinterpreting the "ubiquitous wood and leather of current up-market car interiors" (Livingstone 2003). Robin Page (Bentley) emphasizes the concept of handmade-ness. Here, too, leather trim is used to illustrate his point. According to Ruediger Folten of Volkswagen Design in Wolfsburg, Germany, market demand is a driving force on vehicle interiors as consumers demand more value for their money. Such emphasis on perceived quality is echoed. Folten states that “the interior has always been important to customers, but today they are more aware in the way they are perceived.” The feel of quality is also thought to play a major role. Thus, this poses “the most important challenge for interior designers” (quoted in Mayne 2003). Leather trim is used to perceive and experience quality.

To summarise, leather has properties that make it a material of choice for interior designers. It is tactile, mellows (i.e. ages well), has an agreeable odour, is durable, and has connotations of heritage and craftsmanship.

It is a metaphor for quality and bespokeness, which is important in an age of personalization. However, presenters at the Automotive Interiors Expo 2010 predicted a shift concerning the package of car ranges and perception of interiors, with somewhat contradicting trends towards lightness, resource efficiency and comfort. Presentations at Automotive Interiors Expo 2016 confirmed these trends and added the imperative of sustainability. Furthermore, leather has connotations with luxury (status) and global luxury brands. Luxury has been examined by Velblen (1899) with the concept of conspicuous consumption, and is further contextualized in Berry’s (1994) idea of Luxury (Berry 1994). Borstrock (2018) considers craftsmanship and innovation as core components in creating differentiation between luxury and luxury branded products.

Dictionaries and glossaries clarify the definition of a type of leather, processes and common products. I undertook a literature review including the International Glossary of Leather Terms (International Council of Tanners 1967), Ledertechnisches Woerterbuch (Goulden 1956), Redwood’s glossary (2012 & 2015-18), and Glossary of leather terms (British Standards Institution 1972 & 2015). I also reviewed grey literature and online sources; these serve the needs of the leather-producing industry, but there is scope for illustrated glossaries and terms of practice to inform a non-expert audience, and the design community in particular.

2.2.3 Networks and Connected Communities

Turning our attention to the communities of practice where leather is processed and leather goods are made, the networks around leather have been indicatively mapped in order to identify the principal stakeholders concerning this research. Knowledge management theory on industrial clusters (Porter 1998) and districts (Markussen 1999) is examined through actor-network theory

(Latour 1987). The literature on the generation and management of innovation (Davenport and Pruszak 1998; Van Krogh *et al*. 2000) also supports the theoretical framework that underpins my research.

The literature on knowledge management includes investigations on industrial clusters relating to footwear, such as Porter (1980) and Schmitz (1995). Here, in addition to socially responsive practices, educational and research links between participants in India and Britain are highlighted. Present case studies (further discussed in chapter 4) around leather technology, design and making add to the wider discourse on textiles, natural fibres and the reduction of poverty, which has been described by Papanek (1984) and Thackara (2005).

Speakers at the Natural Fibres Conference 2009 such as Ahmed, Condor-Vidal and Sricharussin exemplify the role of crops and yields in sustaining rural communities. United Nations Industrial Development Organization (UNIDO) reports (2004-12) provide a wealth of resources concerning the economics of leather, fluctuation of raw-hide prices, livestock, the leather industry's value chain and the importance for sustainable development. Through this, the link between leather and sustainable communities is highlighted.

In order to identify the principal stakeholders concerning this research, the networks around leather have been indicatively mapped. Knowledge management theory on industrial clusters (Porter 1998) and districts (Markussen 1999), and the literature on the generation and management of innovation (Davenport and Pruszak 1998; Van Krogh *et al.* 2000) underpin the research.

In the U.K., the government provides strategic guidance on innovation, employability and industrial engagement through a number of publications, issued by the Treasury Department, namely the *Cox review of creativity in business* (Cox 2007) and the *Lambert review of business-university collaboration* (Lambert 2003). Cox put forward several recommendations promoting multidisciplinarity in Higher Education as a driver of innovation. Correspondingly, the Design Council, an organisation promoting design in the U.K., encourages competitiveness in industry and supports growth in the creative economy.

It has been noted that communities in the UK are rediscovering a Victorian-era drive for education. Kelly (2008) states that the reason why municipalities have rediscovered the passion for higher education which animated Victorian councillors. It was because "the big manufacturing towns lacked an educated elite steeped in the new sciences required by the industrial revolution – engineering, chemistry, medicine – so they set up establishments to provide them." In the case of Northampton, its main industry was closely link with shoe making; a technical college and an art school were set up in order to provide the skill needed for shoe design and making.

In the Cox Review, former Design Council chairman Sir George Cox proposed a number of ways in which universities and small businesses should work more closely together. Higher education courses should better prepare students to understand and work with other specialists. Centres of excellence should be established, where multi-disciplinary courses combine management studies, engineering and technology, and the creative arts are taught. (Schaber 2013) As will be seen in the case study with a Northamptonshire leather goods manufacturer in Chapter Three, this has been a lengthy process with all stakeholders learning along the journey.

2.2.4 Co-design and Co-creation

Next, the concept of co-design, which is investigated in detail in chapter 3 (Research Design Approaches). Underpinned by research on co-design approaches in the real world (Papanek 1984), on resilient society (Manzini 2016) and on eco-design and communities (Fuad-Luke 2009), this chapter presents the *breadline* shoe project that I have devised with a partner company to reuse leather waste for footwear in India. The project not only directly benefits children in India, but also offers a contribution to the understanding of sustainability in its context. Schrage (2010), for example, emphasizes co-creation as "the core of collaboration". He further takes the view that customers are at the centre of creating unique value by means of collaborating with vendors, not merely by "customizing."

Areas that should also be noted are the questions relating to mass customisation (Myerson 1997; Clements and Porter 2007); post-industrial manufacturing systems (Atkinson *et al*. 2008); stressing the issues of authenticity, authorship and control – traditionally associated with craftsmanship, and control and autonomy in digital craft technique (Masterton 2005). Digital manufacturing methods allow for yield optimization, reduction of production waste, and a localized and thus a more sustainable production.

In concluding the literature review, policy documents have been reviewed, Strategy documents on sustainability in the livestock and leather industry, and UNIDO Reports which assess technology developments, and outline possibilities to keep leather relevant.

2.3 Findings and Knowledge Gaps in Materials, Manufacturing and Applications

2.3.1 Findings

The findings of this literature review underpin the scope and practice of my research. It will be complimented by learning through making and the context of working with collaborative communities at the RCA, in Northampton and in the field. The spectrum of references and literature on leather chemistry, processes and artefacts has been extensive due to my collaboration with leather expertise around Northampton. It results in the creation of an illustrated handbook with guidelines that selects and communicates relevant terms.

The sampling of literature on new materials in design has been selective and was informed by the practice at the RCA, the Institute of Materials, trade fairs and academic symposia. It presents an emerging landscape of structural biopolymers and materials from natural fibres, which is an opportunity to re-evaluate leather materials which have been found to display unique and desirable performance properties. The design practice of experimenting with living natural matter, such as mycelium, warrants further investigation. The literature review revealed a wide spectrum of case studies, especially in the area of textiles, that consider sustainability and circular thinking (Earley 2015, Franklin and Till 2018). Proposed life cycles can be reviewed, tested and potentially transferred onto leather, for low footprint production, life cycle assessment and rethinking current systems and approaches.

Ashby (2009) has specified eco-informed material choices and properties, including natural fibres and biopolymers. A wider range of leather materials could be included in the catalogue, and the addition of hybrids and composites may lead to new research and commercial opportunities.

Covington (2009, 2020) signposted areas of innovation for leather, based on scientific understanding of chemistry and processing. New tanning agents and manufacturing processes have been developed which impact the environment to a lesser extent. Here, I see the scope to find new applications for novel leathers, using the concepts of lightweightness, breathability and hypoallergenic interfaces, through films that carry sensors, with inbuilt conductivity and micro-perforated matrixes for responsive surfaces and smart material applications. There is potential for applications in health and wellness. A proposal for smart collagenic fabrics will be demonstrated in chapter 3, and this possibly could lead to speculative designs with interlocking or smart materials.

The literature on knowledge management includes investigations on industrial clusters relating to footwear. Both Porter (1998) and Schmitz (1995) present cases where a tension exists between collaboration and competition amongst industrial districts in leather goods production. New models of open design and co-creation around leather expertise could be proposed and developed, perhaps in an educational setting. Localized manufacturing supported by digitally skilled makers, and the intangible cultural heritage with a branding of 'Britishness' offer opportunities for Midlands businesses and start-ups working with the material.

An understanding of the collagenic structure of skin, gained through literature and scanning electron microscopy of various animal sources, may lead to bio-inspired generative design (based on bio-mimicry) with potential for skin scaffolds, or, 3D printed artefacts to emulate or regrow fibres, surfaces or structures, thus exploring the future fabrication. This will be followed up through investigation of generative technology in CAD based upon the leather micro topology which is currently being explored (Ashuach 2019). The literature on digital fabrication directs towards seam and seamless technologies, no waste nesting and patterning, scanning and 3D printing.

2.3.2 Knowledge Gaps and Questions

Whilst there is emerging literature on new eco-inspired materials and new uses of waste for design applications, a critical examination of the complex issues concerning leather material, processes and applications is awaiting. Although there is the established science of leather technology with prescribed methods, here I propose a design practice perspective in the light of sustainable development, incorporating circular economy principles which may develop and update the leather material discourse.

How does my investigation add to the discourse? How my design practice can create value from the off-cuts and waste found in the leather industry will be explored and evaluated through experiments and the making of artefacts and prototypes. User-centred design methods and prototyping can be deployed to inform and develop a technology driven industry, so as to keep it relevant in a time where sustainability is paramount. I will discuss the artefacts that I have produced as the practice element in this study, in the context of the recycling, upcycling and use of leathers, alongside circular business models that may be incorporated into current leather practice. This may encourage communities of practice to engage in more circular processes.

To sum up, the crucial questions are: Can design research overcome barriers to embedding circular economy principles in the leather industry? How can we make leather a sustainable material of choice for the future? In conclusion, through this literature review, I have identified several knowledge gaps, which helped me formulate my research questions further.

Chapter 3

Research Design Approaches

The chapter discusses a design-led methodology for the practice-based research part of this project, and, in particular, prototyping circular practices through hands-on investigation in a design laboratory and tannery environment. This follows with an ethnographically-based study documenting my observations of communities of practice (network mapping) through fieldwork carried out in the UK (2013 & 2016), Italy (2012) and Japan (2013 & 2018). The purpose of these study visits was to understand the links or discrepancies between theory and practice.

3.1 Methodology

This first section presents the methodology employed to answer the research question of how leather can be used as a sustainable material of choice for the future. Several design approaches are considered through the literature review. I then selected methods that might be appropriate for a design research approach, and with the current understanding at the RCA that Design Research is a 'relational', transformative discipline between people and technologies / artefacts (Hall 2020).

To address my research question, participants and institutions were interrogated across time. My sources were archival data, principally in the museum collections of locations of leathermaking. A record of meetings with designers, practitioners and the leather trade was made, and observational data was collected through attending presentations at congress (such as the Society of Leather Technologists and Chemists Conferences, Automotive Interiors Show), tanning and finishing workshops at centres of leathermaking and design, and in fieldwork settings. Direct observational data included a record of my practice with annotated photographs and artefacts, which were used to create a taxonomy in a display format.

My investigation is consisted, firstly, of participant-observations (fieldwork) in the UK and beyond; and, secondly, making of prototypes to develop the circular future of leather, mainly through action research situated in a design laboratory and tannery setting [Figure 3.1]. Supporting methods were archival studies and the literature review; fieldwork with the visual mapping out of networks and locations; the creation of a taxonomy of processes and materials; exploratory workshops to cut out waste; and the curation of prototyped artefacts in a display. Also, I examined the suitability of the new materials that I have created during this research for the circular economy through cross-case analysis of materials, processes and use.

I describe here the research processes and findings of 1) collaborative communities of practice including design, and 2) new circular systems for leather in response to environmental pressures. This examines the ethnography specifically in relation to the UK, but the data is compared with those collected in other key locations, for example, Himeiji in Japan and Italy. The purpose is to examine whether there is a pattern in the relationship between the leather industries and educational sectors and how designers fit in the landscape. In my practical work, various materials were explored through the design-led method of prototype creation. The results were then compared, to demonstrate the research outcome. This has been communicated through the staging of an exhibition/display on several occasions during the RCA Research Biennale 2013 and the Work in Progress (WIP) Shows 2016, 2018 and 2019.

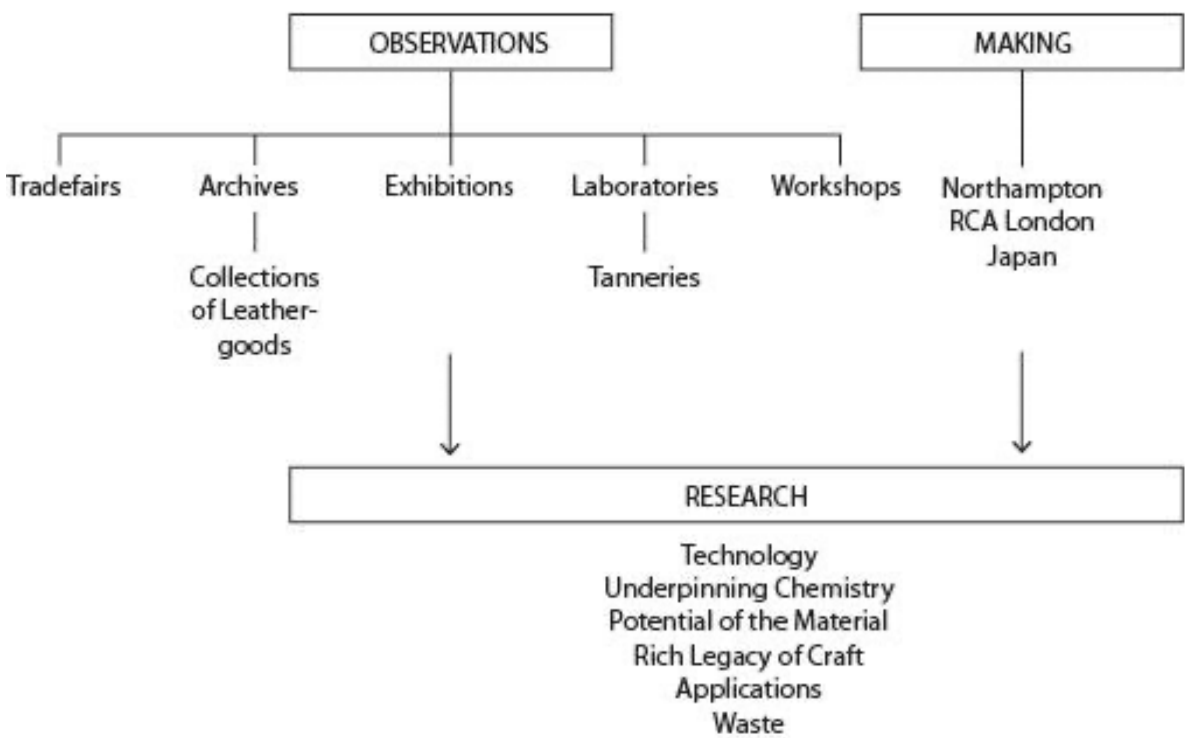


Figure 3.1 Principal Research Methods Applied.

Insight into the practice of leather making in the UK was gained through short term fieldwork in conjunction with attending trade fairs, and visiting partner institutions and companies. Leather processing stages were investigated in the automotive industry, shoe and boot manufacturing, saddleries and tanneries. Having concluded that this gave me a good insight in linear models of production with several waste streams, I then decided to create a Leather Processing diagram [Figure 3.3] which identified and located several waste streams suitable for upcycling and utilisation of waste leather, and, thereby generating new closed loops in line with circular economy models.

My thoughts at the time were concerned with eco-informed material choice in the context of designers exploring natural fibres, biomaterials and appropriate technology. Samples of off-cuts and by-products were obtained during these visits to factories. I measured sizes and went on to experiment with reconfiguration of the fibres through the processes of lamination, forming and stitching. I undertook preliminary studies on the performance of artefacts and later experimented with fabrication from off-cuts and leather shavings.

The final stage of my practical research involved creating composite materials (see chapter 4). For this, some of the techniques of papermaking – which I became familiar with when conducting research in Japan – were appropriated; the collagenous fibres were blended and then analysed with microscopy and materials testing, to determine its material properties in relation to other biomaterials and natural fibres.

Raw data in the form of material swatches has been selected, ordered and reassembled in tableaux. These are to be presented in the display as an output of the practice part. In addition, photographic documentation has been evaluated and selected to illustrate the terminologies and processes of leather making included in a handbook of techniques and processes. In the handbook, a collection of data was summarised graphically in three areas: a) actor network map; b) leather processing map; c) atlas map of distribution on location of leathermaking [see Figures 3.3 & 3.6 respectively].

I did consider both quantitative and qualitative evaluation methods. A qualitative evaluation method I used was the material evaluation worksheets of the *Ideo circular design guide* (Ellen Macarthur Foundation 2017 & 2018). Scientific methods to examine material samples, including my own compositions were undertaken through light microscopy and Scanning Electron

Microscopy. Also, an evaluation of the structural properties of these samples was conducted to find out the leather's elongation and strain, through tensile testing methods.

It is worth noting that new evaluation tools are emerging for measuring sustainability performance including carbon footprinting, lifecycle analysis and the Product Environmental Footprint (PEF) (Buljan and Kráľ 2019).

3.2 Prototyping Circular Practices

3.2.1 Leather Waste and Off-cuts

Leather is a unique and highly versatile material. It is a renewable resource, and is a by-product of the meat, wool and dairy industries. Waste is produced in the process of making leather, from the conversion of raw hide and skins into finished leather, and through the chemicals and technologies required in the process [Figure 3.2]. Daniels (2013: 98-9) devised a mass balance diagram that shows the quantity of waste generated from one tonne of finished shoe upper leather and split leather hides. Here, Daniels' study contains 100 kg of trimmings, 300kg of fleshings, 107kg of unusable splits, 99kg of shavings, 20kg of offcuts, 5kg of trimming waste, and 1kg of buffing dust. In contrast, the resulting products from 1 ton of hides and skins are 195kg of shoe upper leather and 60kg of splits. This means that two thirds of the skin are treated as waste.

Figure 3.2 Vegetable Tanned Leather Waste in Japan, 2013.

Although I was surprised by the amount of waste, I thought I could use this waste for practical material experiments. This was the key to leading me towards the idea of new structural bio-materials. I concluded that my readily obtainable sources included unusable splits, shavings, offcuts, trimming waste and buffing dust, which amount to about 25% of usable raw material. The quantity of this material matches closely to that marketed by the tannery as upper leather and split leather (Daniels 2013). I then devised practical material experiments to understand its material characteristics through tests and applications. At a later stage of my research, I had the opportunity to fabricate blended materials and composites from shavings in a laboratory environment in Japan.

I also obtained leather off-cuts from shoe and saddlery production and commenced with nesting and tessellation techniques. Making best use of irregularly shaped scraps and trimmings, I then devised a workshop with undergraduate design students (Cutting-out Waste in 2014) to come up with new product ideas. This corresponds with a cottage industry where designers and artisans turn leather trimmings from tanned and coloured skins into small leather handicraft goods, including small cases for memory sticks, mobile phones, key fobs etc. (Daniels 2013: 111).

Considerations were taken of the usable shoe upper leather and splits, which would include scars and surface defects on the animal skin. Through a practical laboratory-based workshop in the Italian tannery district in Arzignano, Italy that I participated in (2012), I learnt to apply processes to conceal defects through stucco, resins and heavy pigmentation, or, to enhance these characteristics with techniques such as pull-up effect and distressing. In my view, I felt that the industry was making undue efforts to conceal defects with polyurethane resins, thus creating uniformly coated materials that disguise their original natural properties.

Is it the choice of the consumer that asks for blemishless leather, or, the choice of the leather manufacturer or the designers of leather goods? What is the role of designers in the car industry, where very high-quality standards and specifications are demanded? I investigated what is expected of leather goods in other areas of industry to broaden my understanding of the trends, through visits to showrooms, trade fairs and presentations relating to leather products (these insights will be further investigated in the Discussion Chapter 5). With this consideration in mind, I undertook re-creation of distressed finishes through my practice, leading to a first exhibition display (2013). A major insight was the potential to change the user perception of a living material that displays growth and scars, and which naturally mellows and ages gracefully.

3.2.2 Alternative Tannages

As seen in the Literature Review, the properties of leathers are mainly the result of the tanning process. Most of the leather is currently tanned with chromium. Globally, 80% of the leather is currently tanned with chromium. This was confirmed when I observed a preference in shoe factories for chrome tanned leather that has a shrinkage temperature that exceeds the 100-centigrade mark (Heidemann 1993: 275) and is suited to be steamed and shaped under heat and pressure. In contrast, vegetable tanned leathers are used for shoe soles and applications where fullness and stiffness are desired.

In my practice, I developed a preference for using vegetable tanned leathers, because I obtained better output when using laser cutters, embossing presses and cutting knives. Furthermore, I appreciated a very pleasing natural colour and odour in vegetable tanned leather. As my practice progressed, I used mainstream commercially tanned leather made from mimosa tannins, and sampled leathers that were treated with the extracts from the leaves, bark and roots of plants such as chestnut, oak, tara and quebracho. I handled leather made from old recipes such as Russian birch tar tanning, which retained a distinctive smell.

My insight from literature (Heidemann 1993: 372) was that most plants have to a certain degree of natural polyphenol tannins which can be used to produce vegetable tanned leather. This led me to seek out farming waste streams and to undertake experimental tanning with waste from forestry, and waste from farming and beverage production which are further detailed in my practice (4.2.3) through trials with cherry, alder, apple fruit and mulberry. I also explored past practices and inquired about the potential for current and future use; for this purpose, I observed smoke tanning in a rural part of Japan (2018); an ancient leather production technique to preserve skin using the smoke from burning rice straw and used, for example, for archery gloves.

My explorations relate to the work of Eliza Axelson-Chidsey, a RCA graduate. Her MA presentation (Show 2014) called “Leather diplomacy” reviewed and applied tanning techniques used in Native American cultures and the “bushcraft” of self-sufficient communities in Northern America, using vegetable tanning, alum salts, oil, fats and brain substances. Both of our research projects try out traditional techniques and we have proposed applications, which can make a contribution to a sustainable use of leather.

In the course of my research, I also witnessed the reintroduction of localized tanning in the UK, using vegetable tanning processes. For example, at Skyeskyns and at Billy Tannery, located on the Isle of Skye in Scotland and the Midlands of England respectively, *micro-tannery* operations are supporting sustainable rural communities by offering local employment, processing and value to their by-products, that now “complete the circle from food to leather.” The Billy Tannery company has also developed a range of leather goods that are designed, produced and marketed as “Made in England.” Skyeskyns has recently - 2019 - diversified to include mimosa tanned product lines.

Innovation of new leathers with plant waste from the beverage industry (beer and coffee) concludes my explorations to create and demonstrate a zero-waste manufacturing process. Set up as a co-design approach through collaboration with leather technologists and farming communities, hop plant fibres and ground coffee beans (Davis and Tran 2019) are being developed into sustainable feedstock for the tanning of cowhides. My proposition is that this will be an attractive circular material of choice for fashion and designers alike.

3.2.3 Introduction of Novel Capabilities into Leather – Smart, Sensory and Healing

In the *Ideo Circular Design Guide*, the Ellen Macarthur Foundation (2016) emphasizes the importance of making materials from safe ingredients that can be continuously cycled, as materials play an essential role in a circular economy. Are smart materials suitable for the circular economy? Are there new possibilities for health and wellbeing? Smart materials have properties that respond to external stimuli such as temperature, moistures and electric fields. Due to this, the smart materials are considered to have great potential as a carrier of sensors or imbedding some healing properties. In Italy in 2012, I witnessed an application of heat reflective coating on motor-cycling clothing that was visible under infrared light. It reduces the impact of heat from the sun and increases comfort for the motorcyclist. This is just one example of a possible application of smart materials.

Thermochromic coatings were demonstrated by a Dutch leather chemical supplier and integrated into concept cars from the eye-catching glow-in-the-dark leather in the Rinspeed Etos, to durable and sustainable matt and scratch-resistant leather finishes (Stahl 2016).

Observation of the practice of designers from the Royal College of Art led me to the exploration of smart material properties through the introduction of sensory and conductive capabilities into leather. This was initiated by participating in the 'Bare Conductive' workshop led by Matt Johnson (2013). This half day workshop introduced conductive ink, which we applied to various substrates including leather to create electric circuits. As a result of this workshop, I continued to pursue designs that in some ways led to a material that is enhanced with new properties. To achieve this, I then applied the techniques as follows: micro perforation through laser cutting, conductive coatings through metallic tannages and the embedding of sensors (described in section 4.2.5).

It should also be noted that I gained further insight through the 'Plastics Electronics' (2013) and 'Textiles for Health and Wellbeing' symposia (2018) held at the RCA, which introduced key concepts of inducing smart material properties and proposing future applications. I was particularly interested in the work by Jenny Tillotson on scent design with consideration for wellbeing. We may ask whether 3D printing investigation in fabrics – by J. R. Campbell, Glasgow School of Art and the Textile Futures research group at the University of the Arts London – can be extended to other fibrous materials such as leather. Examples may be novel usages through electroplating or inbuilt electroluminescence and conductivity, all with potential industrial applications. There is also the question of whether we can further its hypoallergenic properties or introduce therapeutic properties into leather. Here is scope to coordinate health-related research currently undertaken at the Helen Hamlyn Centre.

3.2.4 Creation of a Taxonomy of Processes and Materials

To further develop my practical understanding of the materials and processes in a tannery environment, I attended short courses in Arzignano Italy (5 days in 2012), Northampton ICLT (3 days in 2013) and Northampton ICLT (5 days in 2017). This complemented my theoretical understanding gained from the literature (Heidemann 1993; Daniels 2013), and I felt compelled to consolidate the learning through diagrams and visuals. The visual aims to map out areas of concern, boundaries and overlap. My investigation resulted in the infographic of a leather processing map [Fig 3.3], originating from a series of hand drawn diagrams and evolving in several iterations over a period from 2012 to 2014. In the process, I was dealing with matters of complexity, classifications and feedback from the designers and technologists that I had consulted.

The infographic lists and names several production processes from the raw material to the finished item, in 22 steps. Several technical handbooks were consulted; for example, Daniels (2013:8-9) devised 41 steps from the rawhide to a crust. Infographics from textiles (linen) manufacture were also compared. The infographic [Fig 3.3] highlights several potential areas for interventions during the pre-tanning, tanning or finishing stages. As for Silvateam's Eco-tan (2018) and Wet-Green tanning (Olivenleder 2020), these are relevant approaches that inform my prototyping (see further detailed in Chapter 5).

Practical experiments were conceived and organised around the headings of collagen chemistry, alternative tanning technology, fibre usage with composites, 3D printing, smart material, digital manufacture, and application. 20 interventions were explored in person through fieldwork, visits or training. I also investigated the practices of other designers: these include RCA graduates Simon Hasan who developed *cuir bouilli* – boiled leather (Cheshire 2011), and Eliza Axelson-Chidsey who undertook leather treatments that are practiced by native Americans. Finally, a few interventions were considered that were more speculative in nature.

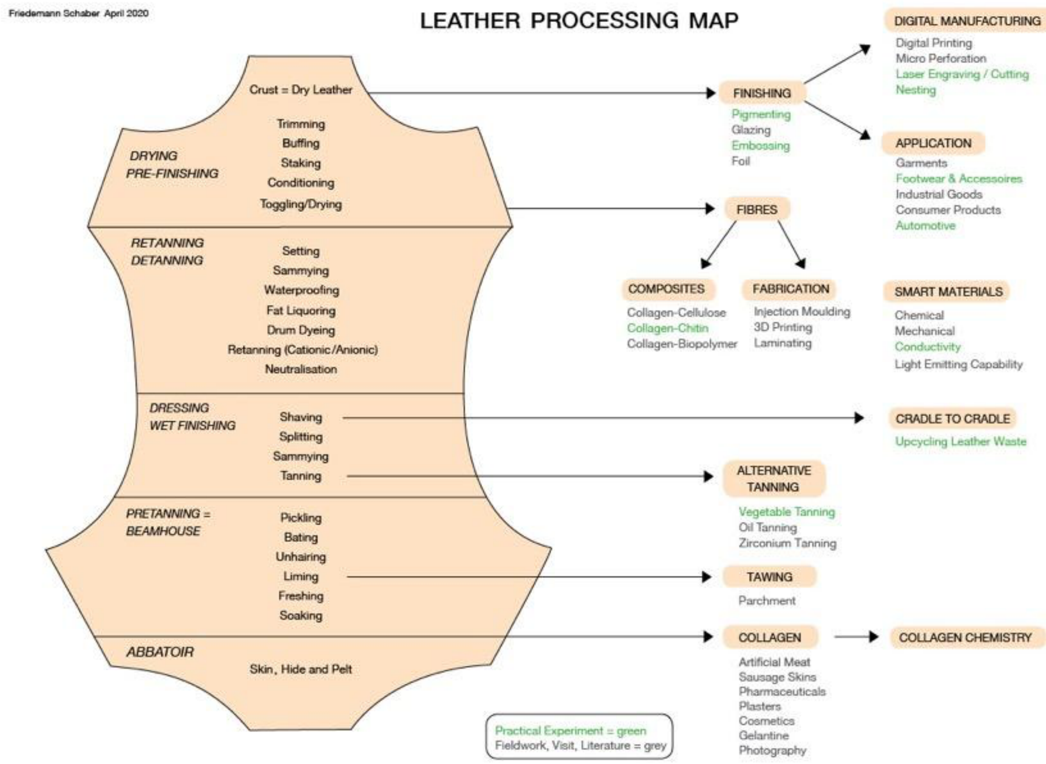


Figure 3.3 Leather Processing Map.

The implication of this diagram influenced my experimental work and served as a tool for ordering, structuring, grouping, excluding, classifying and attempting a hierarchy. I sought an area where product design knowledge can be transferred. For example, in the finishing processes, several design interventions can be made, whereas working within the beamhouse aspect of leather processing was not seen as a priority to me. This was because the beamhouse operation refers to the steps required in the cleaning stage of leather – such as soaking, unhairing, and liming the raw hides – that take place prior to the tanning (Daniels 2013: 24-5). The recovery of waste from this process has already been extensively investigated (Onyuka 2010).

In summary, I sought out the level of the interventions and the degree of transformation I could foresee. I followed the designers that previously worked in leather making. I was also inspired by a community within the vehicle design department and people who were drawn towards addressing sustainability, through the application of ecological design principles.

The learning from the circular economy made me review my position and my mapping, aided by the tools provided by the Ellen Macarthur foundation. Through a critical review, I came to reconsider the order of my diagram and thinking. I posed a question as to whether it is still appropriate to pursue a linear process of leather manufacturing; does the production process remain linear, from abattoir, to finished item in the circular economy.

I noted that the leather community that I was working with started engaging with aspects of biofabrication with collagen. Papers on bio printing and the creation of scaffolds for skin growth were discussed, and lab-grown collagenic products developed by Modern Meadows were presented to the UK leather community, in congress (SLTC 2017). This resulted in a visual that is based on a circle or sunburst arrangement of processes.

Subsequently, I proposed a circular shaped diagram of leather process and collagenic fabrication [Fig. 3.4] that includes new domains of fabrication. I chose to include stages to do with finishing, composites, fibres, forming, moulding, 3D printing, digital manufacture, smart materials and biofabrication. This illustration helps explain the transition from a current thinking of leather processing, to a future for leather that includes collagenic fabrication and new biomaterials from natural or reconstituted collagen (Covington 2020: 658).

In Chapter 5.1 I refer to other companies and researchers already working in the areas of Bonded Fibres from Leather Waste, presenting a comparative table between materials/artefacts. The Framework of Leather Processing and Collagenic Fabrication [Figure 3.4] maps out and locates where my practice sits in relation to other leather innovations and inventors.

This new taxonomy of leather frames innovative uses of leather, by selecting and arranging 99 relevant material samples and processes. The Design Thinking method of creative visualisation is being introduced into the leather supply chain. The sequence of segmented rings is mapping domains of leather processing towards collagenic fabrication, including the current technologies of 3D printing, smart material investigation and biofabrication.

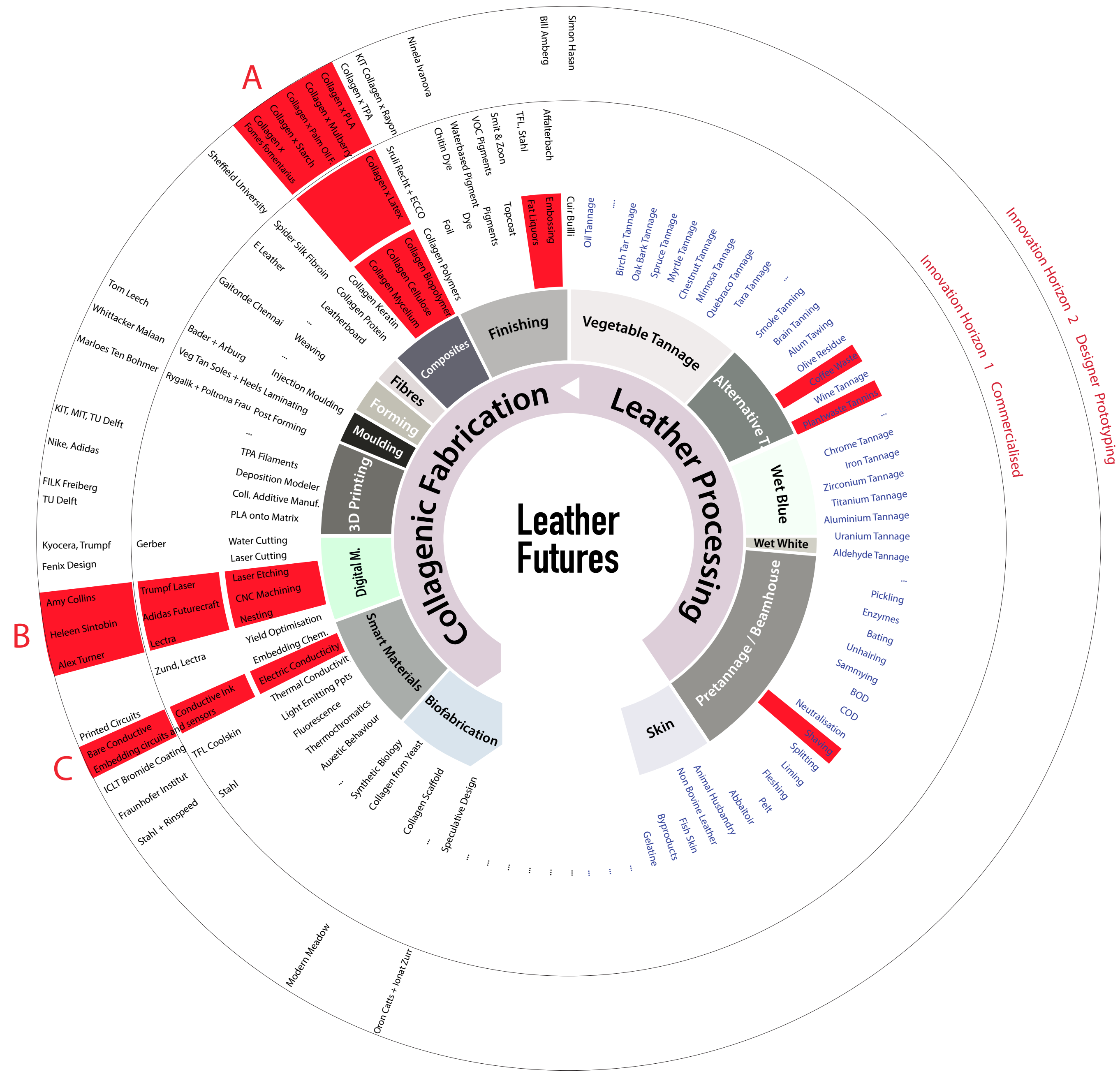


Figure 3.4 A Framework of Leather Processing and Collagenic Fabrication.

3.2.5 Pilot Workshops of Converting Leather Wastes – Breadline Shoes

To complement the study of academic literature and trade journals, presentations at trade fairs and annual conferences gave insight to considerations for the environment, regulations and directives, product origin tracing, and integrated manufacturing. In the research, I devised projects to find solutions for systemic environmental challenges, as outlined in the UN's Sustainable Development Goals. Other projects around defined applications such as *cutting out waste* led to the experimental use of digital fabrication, laser engraving and cutting, digital nesting and tessellating, pattern stamps, and screen printing circuity onto substrates and a wide range of artefacts.

In my academic capacity as a Product Design Lecturer, I undertook a number of Knowledge Transfer [UK government sponsored business consultancy projects] activities with local industry, several of which were linked to the leather supply chain located primarily in Northampton, with both a local shoe manufacturer and a company based in India, respectively. Conceptual models and prototyping systems for design and production devised through these projects, in turn, gave me insight into these industries. This resulted in further collaboration between the leather industry and a university in Northampton; live client projects were introduced into the design curriculum of a BSc Product Design Programme. Drawing from my concurrent research on undergraduate design learning (Butcher and Schaber 2013), I conducted pilot workshops of converting leather wastes, namely *breadline* shoes (2012-13) and *cutting out waste* (2014-15).

The *breadline* shoes project took place in collaboration with a commercial partner designing footwear for the poor. This led the University of Northampton to both expand the scope of engagement with India and to encourage undergraduate design students to satisfy real needs. The students' skill sets were facilitated to realise appropriate and practical solutions that can alleviate poverty. Firstly, students were briefed to create protective footwear for children in India. Project partners were the British School of Leather Technology and a footwear manufacturer based in Chennai, India. For the client, it was important that these shoes would be as widely available as possible, perhaps through the use of a waste material commonly available in the locations where children must walk a long distance to school [Figure 3.5].

Colleagues in the university's waste management centre helped students make informed choices by understanding the dimension of leather and textile waste, glues and cements, biodegradation of natural rubber and the implications of recycling car tyres. This learning anticipated that life-cycle assessment methodologies will be part of skill sets for design graduates, and parallels developments at other UK institutions. In response to real needs, Product Design students and myself created prototypes of shoe and sandal parts from natural fibres and waste materials. We applied the relevant design and production methods, with consideration of appropriate technologies suitable for manufacturing in an Indian community or 'cottage-industry' context. The aim was that affordable shoes would be offered to children in India as part of getting them to school regularly (Schaber 2013b: 5737).

Through this co-design approach, both partners in the UK and India gained new insights in the resourceful application of leather off-cuts, textile waste and natural fibres, discussing *appropriate technology* and *cradle to cradle* approaches. The co-design approach re-aligned the roles of students, researchers and users in the project, and the participants realised the benefits derived from an association with multiple partners in the teaching of socially responsible design.

Figure 3.5 Breadline Shoes Project. Client Briefing (top left), Making and Display of Shoe Uppers and Soles.

Each interaction between undergraduate designers and the client was monitored through field notes. Evaluations were conducted via a reflective student group report. Triangulation came from industry mentors, and student and staff feedback, who assessed the outcomes. The effectiveness of undergraduate learning was assessed through (a) student oral and written feedback, (b) client engagement and oral feedback, and (c) summative student assessment through presentations and multi-angled feedback by staff and peers.

This workshop revealed where I wanted the research to go: creating value from waste materials through partnership models involving designers and the leather industry with a co-design approach, benefitting the community, and advancing environmental and societal aspects of sustainability.

3.3 Observations in the Field

3.3.1 Fieldwork

Ethnography is a qualitative research method: studying social interactions, behaviours and perceptions that occur within groups, teams, organisations, and communities. In order to document the culture, perspectives and practices of the people in these settings, I used the participant-observation method of aiming "to 'get inside' the way each group of people sees the world" (Hammersley 2017). Ingold (2014: 388) describes the progression from meeting people when conducting our research and 'encountering the world' to 'observing from the inside', as an 'education by attention.'

My principal research field work was carried out in locations both in the UK and in Japan amongst leather manufacturers, very often by interacting with practitioners. The rationale was to shed light on the contribution of design and networks in the transformation of the shoe industry and leather industry, which are different trades related by a common material. In Japan, I undertook observations in districts where tanneries cluster, and two locations relating to manufacturing, design and retail. To complement a logbook and sketchbook, following Aldersley *et al*. (1999), video and photographic recording devices were used for some observations of practitioners. The output of fieldwork in Japan is sampled in a handbook with assorted artefacts as part of my practice, and is on display.

Leathermaking in Northamptonshire

How did Northampton as a location contribute to my Material Futures investigation? Based in Northamptonshire, a county with a tradition of shoe and boot making, I had readily access to my field of investigation. As described in the Introduction, Northampton constitutes an industrial district of manufacture in leather. This cluster includes education, research and development expertise which I captured and interpreted in a network map and a UK wide atlas of relevant location, including SATRA, BLC British Leather Corporation, Leather Conservation Centre and National Leather Collection. In addition, there are consultants that bring their expertise to the industry (such as Leatherwise, Authenticae and Richard Daniels) which I have engaged with to communicate an ever-increasing volume of knowledge from technical sources. In addition, the Institute for Creative Leather Technology at the University offers research, consultancy and leather related higher education, serving a globalised industry with the majority of leather technology students coming from overseas. Through the Society of Leather Technologists and Chemists' annual conferences held at Northampton, new developments in leather chemistry were presented and connections made with presenters led to knowledge exchanges and excursions. An example of this was the meeting of a team of Japanese tanner, academic and photographer which initiated my work with a leather cluster in Japan.

I found that Northampton is linked to other industrial districts through commercial and educational routes. Principally, there the leather centres in Santa Croce and Arzignano (Italy), Novo Hamburgo (Brazil), Waalwijk (Netherlands), Pirmasens (Germany), Himeji (Japan), Kanpur and Chennai (India) and Chengdu (China). Knowledge of and access to these locations have been relevant to juxtapose my case study on Northampton.

The University of Northampton, a local university, is found to be at the hub of networks of organisations and people such as London livery companies, leather material scientists, designers and makers of Jeffery-West or Church's shoes. It is part of professional networks which are defined through membership in a guild or society, such as the Worshipful Guild of Leathersellers, Cordwainers, Glovers, Drapers, and the Society of Leather Technologists and Chemists. Furthermore, informal or formal creative communities evolved from the craft around leather in an industrial district in which they are physically located or are associated with. Global networks also emerged as local companies manufacture or trade with abroad, or became part of the luxury goods market. For example, Church's Shoes is a part of Prada and John Lobb, a brand within the portfolio of Hermès. New links and collaboration with French and Italian fashion houses can be observed with students benefiting through placement and job opportunities (Lloyd and Schaber 2019).

Kyoto Fibro Science Laboratory

A short-term scholarship let me undertake a period of intense project-based studies in designing materials from waste fibres by investigating the craft processes of papermaking, lacquering, screen printing and tanning that have been preserved in the Hyogo and Kansai region of Japan. At Kyoto Design Lab within the Kyoto University of Technology I worked with staff from the fibro science department on the creation of samples from plant and leather fibres waste. Led by fellow design researchers I undertook the blending and stabilising of natural fibres, resins and binders, through an experimental and iterative process. Originally, the department has been set up in support of the silk textile industry and I realised how deep knowledge derived from papermaking has been appropriated for composites fabrication and can be harnessed to fabricate fibrous biomaterials. The exhibition of spinning looms at Toyota in Nagoya and the Japanese leadership in carbon composites and microfibers demonstrate the transformation of industrial districts through design innovation. I appreciate the need to engage in research with impact and was able to communicate it to a Japanese audience, through contribution to the Kyoto design yearbook.

Royal College of Art

The place of my research studies, the RCA advances learning and knowledge in design and as such attracts students globally for its masters and research programmes across its schools. The college conducts a wide range of lectures, exhibitions and events, which I sampled throughout my studies. In particular, the *SustainRCA* lecture programme expanded my understanding of eco-informed practice, as the department’s head Clare Brass offered a platform to a wide range of emerging designers and their practice that are tackling environmental issues around material and consumption.

The annual *AcrossRCA* project week provided insights of the effectiveness of working within multidisciplinary teams of students, to address systemic problems which I explored through mobility scenarios in the week-long project with Nissan as industry collaborator.

At annual *Work-in-Progress Shows* and *Summer shows* I met with fifteen graduates who work with leather in a way that is relevant to my research, including Helen Sintobin, Tomek Rygalik, Simon Hasan, Eliza Axelson-Chidsey, Marloes ten Böhmer, Julia Lohmann and Tom Leech. These makers extend and develop craft practices with the use of laser cutting, CNC technology, heat treatment, vegetable tannage and moulding. My decade long observation is that designers outside footwear, accessories and fashion continue to select leather as a relevant medium for their practice. The designers modify established craft practice though industry tools, conjure new possibilities as "each context and application of a material requires specific material properties as well as functional and aesthetic considerations that, once realised, become an instance of the cultural reference system. For example, leather gloves require different leather properties than a saddle so the objects define two instances of 'leatherness' on the cultural reference system for leather" (Lohmann 2016: 83).

In the course of my research, the RCA facilitated materials practice workshops together with a consortium of other London universities, which expanded my network and insights to mycelium and collagenic fabricators at the seminars such as Materials Futures: How Do Objects, Materials & Media Inform Design Research Practice. To exemplify, the designer Amy Congdon collaborates with a collagenic fabrication company and shares her new practice at events such as Spare Parts: Rethinking Human Repair at the Science Gallery. It is notable that Congdon, having started from a textile background, began to utilise her craft skills to facilitate her "learning to grow human tissues" (Congdon 2014).

3.3.2 Network Mapping

Leather Trade Networks and Communities of Practice have been mapped as in [Figure 3.6 and 3.7] below. It was possible to observe companies and their relationships by taking a network perspective and relating these to the industrial districts found in various regions in Europe, Asia or in South America; that is, a core of roughly equal enterprises bound in a complex web of competition and cooperation. Markusen (1996) suggests a typology of industrial districts, a useful concept to help us understand the overlap between purely local networks and the wider network, in which firms and industries are placed.

This holds true to Northampton, a town renowned for its tradition of shoe-making. In support of its core industry, teaching institutions were established, namely, the Colleges of Art and Technology. Today, this expertise is part of the University of Northampton. Within the fashion department, a footwear and accessories provision evolved, which engages in Knowledge Transfer in support of the London-based fashion industry. New links and collaboration with French and Italian luxury brands can be observed, with students benefiting through placement opportunities. For over a century, its British School of Leather Technology has educated staff on the global tanning business. Furthermore, since the 1920s, Indian tanners have been trained at the school, and this three-generation-old relationship provides insights (Schaber 2013b).

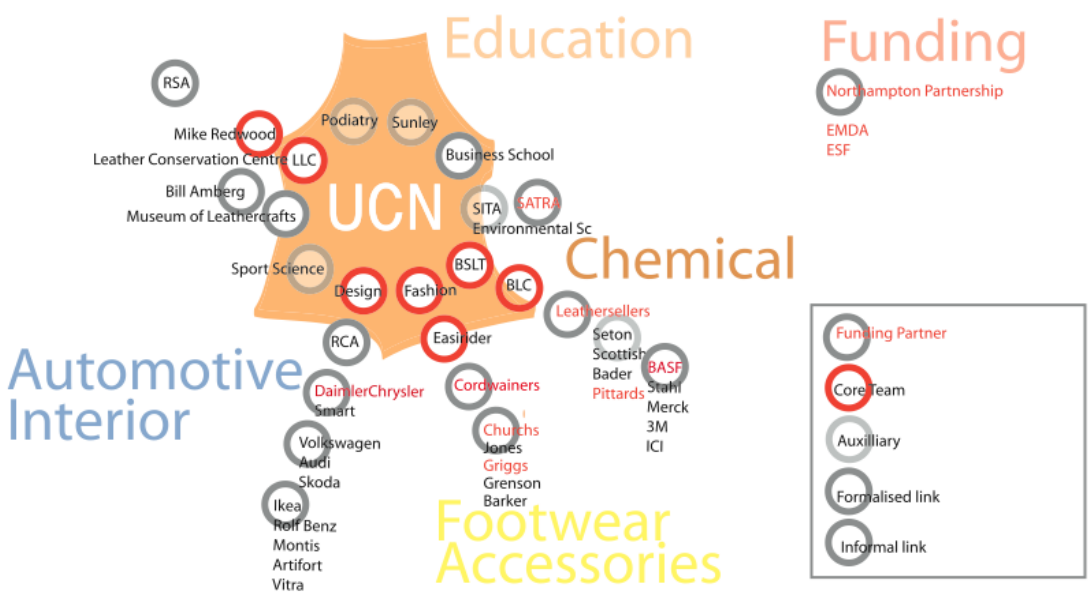


Figure 3.6 Leather Networks with Northampton at the Hub.

My diagram, [Figure. 3.6] above, maps past, existing and emerging networks around leather in the UK. and identifies selected stakeholders which are significant to my research. The benefiting college, i.e. the local university, is found to be at the hub of networks of people. These include

London livery companies, material scientists, designers such as Bill Amberg and Zandra Rhodes, and the makers of Kinky Boots, Jeffery-West or Church's shoes. Of note are the networks which are defined through membership of a guild or society, such as the Worshipful Guild of Leathersellers, Cordwainers, Drapers, and The Society of Leather Technologists and Chemists. Furthermore, informal or formal creative communities were found, evolving from the craft around leather in an industrial district, in which they were physically located or were associated with.

In Northampton, it was found that people were linked through apprenticeships, through training at the local technical college or Cordwainer's College in London, or working at and with the shoemakers in town. Sherwood (1998) also identifies these educational links in an article on the shoe designer Andres Hernandez, who was a principal at John Lobb Bootmakers. Global networks emerged as local companies began to manufacture or trade abroad, or become part of the luxury goods market. For example, Churchs' became a part of Prada and John Lobb Bootmakers, a brand within the portfolio of Hermes. New links and collaboration with French and Italian fashion houses could also be observed, with students benefiting through placement opportunities.

Michael Redwood, a Visiting Professor in Leather Strategy at the University of Northampton, fostered my understanding of leather industry networks through conversations. This was aided by the theory of actor networks (Latour 1987) and the definition of a cluster as an industrial district, i.e. "a core of more or less equal small enterprises bound in a complex web of competition and cooperation" (Piore and Sabel 1984). The hub and spoke type and the satellite platform type only function as a result of the participants recognising that they are managing within a network, which extends beyond the locality. My concept of geographic alignment to leather industry is derived from Porter (1990), whose concept on the advantages in innovation and flexibility is defined as "clusters." This name was coined after his investigations in to the Italian footwear and textile industries.

Taking on this concept, it was possible to observe companies, relationships and outcomes by taking a network perspective (Håkansson and Johanson 1992). Redwood, emphasised the importance of the network for ensuring the future of leather industry and education in the UK. He states: "In Northampton, we all knew we had to strengthen many connections and make new ones, that this involved identifying our best current partners, looking for new academic partners, and linking into the Fashion School network, so Fashion and the British School of Leather Technology could share relationships and thus strengthen them" (Redwood 2009).

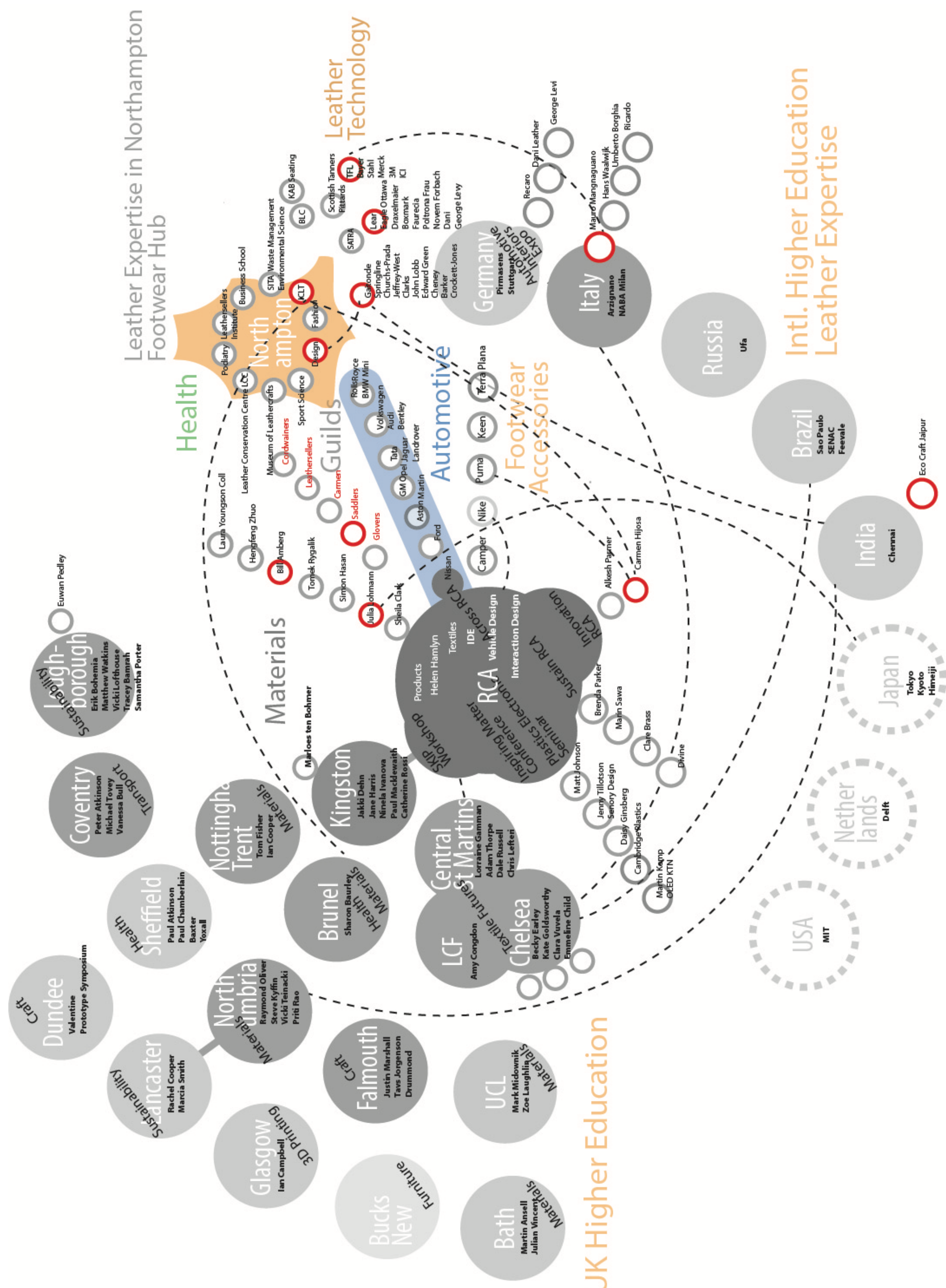


Figure 3.7 Network of Research and Practice.

[Figures 3.6 and 3.7] illustrate the networks, with the RCA and Northampton at the hub and the relationships to the education funding partners and industry. In [Figure 3.7], in particular, the network was extended to include the relationships that were linked through leather. We can see here that multiple hubs are displayed in this model. It developed from the leather expertise in Northampton and extends further to research practice networks.

The aim of my work is to demonstrate multiple connections and the movement of actors within the network. In the discussion section, I emphasise the importance of networks for making leather a sustainable material choice, and at the same time, how it shaped my practice. My task is then aiming to connect this map in the context of the circular economy model, knowing of the importance of collaborations to address systemic issues. My key insight was that my research is relational, and subsequently, I came to a deeper appreciation for the connection and the position of practitioners (designers and makers) and their affiliations, throughout my studies.

This model shows transactions between industry and organisation, and the connections and movements of several key practitioners that I found relevant for my research. These are further analysed in section 3.3.4.

3.3.3 Communities of Practice

My research developed by observing communities of practice (Wenger 1999), with the aim of identifying key practitioners, their relationships, ways they transmit knowledge, and to understand the role of design and education. A network of actors was identified, tentatively mapped, and further grouped according to ‘transactional links’ and the relationships in the leather industry, education, technology and design. To develop the research, a network framework was created by drawing from literature on design, knowledge management (Von Krogh 2000; Porter 1998; Markussen 1999) and social science (Latour 1987). The approach is also influenced by the Actor Network Theory (ANT). An actor network approach has become more common in design research, as exemplified by Ricci (2010) and Schneider *et al*. (2010). Literature that makes use of ANT in empirical work is for example: Popovic *et al*. (2011).

It configures all things of any scale – human or non-human/conscious or non-conscious – as actors that interact and comprise a study network. This theory argues that all actors, in the dynamic and heterogeneous network, have equal weighting and create interconnections and associations.

For my research, designers, entrepreneurs, leather technologists, and educators and designers from the UK and beyond were interviewed. From my list of contacts, 17 were selected and a further 19 are additional informants. The majority are male and based in the UK. The interactions were face to face conversations, and were carried out informally without a written questionnaire. My methods included shadowing, photographic documentation and reviewing literature of and by my informants, such as web pages.

The National Leather Collection in Northampton has been a unique resource for artefacts. The museum seeks to reach out to new audiences through the large collection that it is safeguarding. The curator, Philip Warner, anticipates that relocation of the Museum to a central town venue will be a stimulus for achieving this goal, alongside the online presence that showcases the collection, outreach events and opportunity to handle and study the artefacts. The museum seeks to reinvigorate Northampton's heritage through the establishment of designer maker studios that are modelled on 'Cockpit Arts' in London funded by the Leathersellers Guild.

How did I scope out my community of practice, current and future trends in design – covering automotive and interior design, and fashion and accessories related to leather? Where did I find out about and meet key practitioners? Principally I gathered these by attending relevant trade fairs and conferences. In the UK, the venues included the degree exhibitions at the RCA, also the New Designers graduate show; London Design Festival; and, associated shows such as Designjunction and 100% Design. Insights gained from these encounters complemented a literature review. Correspondingly, the designer Chris Lefteri emphasises the importance of trade fairs for his forecasting practice as he considers it as an effective way to gather and exchange knowhow of new developments and materials, equating to months of desk research (Lefteri 2017).

3.3.4 Practitioners

From the outset, it was important for me to shed light on individual contributions and ideas by designers, curators and technologists that had an impact on my own practical work, finding knowledge gaps in leather practice that have not yet been fully explored. Principal informants and their influence on my practice have been selected and featured here. The research documents the interactions with individuals and other stakeholders relating to leather.

In the early stages of the research, I strived to develop a dialogue with designers that have a practice that includes leatherwork, because I was seeking connections and transactional links between the design discipline and the leather industry [Figure 3.8]. My focus was not on leather for garments, footwear and accessories which have been documented in an anthology by Quilleriet (2004).

Figure 3.8 Shoemaker Nick Cooper and Designer Simon Hasan discussing Goodyear Welted Footwear in Northampton, May 2014.

Rust (2007) states that new artefacts provoke insights and for the creative investigation into leather, as I learned from prototypes by designers graduating from colleges such as RCA over the last 15 years. Hasan (2008) explores changed properties of leather by heat treatment, through a discovery of an ancient technique of boiling leather to achieve a plastic-like structural quality. Expanding craft or vernacular traditions, Tomek Rygalik's *Raw Chair* (2005) facilitates the inherent properties of the material for furniture in which leather itself is the supporting structure, a process that was piloted by Bill Amberg in collaboration with the Claytons of Chesterfield tannery and published in Blueprint (Richardson 2005: 38). Julia Lohmann's *Ruminant Bloom* and *Cow Benches* (2004) are exemplary designs using sheep intestines and bovine skins, exploring the threshold between animal and material, and alluding to questions around animal usage and consumption. Atkinson *et al*. (2008) refer to these kinds of approaches as designing parameters rather than end products.

Figure 3.9 Constructed Footwear by Marloes ten Bhömer, 2013 (Photo: Bhömer).

I was particularly interested in the design strategies of recent RCA alumni Marloes ten Bhömer [Figure 3.9], Heleen Sintobin and Tom Leech [Figure 3.12]. Their respective final degree show exhibitions intrigued me, and I felt that their work demonstrated an advanced understanding of what leather's future could be. These designs are propositions to do with the forming of animal hide through adapting industrial modes of construction by using moulds, selective manipulation of properties through CNC milling, considering downloadable designs, and the exploration of designs for disassembly.

The major insight of these approaches was the application of eco design strategies in the fabrication stage; offering designs for improved functionality to be customizable and emotionally durable; the designs have an increased product lifespan in that they are physically durable and repairable. Furthermore, they considered new life phases through remanufacture and designed for recyclability. Reflecting, I devised to further explore the eco design strategies (Fuad-Luke 2013: 322) of recycling and reduction of waste production, and to explore disposal, the end-of life and new life phase, to advance biodegradability, and to design for need.

To note, these advancements were offered by designer makers rather than formally trained leather craft people. As attested by Lohmann (2016), as designers, they selected leather for its malleable possibilities, and later they acquired craft knowhow [see Figure 3.10]. The symposium *Prototyping- the Future of Craft* at Dundee in 2010 and *Power of Making* at the Victoria and Albert Museum (Charney 2012) showcase designer makers as innovators, disrupting craft.

Figure 3.10 Designer Julia Lohmann with Cow Bench, 2014 (Photo: Lohmann).

These designers critically interrogated leather and thus travelled to Northampton to seek out local industry and tannery expertise [Figure 3.8], and to take part in exchanging leather knowhow, as did Lohmann in 2005, Hasan in 2014, Leech in 2016 and 2017 and Sintobin in 2019. RCA Textiles doctoral student Carmen Hijosa work with Northampton's tannery was remarkable in that she successfully transferred leather finishing technology to stabilize, bond and test a new natural fibre from pineapple waste (Hijosa 2014).

Design for Transport

MA Vehicle Design alumni Giles Taylor and Marek Reichmann are leaders in the world of automotive design, with senior roles as Heads of Design of British premium car brands. In conversation, I learnt of their understanding of leather as an enduring material of choice for the automotive interior, which was illustrated in presentations to an RCA audience. Reichman refers to Northampton shoes and relates them to the *handmadeness* and *shutlines* of his automotive creations (RCA Design Leadership Lecture 7, November 2013). Taylor and Reichmann both exemplify that there are existing relationships of transport designers working with the British Leather Industry. In turn, the Scottish tanneries which are producing automotive leather state their proud heritage as suppliers to the car and aviation industry, with their vision to continue 'as the most successful and respected group of leather manufacturing companies in the world.' The commemorative brochure to the Scottish Leather Group's (2015) 50th anniversary features Jaguar's then Head of Design Ian Callum handling Scottish cowhide, another notable alumnus with a postgraduate master's degree in Vehicle Design. The Bridge of Weir company supplies automotive leather to several premium car brands and became the sole supplier to Aston Martin in 2002. In the discussion section, several conflicting trends of leather in automotive interiors will be analysed and new approaches proposed.

Figure 3.11 RCA MA Vehicle Design 2015 Jaguar Project: Laser cut Leather Seat.

Several MA Vehicle Design live-client projects facilitated meetings with relevant designers from industry, such as Audi (Rimmeli), Fiat (Wunninger and Jensen), Nissan (Winsor) and Jaguar (Miller and Druka) [Figure 3.11]. Here, I used the opportunity to question the social and cultural histories of leather in transport, with upholstery traditions from the age of horse and cart. I learnt of the importance of comfort in seating, and the evolving integration of sensors, actuators and navigation systems, towards autonomous transport, with leather's potential as a touchpoint and authentic interface. The high specification requirements within the automotive industry currently favours leather upholstery as a dependable design that provides a required service over many years. This is due to the unique 3D fibre orientation of collagen fibres in skin. Furthermore, I learnt about existing alternative fabrics and the perceptions of them. In the process, questions arose as to whether current knowledge of material and digital skill can respond to changing usage in car interiors. Informants raised the waste issue found in their production. This led to meetings with Rolls-Royce's materials team in Goodwood and in Northampton, working on an experimental interior, the result of which later shaped my prototype creation.

Regarding the informants in the field of Fine and Applied Arts, Laura Youngson Coll was trained at the RCA in Fine Art sculpture, and went on to work in bookbinding for a leatherworking firm in London, alongside her own work in vellum, which has been displayed at Jerwood Makers Open in 2017 (McNay 2017). Her connection with Northampton came through an archaeological leather interest group. Laura's work, including an object called "geodesic lichen" – crafted from veg tan leather and wire – inspired me; this was a precursor that brought the worlds of leather and fungi together in an artistic form, full of biological detail and understanding. My practice would build upon this connection between the Linnaean kingdoms of fungi and animals, and blend mycelium with leather shavings as feedstock.

Visits and contact with the principals of Walsall-based manufacturers of equestrian saddles led to the discovery of waste streams in the factory consisting of high quality veg tanned hides that had been cut by dye tools, leaving unevenly sized off-cuts behind. This resulted in the development of creative concepts and was framed as a student workshop in 2014 to creatively reuse and add value to leather waste. This parallels a RCA Design Products project with Brookes Saddles, up-cycling their offcuts and by-products into design-led artefacts such as spectacle frames; *Specs* by Sukjin Moon, MA Design Products 2012.

Turning our attention to the leading designers in the discipline, their special fields of interests in line with my own research are discussed below:

The Northampton-born designer Bill Amberg is regarded as the leading designer in the UK currently working with leather (Richardson 2005). and his artefacts that have been featured in the cover story of Crafts magazine July 2018. For a considerable amount of time, Amberg has been experimenting with the structural self-supporting properties of thick vegetable tanned hides and laminated tiles from offcuts, which he referred to as *Stacks* (Amberg 2017b). Amberg is a liveryman at leathersellers, a trustee of the leather museum, and has curated the Exhibition *Leather- Then and Now*, hosted at Leathersellers Hall during the London Craft Week 9-13 May 2018. Reviewing the show, Green (2018) remarked that, in almost all the objects on display, it is clear how the historical has influenced the contemporary. Age-old traditions like hand-stitching and hand-cutting are proudly featured alongside contemporary craftsmanship. Green then summarises that leather continues to be relevant, as “with a spike in the trend of ‘buy once, buy well’ and ‘Make it British’, good craftsmanship and locally sourced materials are more desirable than ever.”

Figure 3.12 Thomas Leech RCA Design Products MA Work Station, 2017 (Photo: RCA).

Representing the industrial cluster of leatherworking in the Midlands, a leathergoods supplier in Wellingborough in the county of Northamptonshire sought digital skills to produce leather goods, which could be filled by design graduates; as does the saddlery in Walsall, which invested in a water-cutting table for their equestrian saddle production. Car manufacturing plants in the region use a pattern/cutting table to optimise their leather production, and gain expertise in micro perforation and laser weakening in automotive interiors. This corresponds with the leather technology institute in Pirmasens in Germany, which operates an oscillating cutting table for digital upskilling of their industry partners. Scottish Tanneries collaborate with design education, using laser cutting, and RCA industrial design graduate Alexander Taylor, who collaborates with Adidas' *Futurecraft* Shoes, developed a CNC milling process for a seamless piece of leather [Figure 3.13], so "to transform leather into a resource for advanced performance footwear" (Designboom 2015).

Figure 3.13 Adidas CNC Machined Footwear (YouTube Screenshot, 2016).

Of note, Sruli Recht has been innovating with the material such as “Apparation” translucent leather and also a lightweight bonded leather onto a high density matrix in connection with the ECCO tannery in Dongen (Ecco 2017).

To conclude the overview of exploratory leather interrogation, Jorge Penades forms “structural leather” through shredding and forming with bone glues into moulds, robust enough to be used in furniture. He is using production techniques from other sectors such as compressing his material in iron moulds (Solanki 2018: 13).

These observations led me to reflect on my methods of observation, making them more specific to the design process as outlined in the Methods section, as well as the literature on Design Research Methods (Jones 1982; Aldersley *et al.* 1999; Rogers 2013).

3.4 Research Outcomes and Analysis

3.4.1 Reflection

At the beginning of the research, my approach was loosely defined as exploring and evaluating innovative uses of leather. My aim was to connect this with the regeneration of shoe manufacturing and leathermaking in the UK. This approach evolved, following fieldwork and observing emerging practices at the Royal College of Art (RCA) and their graduates. The context of the Circular Economy became clearer, and the research question was shaped to address an enquiry of “How leather can be used as a sustainable material of choice for the future?” My sampling strategy for gathering information advanced as the research progressed; data and insights were obtained from locations of leathermaking, through observing leather technologists and designers, and from reflecting on my own practice.

Whilst reviewing literature (chapter 2), I came to notice the necessity to understand the science of leather technology and its community. At the same time, I observed that the field of eco-inspired materials was emerging, and noted that a new generation of designers were actively engaged in the process to 'rethink materials for a sustainable future' (Franklin 2018). Through comparisons of materials, processes and applications, I assessed the relationship between current leather practice and the potential for sustainability. As discussed above (sections 3.2 Prototyping Circular Practices and 3.3 Observations in the Field), it became apparent that there was a knowledge gap in the scholarship concerning leather in the context of eco-informed material choice.

Exploratory workshops with students, that I initiated and conducted in the early stage of my research, confirmed the potential of addressing waste minimisation in leather, through design. These 'pilot' studies also helped me to trial an interest in the question by academia and industry partners. The insights identified the potential of cutting yield optimization, with a focus on tessellation and nesting. Other aspects of digital technology such as laser scanning, cutting, engraving, and CNC machining were explored in the practice, extending to the integrated physical digital practice of *Hybrid Craft* (Golsteijn 2014).

However, I felt that I had to move on from a focus on rapid prototyping approaches, as the leather material properties do not conform to the designer's intent. Leather is found to be stubbornly nonuniform, as it originates from heterogeneous animal skin. In addition, the properties can be widely influenced by the tanning process, which warrants further investigation. In addition, the environmental, social and economic impact of leather practices have been found to have a complex nature. This requires more thorough guidelines for designers and users, to assist them in appreciating and making full use of the potential that leather can offer.

Covington (2020: 658), therefore, calls for a paradigm shift in thinking. He considers that the sustainability of the global leather industry is dependent on its ability "to address the fundamentals issues as perceived by society in general and to make the most of developments offered by leather science." Here, he takes a stance where science and technology are integral parts for making tanning sustainable. In contrast, the concept of sustainable Product Design crucially recognises the need for designers to embrace the social and ethical impact of their designs over time, in addition to the environmental impact (Fuad-Luke 2009: 12). This then led me to a more systematic research of leather material, processes and applications in the context of eco-informed material choice, which I consequently explored through practical experiments (see chapter 4).

3.4.2 Between Theory and Practice

The framing of my research evolved from an early stage around collaborative practice, craft and eco-design, to a more fully formed appreciation in the later stages of framing my research through the model of the circular economy. This came about through my projects presented at postgraduate research design seminars, and subsequently by taking on feedback from participants and supervisors. Having concluded collaborative workshops with undergraduate students, I then decided to collaborate with scientists and businesses to solve systemic problems. This was carried out through the NERC funded doctoral *Innovating for Sustainable Development* programme at Imperial and Reading universities, which lasted from December 2016 to March 2017, through a series of facilitated residencies, workshops and pitches to businesses and funders.

Following Manzini's (2016) idea of cosmopolitan localism of sharing knowledge and adapting it to local contexts, I came to a deeper appreciation of Collaborative Design, which I applied to the communities of leather. I was seeking out collaborative activities and researched co-design approaches, and was also interested in synergies and the contribution that design could make. According to Charney (Franklin and Till 2018: 114-15), connectivity and knowledge sharing are "a way we can deal with complex problems in the world, with craft design and making can be a tool for social change." At that time, I realised that the real importance of the RCA for us design researchers was its emphasis on collaboration. To illustrate, the Across RCA workshop (2013) provided me an opportunity to work with Nissan on future scenarios, where car sharing was part of a connected urban transport; and a Design Practice consortium and workshop series (2014) led to synergies with material designers at UAL London and Kingston Universities. However, the issue of authorship in co-design and collaborative work is a contentious topic for discussion. I, therefore, must clarify my own contribution to collaborative projects that I undertook in course of the research (see chapter 5). This includes my involvement in undergraduate dissertation supervision, where I directed students' output for a new application of conductive coating on leather.

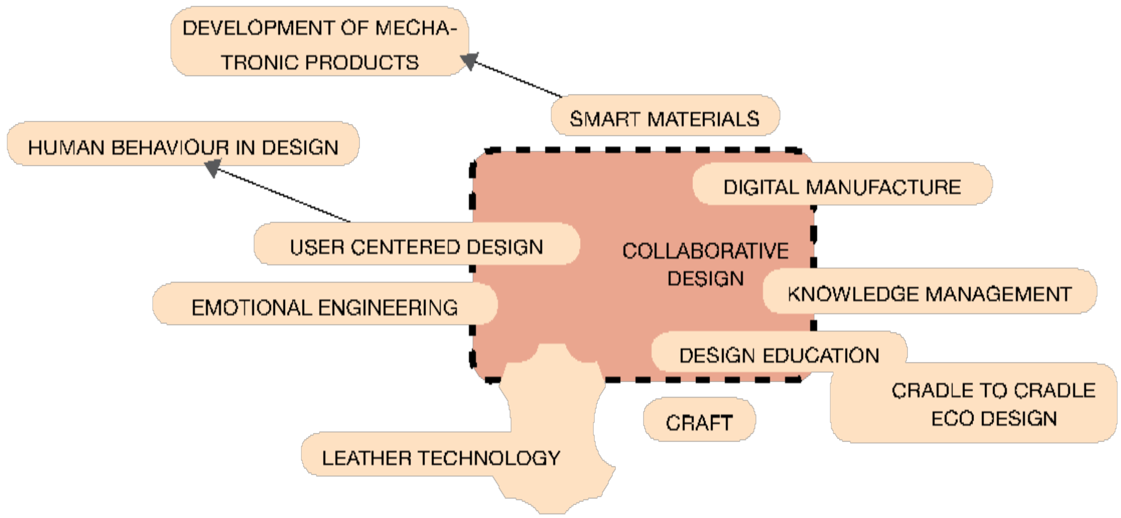


Figure 3.14 Framing of Research and Trajectory.

Shown in [Figure 3.14] above, in the early stage of research, I set out with the ambition to undertake new product development, through engagement with the leather and footwear supply chain.

Through practice-led research, exemplary prototypes were presented using recently developed technologies such as rapid prototyping and artefacts, that when put to use and tested, reveal new ideas and research opportunities. I developed through practice a knowledge base for leather and requirements for potential applications, and explained this through diagrams. These are included in a glossary / handbook where research and practice converge. The illustrated handbook codifies my tacit practice.

My major insight in the pilot studies was the potential of co-design approaches relating to leather. Several scholars, such as Manzini (2016), Papanek (1984) and Thackara (2005) observe social innovations by communities worldwide and identify design as a catalyst, creating visions of possible futures. The *breadline* and *cutting out waste* pilot studies tried to construct case studies within the context of shoe and leather manufacture in India and the United Kingdom, analysing sustainable Design and co-design initiatives where designers tackle problems in their environment, and highlighting programs with grassroots and enterprises.

I would argue that this research contributes to the methodologies for partnership practice relating to social and sustainable design; the scope and reach of opportunities in education and off-campus was explored. The challenge is working with multiple partners ranging from research, community grassroots, users and external agencies, with varying stakeholder intentions. As exemplified in my pilot, the Product Design students and myself benefitted greatly from interacting with multiple professional practitioners and through working with real constraints. For the first time, the students faced the issues of socially responsible design, user focus and resourcefulness.

It is most important to understand and appreciate the value of designers as they significantly influence fashion and product demand. It is also important to recognise that designers do not want to be restricted to synthetics materials, or heavily coated leathers of limited scope. Leather can always offer designers – and in turn consumers – an attractive and flexible alternative to mass production and materials (Kráľ *et al*. 2014: 9).

Chapter 4

Practical Experiments

This chapter contains the practice and experimental work undertaken during my research. It presents each of the experiments with descriptions and highlights findings and relevant links to the other work. The experiments cover ground from fibre experiments, to material experiments, to material applications/processes. The rationale is to present experiments that are progressing from a micro scale (such as to view the composition for waste fibres under a microscope) derived in a laboratory environment, to full-scale (with table-top-sized dimensions for these experiments), considering applications and the scale of manufacture.

The practice has been arranged in three themes that relate to circularity: sustainable future leather materials; processing and manufacturing; and, application. Firstly, several of the created material samples were presented, illustrating how practical materials experiments were carried out. These were then reviewed and grouped under the categories of A) creation of bonded fibres from leather waste; B) recycling of leather off-cuts, and C) deep 3D relief effect. Following from this, the second section discusses several experiments I undertook to find ways incorporating sustainable processing and manufacturing for leather. Lastly, the final section demonstrates the prospective, sustainable future leather use, which culminated with my Final Projects in a display.

While reviewing relevant literature, I identified the amount of solid waste produced in the tannery; and thus, investigated closing loops by reconsidering waste streams, which is a concept of circular economy. When carrying out my fieldwork in leather tanneries, I selected to work with waste shavings. Through review and observation, I came to realise what other designers have done so far with waste; through the pilot studies of *breadline shoes* and *cutting out waste* projects, I could see the scope for reconstituting collagenic fibres and reconfiguring leather off-cuts from leather goods manufacture.

Figure 4.1 Illustrating the Structure of Practice Section.

To highlight the consistent structure across physical samples and their display and the written work, an identifier is introduced in a rectangular ‘tag’ or ‘index card’ format, containing project descriptors including title, date and area with a representative image [see Figure 4.1].

The chapter, using a simple critical approach, explains why a particular area of work was done, why it is important, and the scope and detail of different experiments in each area. Then the findings are presented with the scope, limitations and implications from these experiments and for successive areas of work.

4.1. Practical Material Experiments

4.1.1 Creation of Bonded Fibres from Leather Waste

This series of experiments on “upcycling waste fibres”, undertaken in a fibro science lab at Kyoto Institute of Technology, Japan, investigated chrome and vegetable tanned fibres from production waste, which I collected from tanneries’ shaving operations in the UK (chrome and vegetable tanned leather) and in Japan (chrome tanned leather).

As illustrated in chapter 3, the amount of solid waste produced in a tannery process prompted me to reconsider waste streams and 'closing the loop' of product life cycles, with a view of the Circular Economy. A sustainable approach is the upcycling and reusing of the production waste of leather fibres from the tanning industry. Current practice is that the leather fibres are discarded into landfill, or are being incinerated. In the sites that I visited, it was apparent that waste management needed more effective systems in terms of how it is collected and reused. Production waste fibres are of chrome or vegetable tanned origin and come in the form of shavings and dust in different consistencies. When carrying out my fieldwork in leather tanneries, I selected to work with leather fibres from the shaving process, which amounted to an average of 99 kg per tonne of processed hide, i.e. 10% (Daniels 2013). The technical editor of International Leather Maker Magazine advised that the shaving operation produces dust which should be sold to add value. However, chrome tanned shavings make disposal complicated (Flowers 2019).

The Scope and Detail of the Experiments

My initial objective was to create a new material and new applications using shavings of leather waste. In my research proposal, I set out to examine creative usage of leather and related hybrid materials in broader cultural contexts, such as Japanese paper, lamination and composites manufacture. Some of these processes were preserved in Kyoto, Japan and were transferred into modern manufacture. This research fieldwork was supported short-term with a scholarship from the Japanese Government’s Student Services Organization JASSO, and was carried out under the auspice of Kyoto Institute of Technology. The institute was a research university with a history of research in support of the silk and weaving industry, which developed into fibro science and established Kyoto Design Lab as an incubator for material and design innovation, with designers working in an interdisciplinary process (Kyoto Design Lab 2016).

Figure 4.2 Photographic Record of Fibro Science Lab Experiments, 2018.

The *Washi* Lab in Kyoto

The process of making traditional Japanese paper *washi* has been found to be suitable to bind and reconstitute leather fibres [Figure 4.2]. Experiments were undertaken from 9 to 28 March 2018 during a residency in Japan. In my experiments, the fibres are converted into a range of bonded materials through a traditional method of paper making using fibre pulp [Table 4.1]. Shavings and water are mixed and mulched in a food processor until the pulp loses any texture and has the consistency of a slip, which is scooped onto a screen and agitated in water to spread the fibres evenly. The result is a handmade paper-like fleece that retains a texture from the screen's mesh [Figure 4.3]. Guided by a skilled lab technician who had mastered the art of paper-making, and supported by a researcher-in-residence, I came to optimise the fibre composition through the shredding and pulping with water in a ratio of 1:1 by volume, and pressing the waterlogged composition with felted paper to remove any surplus water. Samples were placed on felts in a temperature-controlled room to dry overnight. The samples were discussed, filed and later brought back to the UK for undertaking further processing and tests, including microscopy and tensile testing.

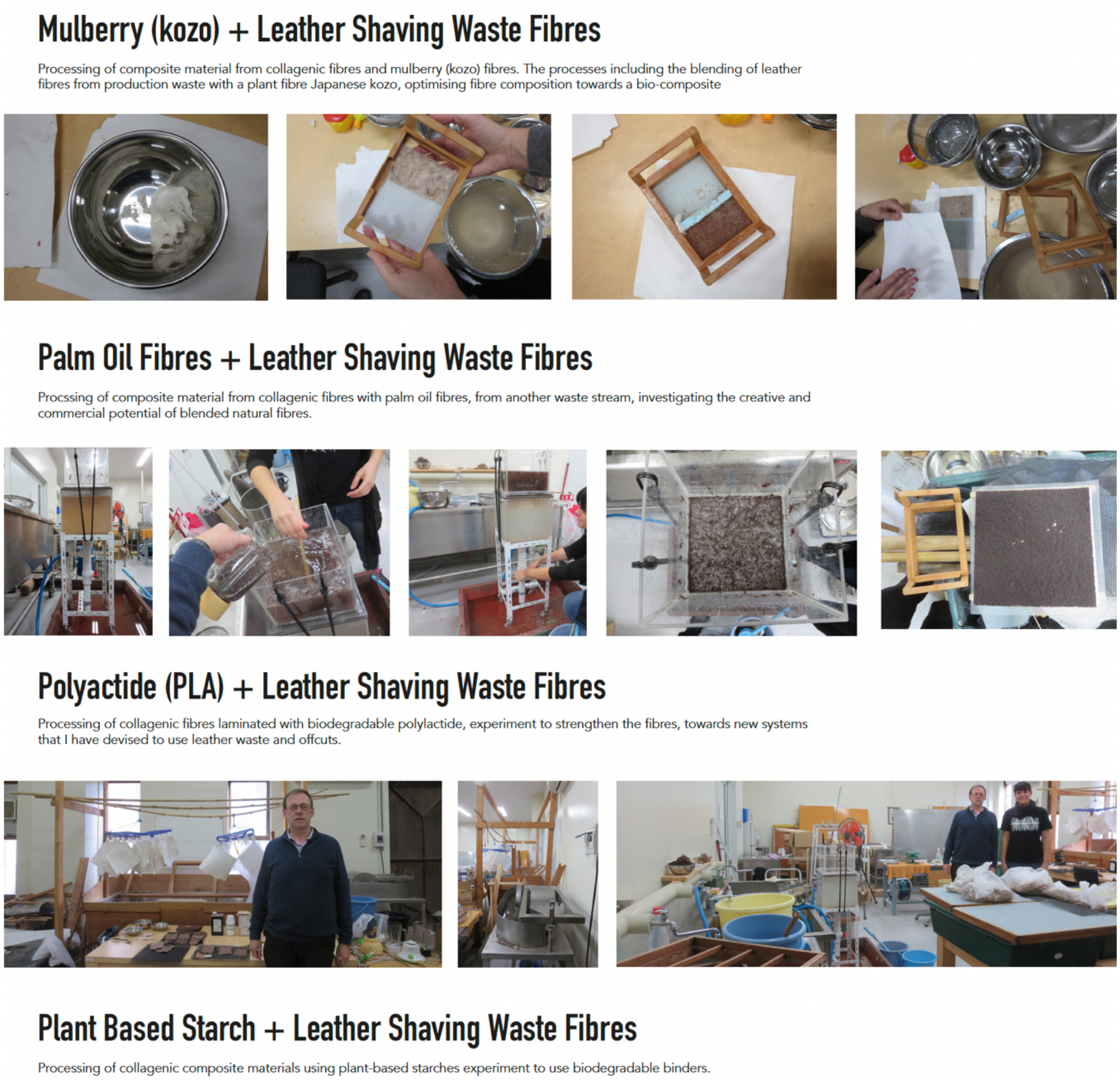


Figure 4.3 Fibre Generation in Fibro Science Lab, 2018.

Having established the suitability of the approach and acquired the manual skills for the process, further experiments were facilitated by a vacuum suction apparatus whereby leather pulp is suspended in water, poured into a container and drawn through a filter, using vacuum suction. This warranted an even spread and denser composition of the fibres in 220 x 220mm sized sheets.

My trials blended leather fibres from chrome and vegetable tanning production waste with several plant fibres, and binders [Figure 4.4]. I conducted ten experiments that included blends with mulberry fibres and palm oil fibres. Rice starch and persimmon were proposed as traditional binders that I tried out on samples. Also, liquid polylactide (PLA) was applied and leather fibres were suction pressed into cotton fabric and polyester meshes as a backing matrix. I visually inspected the results against leather fibres that were formed without any binder [Figure 4.3].

Whilst in Japan, I discussed the scope of the experiment with a materials scientist at the university. It involved a lightweight bonded product using vegetable tanned leather fibres; the backing was to be made to utilise a biodegradable matrix from rayon, which is a biodegradable cellulose fibre. (Okubayashi, in conversation 2018).

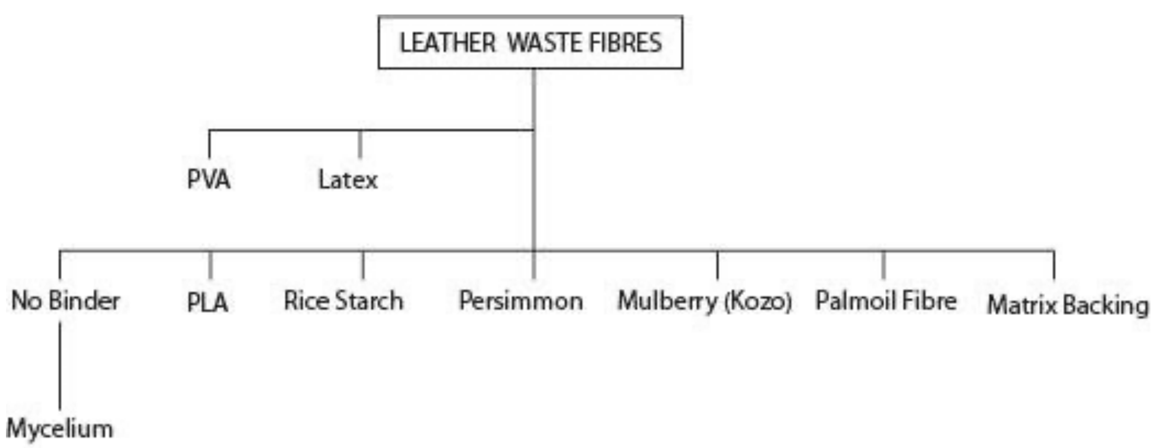


Figure 4.4 Illustrating the Structure of Leather Waste Fibre Experiments.

The experiments resulted in a collection of new material samples as follows [Figure 4.5]:

1 Sample of leather waste fibre, laminated with biodegradable polylactide (PLA).
2 Sample of blended leather fibre with rice starch as an adhesive in the papermaking process.
3 Sample of composite material blended from leather fibres and mulberry in a ratio of 2:1 – fibres from the inner bark of the paper mulberry (*kōzo*) bush. The mulberry fibres

strengthened material properties; it improved tactile features and made the processing easier; it also benefitted from traditional papermaking technique.

4 Sample of composite material from collagenic fibres with palm oil fibres. The processes consisted of blending leather fibres from production waste with a plant fibre from another waste stream. Prior to my arrival at Kyoto Design Lab, the creative use of palm oil fibre has been recently investigated by the designer Nataša Perković at the institute (Kyoto 2017). This investigated a commercial potential of blended natural fibres from waste.

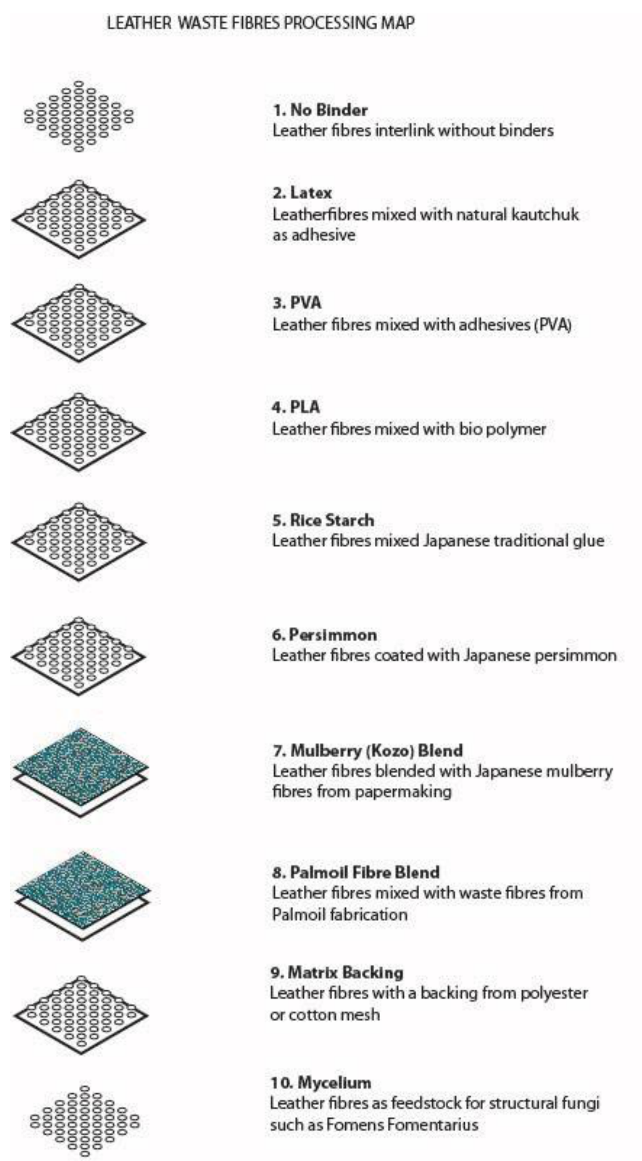


Figure 4.5 Illustrating Leather Waste Fibre Experiments.

Upon my return to the UK, my experiments with waste fibres were scaled up from small to larger samples, and progressed from material experiments to processing and application [Figure 4.6].

- Mouldmaking and spray coating application of collagenous fibres with and without resins, binders and foils for upscaling of production, on display at RCA Work in Progress Show (WIP) 2019;
- Several artefacts and prototypes with composite and binders were experimented with during December 2018 – January 2019. The leather pulp was applied to matting inside the silicone moulds; the same process was applied to artefacts that are presented as final projects, in section 4.3.1.

The experiment progressed from an individual project to a collaborative effort. Furthermore, material properties were explored, and future uses proposed as desirable properties were exhibited, but their value has not yet been fully realised. My experiment showed that the fibres are mouldable into forms, lightweight, can be tinted with a range of dyes, developed into sheet material or cast into blocks. The material experience resembles that of cork, in that it is warm to touch, lightweight and flexible. The project is working towards a zero-waste manufacturing process.

Limitations: It is a craft process; thus, industrial papermaking processes and skill is required to scale up. Samples were shown to perform poorly with regard to tensile strength. The majority of shaving waste will come from chrome tanned processes. Plans for eventual biodegradation will remain an issue as extraction of chrome is complex.

Experiment importance lies in the scope for innovation. It adds to the literature on leather fibre composites. The composite materials from collagenic fibres are related to new emerging manmade materials that are presented as vegan leather or alternative leathers.

The implications from these experiments and to successive areas of work were insights on suitable adhesives, fabrication and potential industry partners in the leather industry. There is an opportunity to develop a collagenic fibre-rayon composite, responding to market interest in novel bio materials with good sustainability credits. In particular, there is a demand for lightweight materials with enhanced performance properties that address the “end-of-life directive” in the automotive industry.

Date	Prototyping Process
8 Feb 2018	Induction. Researchers and technicians were consulted about corresponding processes used within their studio practice. Assorted leathers and fibres were inspected, waste leather shavings sourced.
8 Mar 2018	Grinding and shaving of assorted leather fibres to size, acquisition of traditional binders – *nori* paste
9 Mar 2018	In *washi* studio with leather shaving fibre, pulp 5 samples, acquire scooping technique.
19 Mar 2018	In *washi* studio with leather shaving fibre pulp 5 samples, technician (*Shiki san)* created 2 x matting with vacuum filter apparatus. Advised on fibre length and adhesion.
20 Mar 2018	In washi studio with leather shaving fibre pulp 3 samples, 3 layered composites with PLA, 1x palm oil fibre 50%.
22 Mar 2018	Several samples, persimmon applied on 4 samples, applied and melted PLA with hot iron, laminated to 6 layers
23 Mar 2018	Four samples with vacuum sieve apparatus. 1 fabric bag mesh with pulp on the reverse side, 1 fabric bag mesh with PLA on back, cotton handkerchief on back, 1 sample with 30% *washi*, 10% palm oil fibre, 60% leather fibres.
28 Mar 2018	Chrome shavings from Japanese tannery applied, several leather fleeces to optimise fibre size. Sample with 40% *washi* 60% chrome leather fibres. Sample with 50% chrome 50% vegetable tanned fibres. Labelling of fibres and boxing for scientist's future use.

Table 4.1 Summary of the Experiments in Japan.

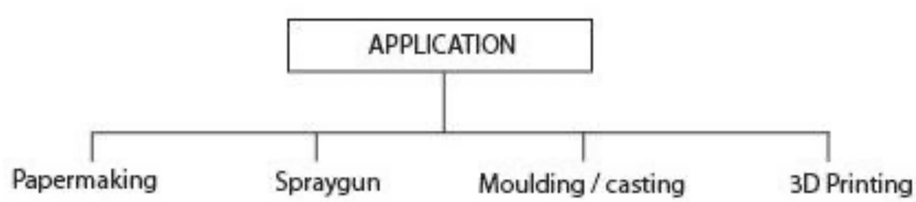


Figure 4.6 Illustrating the Structure of Trialled and Proposed Applications of Pulped Leather Waste.

The Scope and Detail of the Experiments

My objective was to learn how leather technologists stabilise fibres into a material that has performance capabilities. A trial was undertaken in a laboratory setting and conducted by a technologist in the finishing area of the ICLT. Old and current practices were explained to me, and assorted resins were applied with a spray gun and in steps, with a process as follows [Table 4.2]:

Step	Process
1	Resin Impregnator (Stahl RI -115) with good grain tightening property, compliant with the Zero Discharge of Hazardous Chemicals (ZDHC), substituting standard synthetic PU.
2	Resin Butadiene (Stahl RB) mixed pigment with viscosity of 13, applied through roller coating and pushing. Traditionally, split leathers were treated with Irish carrageen seaweed backing, used as a thickening/gelling agent.
3	2nd coat RB applied, stops on surface, does not sink in, plated in heat press at 55C.
4	3rd coat repeat RB applied, plated in heat press at 55C.
5	PU Topcoat (HM-3139) Silicone Burnish for abrasion and scuff resistance, a 2-part automotive PU with silicone modifier, for film forming + Wax Emulsion (Fi -50)

Table 4.2 Process of Top Coating Leather Waste Fibres, 12 September 2018.

The results were that the application of top coat chemicals improved

the adhesion of the fibres. Also, good haptic qualities can be created with polyurethanes, silicone and wax treatment. Mechanical tear test showed that the material still performs poorly. Thus, a follow-up experiment was undertaken with a polymer foil and 2-part adhesive (Stahl), brushed onto the back of the foil and set in press [Figure 4.7, right].

Figure 4.7 Application of Topcoat and Foil Finishing, September 2018.

The fabrication in silicone moulds [Figure 4.8] has been undertaken in a sculpture department, and appropriated casts and moulds for the lay-up process. This resulted in an outcome that could be evaluated and displayed.
As for limitations, the lay-up process and drying was found to be time consuming. Application by spray gun was trialled, but limited due to the viscosity of the pulp. Future experiments could follow up with an altered set-up, perhaps through adjustments to the spray gun nozzle.

Figure 4.8 Process of Leather Waste Fabrication in Silicone Moulds, 2018.

Result in Material Sample Fibres under the Scanning Electron Microscope (SEM)

This section presents the evaluation of one particular sample, i.e. 1 x vegetable tanned pulp mat that has been persimmon coated; this has been compared with specimens of other fibrous materials including pineapple fibre and mycelium. The Scanning Electron Microscope (SEM) at ICLT was used on 12 September 2018. I was trained by laboratory staff to operate the SEM, selecting the suitable resolution, finding details and recording the photography. Resolutions of 70, 350, 700, 1200, 6000 are used under the SEM, with the specimen coated with a gold splutter apparatus. The SEM samples were photographed and recorded [Table 4.3].

The images all show the cross section with a horizontal layering of the cross-cut fibre bundles (see table below) with a description and comparison with cross sectional images of mycelium and pineapple fibres.

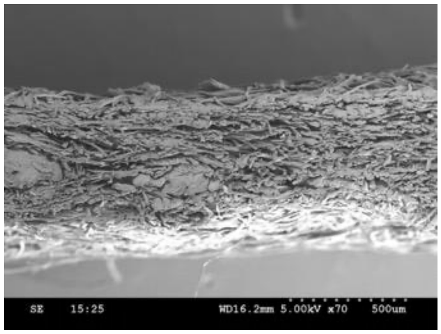
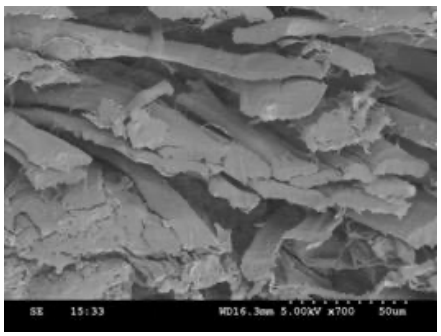
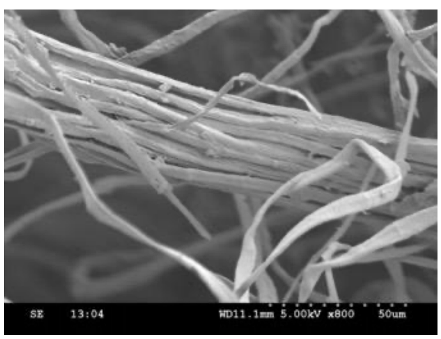
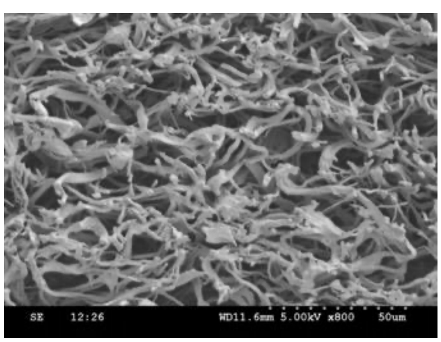
Scale	Photographs of the Specimen	Description
a) 70 X		Specimen of vegetable leather and mulberry fibres blended without binder and persimmon coating applied. At x 70 enlarged the horizontally layered, loose network of fibres is noted.
b) 700 X		No discernible difference between leather and mulberry fibres, with denser fibre bundle on bottom left. Some nanofibers were noted to have low density without wider entanglement.
c) 800 X		Pineapple fibre bundle, tangled and loose strands; horizontal orientation noted.
d) 800 X		Mycelium rhizome is evenly distributed throughout the entire specimen. No directional orientation or layering of density noted.

Table 4.3 Scanning Electron Microscopy of Blended Leather and Mulberry Fibres (a & b); Pineapple Fibres (c) and Mycelium (d).

Interpretation would benefit from a viewing angle other than cross section, and another set of SEM images comparing bovine bonded leather.

Discussion/Limitations

During my experiments, I considered the bonded materials to be 'green composites' that fall into a new category of natural and waste based composites adhering to sustainable design principles (Baillie and Jayasinghe 2017). Nishino (in Baillie and Jayasinghe 2017: 25), demonstrated with cellulose fibres that composites can improve characteristics from cellulose macrofibre through grinding and filtration towards nanofibres; with dramatically increased stress strain characteristics and performance. Nishido explained that the large increases of mechanical properties of nanopaper are mainly due to increased network and nanofiber entanglement density. My tests indicated that I did not achieve any comparable results with my lab setup. Future research may be undertaken with hydrolysis, micro fluidiser and grinding apparatus.

Figure 4.9 Tensile Testing of Leather (7 in Upper Row)
and Blended Leather Fibres (6 in Lower Row).

A task has been undertaken to test and calculate the tensile strength of several fibres and leathers that I have used in my experimental exploration. In the discussion, I aim to relate my findings to other common material properties [see Appendix III].

Material properties were determined through tensile testing with an Instron apparatus. Thirteen waste fibre and leather samples were tested on strain and elongation, so as to relate the physical performance to other natural fibres, elastomers and polymers [Figure 4.9].

When undertaking tensile tests in September 2019, my chrome tanned mulberry blend fibres of 0.8mm thickness achieved a load of 24N and an extension of 2mm. In comparison, a vegetable mimosa tanned specimen of 2mm thickness achieved a load of 300N at an extension of 17mm. Chrome tanned upholstery leather achieved a load of 380N at an extension of 40mm. The resulting tensile strength of my blends is considerably lower than that of a real leather. For this reason, I consider that this composite may not be a suitable material due to its inferior tensile performance. The main advantage of this material is that it is made from a production waste. In addition, the material displays paper-like haptics and light-weightness. Subsequently, I created a number of fabrication processes, and proposed a glove compartment and a door panel in an automotive application to test its capability for the sound absorbing quality. The implication is that more thorough tests are required to constitute a more stable composite, which offers better tensile strength characteristics. My samples 2) and 3) with cotton and nylon backings respectively demonstrate a higher tensile strength [see Appendix III]. It is anticipated that an investigation with a range of backings might lead to a suitable product.

Through this work, I came to realise the area that I wish to focus on for the future experiment; this would involve not trying to disguise the characteristics that the reconstituted material possesses. For example, commercial examples tend to display an artificial grain surface, appearance and properties through polyurethane; they also emulate products such as leather board and so called "e-leather." To set apart from these trends in the market, I was determined to pursue applications that utilise a mould making process that results in three dimensional forms that could lead to industrial applications. One of the examples reproduced detail from the mould, such as audio speaker perforation inserted into a door panel of a car [Figure 4.20].

My focussed experiments echo the future prospect of bio printing that Kral (2014) predicts. He considers that a futuristic technical avenue of development involves producing a sheet material by converting collagen emanating from raw hides and skins through smart material processing technology. Furthermore, he predicts the benefits that the leather products industry will have whilst the leather processing industry changes into a higher-tech form of biotechnology. However, these avenues (Catts and Zurr 2012; Mayer 2019) – bio-fabrication and pure collagen – are outside of the scope of my research.

Turning our attention to the need of binders or backing matrixes, the results show that the performance of elongation and tensile strength were improved through the backing mesh and binders. My examples are typically based on cellulose or synthetic polymer materials. These could negatively influence my intention for creating a material that has a low environmental impact. Based on the experiments, Montalti, Karana, Zeuw *et al*. (2018) reported the potential of mycelium – chitin protein and a building material of nature – and its commercial viability. Through this work, I was prompted to consider bio fabrication with natural fibres, and examined the methods for incorporating fungal mycelium and the development of new materials. Mycelium has been shown to be versatile, strong, and can be cultured in mould. Some mushroom species are found to be non-toxic which benefit the use and biodegradable which addresses end-of-life.

This leads to the question as to whether there is scope to replace binders with chitin for the creation of bonded fibres and composites through chitin. One of my experiments led to a sample and the concept of collagenic composite materials using chitin, fungi, *fomes fomentarius* (horse-hoof fungus) and *trichophyton* (athlete foot fungus). I have set out an experiment to grow *fomes fomentarius* on cellulose and collagenic fibres from a tannery. With support from a London-based biodesign consultancy, I cultivated a mycelium batch to use with leather fibres. Fungal growth is terminated by heat and this adversely affects the collagenic structure of the leather fibres.

The idea here was to harvest a composite from mycelium, cellulose and collagenic fibres. The process would involve firstly introducing a species of fungi (*trichophyton, epidermophyton* and *microsporum*) that is known to digest skin/leather; and secondly, using this initial digestion to make the material more palatable for secondary species such as *fomes fomentarius* and other structural fungi; and finally, binding the substrate together (in a private conversation with Granter, 2019).

Taxonomic history and synonym information has been drawn from sources in the biodesign community, in particular from the British Mycological Society (2019) and Kew (2019). This experiment is ongoing; mycelium of *fomes fomentarius* and *trichophyton* has been grown on agar and the development of the spores has also been documented through light microscopy.

4.1.2 Recycling of Leather Off-Cuts

Practical experiments were undertaken under the theme of "upcycling of leather off-cuts." The experiments focussed on the by-products from leather goods manufacture that were the result of cutting panels from hides with uneven contours.

By far the largest quantity of waste is generated at the cutting step; the cutting rate for leather can range from 25-60% (UNIDO 2012). Waste streams identified in automotive upholstery creation amount to an average of 50%; saddlery 30%, and shoe leather 10% respectively. For this reason, I proposed that artefacts were to be created from small panel sizes, by redesigning and developing leather material.

For this investigation, I reviewed the sources of waste. During a visit to a saddlery in Walsall (19 July 2013), I examined the off-cuts of uneven size that have been stamped by dye tools [Figure 4.10].

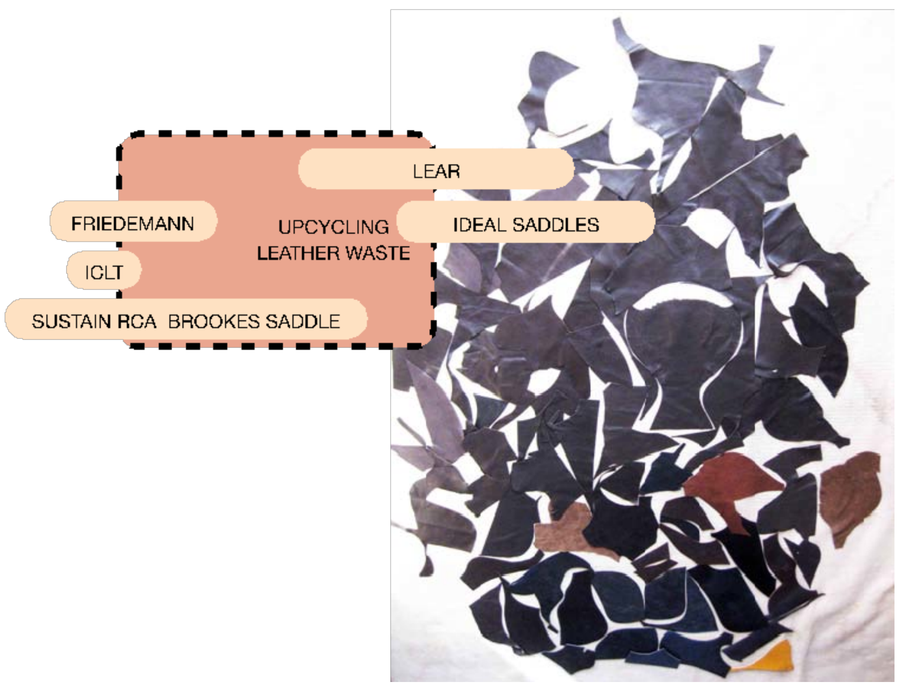


Figure 4.10 Example of Saddlery Waste Recomposed.

I devised student projects with undergraduate students, supported by two members of the staff and leather institute that acted as a client. The assessed item was called "designing out waste." The project ran over 11 weeks from September to December 2014 [Figure 4.11].

Figure 4.11 Lamination and Layering of Off-Cuts, 2014.

The material experiment explored lamination of layered off-cuts and fabrication, including CNC milling and turning. Moving from material exploration, the students then focussed on finding new applications and manufacturing processes. From the submissions, one project is discussed below for their approach.

Student A used vegetable tanned leather from saddler waste to prototype a personalised walking stick handle; that was laminated to blocks and then CNC machined on a 3 axis Roland router, using a file created in SolidWorks software. This is a subtractive manufacturing process, with some finishing processes derived from shoe manufacture such as the buffing of leather heels and soles. Student A explained:

> The way I tried to further save leather through my designs was by using nesting, in which I would use tainted or imperfect pieces of leather, which I would then use as a middle piece in my stack where it would not be seen. … As well as this, I used the same piece of leather

> for more than one cut out, to save leather. I tessellated my pieces of leather so I could fit the most amount of cut outs from the least leather possible.

Here, economical use of leather off-cuts was one of the prime considerations in his design process. Analysis of this product was that it was comfortable; although it was heavier than plastics, products exhibited superior haptics through striped leather aesthetics and offering high value to the product. It is notable that students appropriated the lamination process of plywood. There is also the reconsideration of leather – which is predominantly fabricated as a sheet material – into a 3D artefact with potential applications such as gear knobs and levers in car interiors, through prototyping tools such as woodturning lathe, copy lathe and CNC process, which has been explored extensively by Sintobin (2018) and Taylor (2014).

4.1.3 Deep 3D Relief Effect with Calcium Chloride

A series of lab tests were trialled to achieve three dimensional effects onto leather to get tactile material suitable for embedding sensors. The practical experiments included embossing and debossing, forming and application of chemicals. Here, my discussion focuses on trials with calcium chloride salts to imbue new functional properties. For design, its importance is 1) to embed smart materials properties; 2) to create a decorative two-tone effect; and, finally 3) to increase surface area, which might affect acoustic and thermal insulation properties.

From December 2016 to March 2018, lab tests were conducted. Drawing from 1940s patents by Willard Helburn, trials in the chemistry lab were undertaken, aiming to create a three-dimensional effect onto leather with calcium chloride and screen printing technology [Figure 4.12]. The invention corresponds with a common observation made in that the contact with calcium chloride shrank the leather boots of workmen handling the material. The formulation and application, however, is not described in any accessible information.

In addition, a number of applications were trialled to create this deep 3D relief effect that could lead to a corrugated material for structural purposes. The trials consisted of the following:

- application using a particular tactility (puffiness), such as integrated keyboards, switches or buttons;
- test combinations of soft and stiff properties in one material, such as fold lines or creases;

- and, recording the experiment and interaction with technologists and printmakers as an exemplar of cross-disciplinary collaboration to achieve novel artefacts.

Concentrated Calcium Chloride screen printed on blue suede resulted in a considerable 3D effect through overprinting over an area, which has previously been treated with *indalca*. This sample has not been washed and not heat treated in a drying chamber. It is reported that various chemicals may be employed, such as concentrated solutions of hygroscopic or highly ionisable agents – for example, calcium chloride, calcium nitrate, zinc chloride or zinc nitrate.

These trials led to a proposal for wider application, because calcium chloride is inexpensive and also has a low environmental impact. Consequently, the application might be undertaken with low investment equipment, tooling or set-up in comparison to a digital fabrication.

Figure 4.12 Trials with Calcium Chloride, 2018.

4.2. Sustainable Processing and Manufacturing

The aim here was to find ways to incorporate sustainable processing and manufacturing for leather. In workshop situations, I have observed a wide range of tannin processes including zirconium tanned leather, chrome, vegetable tanning as well as traditional smoke tanning. For the purpose of this experiment, however, I focussed on plant waste as tannins, which led to trials with cherry, alder, apple, mulberry and hop.

4.2.1 Plant Waste as Tannins

I set out to explore the process and manufacture of leather from plant waste material. I wanted to connect this with the concept of the circular economy, which advocated the integration of other waste streams.

My initial objectives were firstly to understand practices involved in tanning operations and to familiarise myself with the terms and the chemicals used. My role here was a participant-observer, taking account of production time and procedures in a modern tannery operation. Secondly, my tasks were to investigate possible alternative tanning methods to the chrome tanning, which dominates current practice. Thirdly, I was to explore rediscovery and the application of old vegetable tanning methods, covering plant wastes from forestry and farming.

Three areas of my research shed light on various aspects of the tanning process and its agents. The literature review revealed what was currently utilised in vegetable tanning. However, it was my fieldwork to ancient tanneries – Colyton in Devon, Bristol and Himeji, Japan – that intrigued me to delve into such tanning agents as mimosa and oak bark. Here, I observed the scale and range of tanning vegetable tannage, which complemented my understanding of chrome tanning as practised in the industrial districts of Arzignano in Veneto, Italy and Tatuno, Hyogo Province, Japan. I also learnt about the feedstock for vegetable tanning agents, which were the extracts from mimosa and chestnut, both of which took several months to transform the raw hide into leather. These were produced through industrial scale extraction (Silvateam 2013). Notably, vegetable tanned hides are a preferred choice amongst designers (Richardson 2005: 38; Amberg 2018: 39), presumably for its structural properties.

A five-day long leather applications workshop that I participated in Northampton, offered me practical experiments consisting of the machinery operations of the tanning drum and preparation of raw hide, to drying on a toggle frame. I also learnt for the second time to operate machinery during an exercise of retanning and softening of hides, through fat liquors in drums [Table 4.4].

Date	**Prototyping Process**
12 August	Plant waste was collected, and this was then shredded with water using a food processor and was bottled, which was referred to as "tea"; at this stage, this tanning content was to be determined via bell test.
19 August 1	Tanning experiment with cherry extract and bovine pelt of 1.7kg weight with a pH of 3. Preparation of a solution of 85g Sodium Chloride salt (NaCl) + 1.7l H2O to suppress swelling. For apple tannage, a bovine pelt of 440g in an Italprogetti laboratory drum was set-up. Then, 50g NaCl in 1000ml H2O was added to suppress swelling with 10 mins drum action, followed by 20g NaCl and drum action for 10mins. Added were 4.4g NS syntan substance with drum running for 1 hour. Then 1 l of apple puree was added.
2	Bring the pH to 4.5 with adding of 1% (17g) TRUPOTAN NS, a neutralisation syntan, which is to assist the penetration of tanning agents (Trumpler 2013).
3	Once the solution achieved a pH of 4.5, added 1l cherry tea + 300g cherry chippings to the drum and commenced with continuous drum action until 3 September.
22 August	During the process, on several occasions the tanning tea was topped up so as to increase the concentration; pH measured and physical test was undertaken, through cutting the leather's edge to observe the cross section for the level of penetration of tanning agent [Figure 4.13]. Added were 4.4g NS syntan substance with drum running for 1 hour. Then 1 l of apple puree was added and with continuous drum action until 3 September. pH testing 3.5, topping up of extract, cross section showed poor penetration just below the pelt's surface.
3 September	Measure apple pH 3.5 and cherry pH4. In order to achieve pH to 3.5, formic acids were added and the drum was left to run for 20 mins. Finally, 1% of antimould solution was added, and then the hides were removed from the drums and were washed, with leather hung onto a frame. Drum action was halted on day 20 (3 September) and partially tanned hides removed for washing and drying.
5 September	The result was reviewed by a tannery manager. The samples were then tested with the Iron 3 indicator method, but no reaction was noticed. Results deemed unsuccessful for cherry and apple. Six pieces of skins were dried on toggle frames for collection, and these have been cut to size and incorporated in the display.

Table 4.4 Vegetable Tanning Processes, 2019

The scope of the experiment was to investigate vegetable tanning processes with plant matter extracted from shredded bark, wood, leaves and fruits with water (Daniels 2013:10). These included chippings from cherry (*prunus*) tree bark and wood; alder tree (*alnus*) branches and leaves; mulberry branches and leaves; and, fruit waste from apple (*malus domestica*). I selected the plants for the non-volatile phenolic substances found in bark and many fruits, with the tannin content analysed for cider apples (Lea 1993).

Practical experiments were undertaken in the pilot tannery held at the Institute of Creative Leather Technology (hereafter, ICLT) in Northampton with stainless steel tanning drums from 17 August to 5 September 2019, over a period of twenty days. The details of the process of tanning with cherry and apple are described chronologically as follows:

Leather is made through a chemical reaction of tannins penetrating the skin and crosslinking the collagen inside the fibres. Through mechanical forces on the fibre network, the speed of reaction can be increased in rotating vessels; these vessels are similar to washing machines. They are equipped with inclined shelves, sticks or paddles in order to maximise the shuffling effect, for the load will affect mechanical action positively (Heidemann 2009: 528). Traditional vegetable tanning in a tanning yard with several pits requires the moving of the hides in the float and a gradual increase of the concentration; a process that can take ‘a year and a day’, and a considerable number of hides have to be rotated over this time. In contrast, the tanning with minerals such as chromium in drums is a matter of hours or days (in conversation with Barry Knight in 2018). I learnt that in vegetable tanning, the objective is to work with low float and then to increase the concentration. Assessment of the timing of when to change the float requires considerable experience of the operatives in the tan yard.

Figure 4.13 Cross Section reveals Partial Uptake of Vegetable Tanning Matter (Cherry Bark).

It was found that a higher concentration of plant extracts with higher tanning content is advised, extracted through autoclave and distillation (Arbenz and Averous 2015, quoted in dos Santos 2016: 29). I undertook the experiment to observe and report a process, to which designers do not normally have access to.

4.2.2 Digital Tools for Fabrication

This section is a practical exploration of the other ways in which we make things, increasingly digital and together. Post-industrial manufacturing through digital tools such as laser etching, water cutting and CNC fabrication allows for speed, precision and yield optimisation. Digital tools have been explored for their potential to bring forth personalisation or digital bespoke, with the prospect of localised production, back in the UK and elsewhere.

Here, I present the learning from experiments with laser cutting technology that resulted in the nesting and tessellation to optimise cutting of leather. This was initiated by a leather technologist's request for designed items that help with the communication and promotion of leather education. An outcome is the design of mascots and playthings resembling animals, fabricated from leather and off-cuts [Figure 4.14]. The project led to questions about the role and the digital tools of both the designer and leather manufacture and of how they can work better together.
Considered were the advantages of laser technologies over other cutting and marking techniques. The laser engraving setting affords opportunities to personalise the surface beyond speed and repetition. Individually, by trial and error, samples were made to determine the best laser engraving parameters for light tan, dark tan and black leather [Figure 4.15]. The cutting of natural fibres including leather typically results in charring and soot. So, there is thought of how to clean and protect the edges of the cut and engraved area from damage. There are inquiries of how to preserve the tonal contrast between engraved and non-engraved areas and the need for protective top-coats.

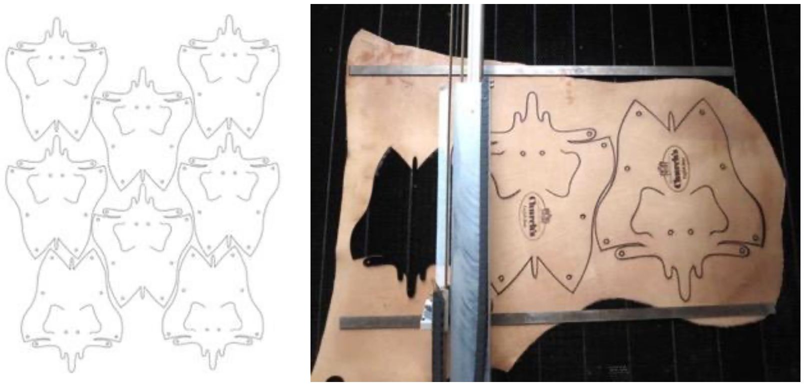


Figure 4.14 Nesting and Laser Cutting, 2014.

There is a wider discourse of innovating and applying recent technologies and direct digital manufacturing. Researchers pose related questions (Walton and Matthews 2009) of to what extent does materials science and fundamentals of laser processing affect creative work? It was posed that perhaps a designer friendly 'handbook' would be useful to share knowledge. I found that technicians that operate laser cutters in design departments develop individual catalogues of cutting and engraving parameters. Technicians also report on preferences for particular leathers to minimise soot or blackening. Trials showed that vegetable tanned leather samples display less soot than chrome or zirconium processed hides. Future research may further determine the role and reaction of tanning metals when exposed to the energy of a laser.

Figure 4.15 Laser Cutting of Vegetable (Left) and Zirconium Tanned Leather (Right), 2014.

4.3 Sustainable Future Leather Use – Final Projects

This section presents final projects that demonstrate sustainable future leather use including prototype creation and curation of a display. Here, I reviewed my final works by applying the eco design strategies (Fuad-Luke 2009) that relate design to the lifecycle phases of pre-production, manufacturing, distribution, use, end-of-life or new life.

4.3.1 Curated Artefacts on Display

During my studies, I put forward aspects of current practice through the medium of posters and artefacts, in addition to presenting at student research conferences. The public display at annual Work in Progress Shows at the RCA allowed me to demonstrate my practice and to publicise my research in the context of my peers in postgraduate research and the wider RCA community. In particular, this has been an opportunity to elicit comments and to receive feedback on my research. For this reason, I invited the visitor to have a physical experience by touching and practical handling of material samples on display. As anticipated, the occasion led to extended conversations and I was able to engage in exchanging ideas and feedback with the viewers.

There were two principal insights that I obtained through the lens of a London-based and design-centric venue. These are as follows: 1) on one hand, the audience with whom I interacted were curious about the leather material and the UK leather industry. However, they were not knowledgeable about the practice, names and locations of the industry; 2) questions were frequently raised on the aspect of the ethics of working with an animal's skin. Discussions followed on were concerning new materials that were commercialised as alternatives to leather. The visitors also voiced critically on meat consumption and questioned the environmental impact of animal use and farming practices. Due to such responses, I came to question the validity of working with leather in design; if the designers, who are instrumental in making choices on behalf of consumers through material selection, were to avoid utilising leather in their designs, what would this mean for the future of the leather industry? Regardless, I always witnessed during the WIP shows and end of year shows that there was a continuous stream of projects, although not many, that involved leather. This meant that there were questions still to be addressed by designers. As such, my work resulted in an illustrated handbook (in Glossary section) as an attempt to explain and illustrate the practice concerning leather.

A chosen method of articulating my thinking was of creating prototypes – an early sample of a product built to test a concept or process to be learned from. I had an idea of the objects that can demonstrate something in a new way, and, at the same time, can perform a function. For example, an ergonomic walking stick handle helps users with limited mobility. At the same time, it demonstrates the use of CNC technology, as it was cut from a layered and laminated block of leather. In an effort to explore conductive and sensing properties, I have embedded force sensors into an embossed vegetable tanned hide, covering a seat. A prototype of a car door panel demonstrates the use of waste leather fibres in an automotive interior component.

Object 1: Distressed Despatch Box and Saddle

The Despatch Box is an outcome of the early stage of my research, embracing the technique of 'distressing' and of artificially aging a product. 'Distressing' is a craft technique of producing an appearance of age and wear. In distressing, the object's finish is intentionally destroyed or manipulated to look 'weathered.' With this concept in mind, I set out to disrupt the characteristics of my primary research material (bovine leather), i.e., its form, surface, and also, distorting traditional processes. For the Research RCA Biennial Exhibition (21st – 27th January 2013) held at the Royal College of Arts Gulbenkian Galleries, I considered the possibilities of employing a distressing technique to bring forth a more sensual material experience.

For my display, I created a briefcase and a saddle in a distressed finish, both of which were fitted to a touring bicycle [Figure 4.16]. My design resembles a UK government's despatch box which is widely known to the UK public, as it is annually shown by the Chancellor of the Exchequer when presenting the annual budget statement. The briefcase that I created features the royal crest of the RCA. The crest has been applied through laser engraving onto red pigmented and dyed upholstery leather which was battered. The investigation and artefact were in response to the RCA Research Biennial call on the topic of Disruption – an investigation on the idea of disturbance, subversion and irritation in an art and design practice. Within the context of a group exhibition, my design explores "the idea of disruption in various practices and intends to outline the consequences of disturbance" (Jean 2013).

Figure 4.16 Distressed Despatch Box and Saddle, 2013.

My prototypes relating to mobility were informed by interactions with master saddlers in Walsall. Again, these artefacts feature distressed finishes, inherent or induced surface defects such as branding, scars or microbial attack. Thus, they challenge the perceptions of tactile interface and recycling properties.

The eco design strategies applied to this object are as follows: first of all, it is linked to a design that increases product lifespan/longevity. Can this be transferred to other products where signs of wear can emotionally connect with users? Examples are phone cases. There is the eco design strategy of simplicity and truth in materials. The distressed and aged material speaks to the user and reveals its origins as a natural material with veins, growth marks and even imperfections, thereby adding value to the object. Chapman (2015: 181-2) observed that jeans are worked on, sculpted and personified. He argues that objects are storytellers, mass-produced goods can age well and they gain character through use. He exemplifies shoes from the Northamptonshire firm Grenson “that will sculpt to fit your feet; they will become Yours.”

The despatch box takes clues from a design of the Victorian era with a socio-cultural durability. It is durable in that it can be repaired for an extended useful functional life. It builds on local, i.e. British craft narrative. The crest and laser engraving show the potential to personalise products to create longer lasting emotional bonds and an extended product life. The implications of making this experiment were manifold. It led to a connection with the company that traditionally crafted despatch boxes for court and government. Also, it led to an inquiry about the legal implication when displaying or using the Royal cypher and/or coat of arms on artefacts, in art, education and commerce. In the discussion chapter 5, it will be assessed whether this product can be viewed from a perspective of sustainability.

Object 2: Material Consciousness: Perception, Performance and Properties of Leather

The artefact and poster have been on display in 2016 during the Design Work-in-Progress Show. The artefact was assembled from a CNC machined wooden shoe last, inscribed in a geodesic structure and sphere crafted from leather bands. The artefact complemented the poster entitled *Material Consciousness: Perception, Performance and Properties of Leather*. It described the digital skills of makers and the tenacity of craftspeople in my field of study.

The artefact featured vegetable tanned leather offcuts from saddlery production. These had tell-tales of cutting and embossing marks, thus alluding to the materiality of leather. The wooden last has the cutting marks from CNC (Computer Numerical Controlled) manufacturing introduced by both Northampton shoe last makers and Walsall saddlers.

Figure 4.17 Material Consciousness Display at Work in Progress Show, 2016.

The main purpose of this display was to complement the poster [Figure 4.17]. My thinking at that time was around the digital skills and tenacity of makers, who I met in the course of my observations. They were the community of people who embraced digital technologies to complement craft practice. The last maker, for example, was making use of CNC manufacturing to speed up the process of delivering patterns to the shoe industry. The object synthesised my grappling with themes at the RCA design school relating to the making of things, culture and heritage, and new technology.

Object 3: Sensing Seat

The artefact considered the function, perceived quality and user acceptance of materials that have enhanced the interactivity through sensors and interfaces. The functional prototype consisted of a swivelling stool and sensors embedded in embossed leather, plus a screen that displays a force distribution map. The seat surface registers weight distribution, which are visualised by yellow, amber and red circles; these circles correspond to the six force sensors, controlled by Arduino Uno and connected via USB cable to an iMac display. The computer interface was written and visualised in Processing 3 format software. The code and the lists of the technical supports are included in the Appendix II. The Artefact was on display in 2018 at the School of Design Work-in-

Progress Show in the Hockney Gallery, Royal College of Art. It was an exploration and embedding of force pressure sensors in a vegetable tanned saddle hide [Figure 4.18].

The functional prototype was designed and exhibited to assess participant engagement with the surface and interface, by:

1. Eliciting cognitive and sensory response to haptic stimuli;
2. Engagement of participants to vary pressure on seat, which was displayed in a monitor by changing postures of the sitter;
3. Use of the functional prototype as a cultural probe, defined by Dunne and Gaver (1999), as that which elicits public reaction and response within social settings. I explored the suitability of utilising the concept of probes in my design research.

Figure 4.18 Seat, Sensors and Arduino Display at Work in Progress Show, 2018.

During the show, I interacted with 21 participants comprising the design research students affiliated at the RCA, RCA community and the general public. Following the exhibition, I assessed my findings. The technical aspect of the prototype worked, in that, the signal relaying on the screen and the apparatus worked smoothly without any interruption or a breakage of the circuit. The only problem encountered was that the monitor had to be rebooted each day. However, there were some questions which needed answering. These were relating to its usage, design viability and market desirability. Regardless, I consider that this research project contributed to increasing my understanding of the issues concerning the design and application of probes, as a means to fulfil specific research and design objectives within the various evolutionary stages of materials and consumer experiences.

Here, my eco design strategies were to rehumanise the technology in the context of material that people are familiar with; I embossed the leather surface in a way to channel the cables and pressure sensors, and to insure the protection of sensors. I consider that this design is a step towards sensing leather surfaces. This seat was inspired by my participation in the 'Bare Conductive' workshops at RCA (Johnson 2013). Following this workshop, I tried to apply conductive ink to leather surfaces and to overcome issues with its adhesion. My project relating to sensors, described above, was informed by a number of the works that I became familiar with. These were: Tecscan sensors, an exhibitor at Automotive Interiors Show (2011); Institute of Materials smart materials workshop (2013); Digital Catapult workshop around wearables and conductivity (2014); Capacitive carbon black dissertation (Galiotti 2017); RCA Living Materials textiles seminar on sensors and wearables (2017), Lisa Pape insole at Show RCA (2016); and, MA IDE bike saddle Show RCA (2017).

In conclusion, I consider that materials – including leather – acquire a new agency and interactional possibilities, and these are important for the discourse of design research.

Object 4: Collagenic Fabrication

My design artefact, entitled ''Collagenic Fabrication'' (Biodesign + Prototyping) was on display at the Darwin Entrance Gallery, Royal College of Art, London, during the Work-in-Progress Show in January 2019 [Figure 4.19]. The artefact, engineered from leather production waste, demonstrates fibre optimisation and upcycling of renewables. Collagenic fibres have been pulped and applied through lamination in a multiple lay-up process within a silicone mould in the form of a lower limb. This was inspired by a Greek sculpture. The design had the following eco-design strategies. I manufactured it with a simple, low cost construction and low energy processes. Leather fibre waste was shredded, blended and remanufactured. The objects have been made into a new material, wholly of recycled waste materials.

Figure 4.19 Display at Work in Progress Show, 2019.

Object 5: Automotive Door Panel Insert

The purpose of this experiment was to recreate a Ford Fiesta MK2 left door panel, which can then be tested for its structural capability of a fibre mix, using various binders and thicknesses [Figure 4.20]. The mould was provided by the courtesy of Sheila Clark. Using the same frame, she created a panel with natural fibres and bio resins. As for my project, I wanted to contrast the material using collagenic fibre, which had been pulped and applied through lamination in a multiple lay-up process within a silicone mould. Stabilising binders (adhesive starch) have been added through brush application, to further increase the adhesive properties of the fibres.

Figure 4.20 Car Door Panel Insert, 2018.

Experiments resulted in a skin with an average 1.5mm thickness that flexes; it also shows a good level of detail in the silicone mould. I noticed a good uptake of mould detail, dimensional stability and integrity of form. I found that it has haptic qualities and a pleasant appearance. It had a good lightweightness compared to that of the leather hide. However, there were tears in corners due to the air-drying process and uneven shrinkage with material accumulation in corners. Also, I found it difficult to laminate at vertical surfaces. Due to handmade production, the process itself was slower than what was desired. Thus, I question the suitability for industrial scale fabrication. I consider that there is a possibility of utilising the paper making process.

Thinking of applications, I ask whether it would be feasible to substitute self-skinning PU in non-load bearing applications with my collagenic material and process? In industry, there are new reinforced composites for structural applications made from bio-based and recycled material. It is also reported that there are signs for growth of biocomposites in various markets (Partanen 2017). Concerning this material, I had a question of whether injection moulding and 3D printing would facilitate the creation and fabrication of bio composites. Collagen is a protein, and as such, coagulates and hardens under heat, with values of around 130C for some chrome tanned leathers and around 80C for some vegetable tanned leathers. Thus, a deployment together with polymers in heated processes like injection moulding and fused deposition modelling seems limited. However, this consideration is beyond the scope of current investigation.

4.3.2 Final Prototype Creation

The final projects consist of three artefacts: a glove compartment, a splinting device for handicapped people and a saddle with a vegetable tanned leather cover. The scope of each of the artefacts reflects three main areas of research hinged on circular economy principle. All three artefacts aim to illustrate different aspects of future sustainable material, manufacture and use. The artefacts below demonstrate ways of utilising three different sources of waste – leather shaving waste, leather off-cuts and plant waste as tanning agents – which embody the idea of the circular economy at its core.

Artefact 1: A Glove Compartment

The glove compartment was crafted from leather shaving waste, whose fibre structure is strong enough for self-support. It was crafted in a mould, and is a mixture of leather waste shavings and mycelium blend. The main purpose of this artefact was to demonstrate a way for converting waste material into a functional item.

Artefact 2: A Splinting Device

The prototype of a hand splinting device is a polymer cast of a forearm, covered in a goat skin. The material was sourced locally and some came from saddlery off-cuts. This material has hypo allergic properties and it is breathable. It is comfortable to touch, it reduces chafing from the user's body and acts like a glove. Our client engages with the Occupational Therapy (OT) Subject Group at the University to develop customised cutlery handles for him to use, following surgery and wrist re-construction. A masterclass with OT and Product Designers led to a clinical assessment and a polymer cast of the client's forearm and hand has been and a prototype engineered. Here, local craft skill is demonstrated in the making process of a customised medical device. The importance of this item in relation to circular economy is multifold: it utilises locally processed animal hide and off-cuts; it also helps enhance user experience, thus contributing to their well-being as a result.

Artefact 3: A Saddle Covered in a Vegetable Tanned Leather

The final artefact, the saddle, features vegetable tanned leather that has been created from plant production waste extracts [Figure 4.21]. In the early stage of my material experiments, I explored various vegetable tannages and surface treatments such as embossing and applied them to I used Mycelium as a mixing agent for leather waste fibre and experiment indicated that new chitin cellulose collagen mixture can be a way forward to combining these materials to strengthen their properties, and yet is biodegradable. Such a process led to the development of novel material concepts and qualities.

Figure 4.21 Vegetable Tanned Saddle, 2018.

My original idea was to develop beverage production waste into a useful commodity chemical. The waste is from a coffee house chain on our high street. Brewing coffee grounds does not fully exhaust the natural tannin compounds contained within; thus, there is significant value remaining in spent coffee grounds – value, which to date, has not yet been fully realised. Hop plant fibres also have a suitable concentration of natural tannins. This project demonstrates a possible collaboration with the farming community that grows hop for beer making. The significance of this project is to reduce waste and to align leather towards the circular economy. Leather technology has to ensure that full value is extracted from these spent plant wastes [Figure 4.22].

4.3.3 Reflection

The practical research includes design experiments that engage with leather technology and its practices. The techniques are participant observation, explorative making, prototyping and curation. Chapter 4 presents a commentary on the practice.

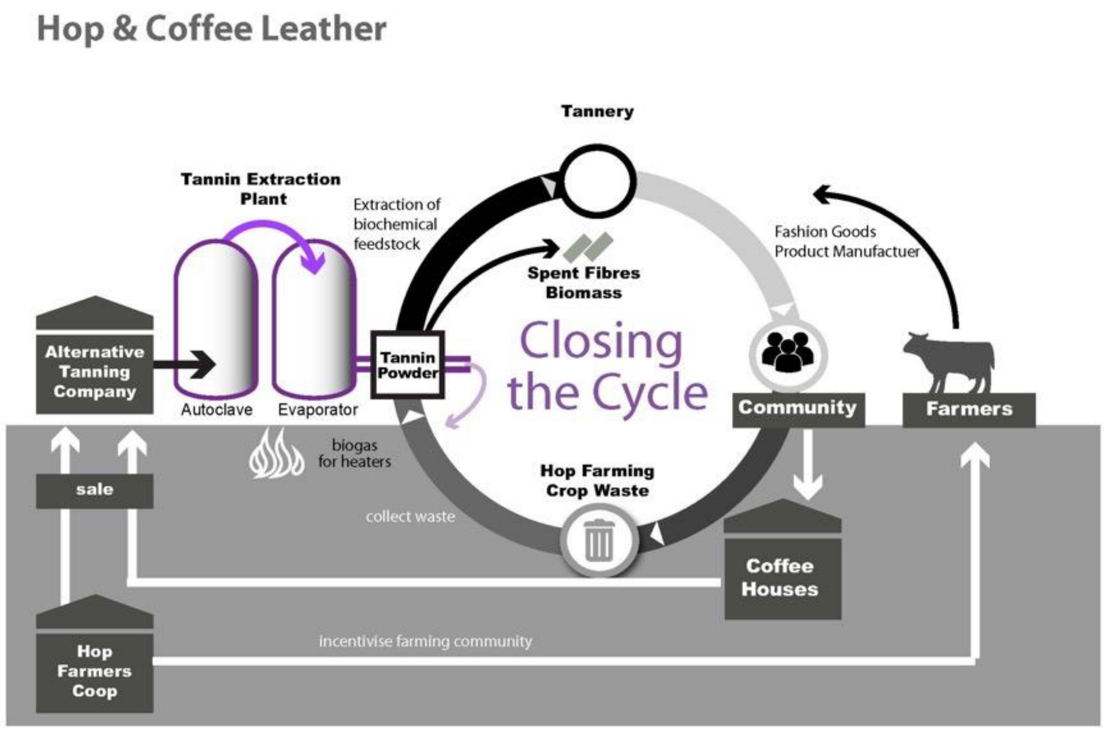


Figure 4.22 Closed Cycle Process with Hop & Coffee Tannin Extracts.

The first section, 4.1 Practical Materials Experiments, examined concepts of creating value from waste fibres and off-cuts.

By rethinking materials by exploring circular approaches, I cross disciplinary boundaries; first, I become an artisan who scoops pulp in a paper lab, then the cultivator of fungi – living materials that may digest and bind my waste fibres. This is followed by becoming a technologist, so as to measure tensile strength and to determine the material properties and relations to other natural fibres and hybrids.

In working with optimistic design students, we are making good use of leather off-cuts with well-meant proposals for waste reduction; only to come in conflict with the market realities of optimum and optimisation. The cutting ratio in leather is generally being optimised by the operators, where the only criterion is the optimisation between labour cost and material cost. This positions design as an optimistic practice which seeks ways to make things better. It is their undisciplined exploration through making and their speculations about ‘stuff’, which sets designers apart from other communities of practice.

The next section, 4.2. Sustainable Processing and Manufacturing, tackles the way in which we can rethink linear processes, closing loops towards circular models by identifying other waste streams that will be feedstock for our process. Crossing boundaries again and being situated in a laboratory, technologists guided me towards plant waste as a source of tannins by extracting phenolic substances from tree bark and cider apples. The idea to make leather with spent tea bags, coffee ground or hop waste may be heralding a resurgence of vegetable tanning processes and a rethink of waste materials for sustainable fashion and design.

Then I explore the other ways by which we make things, increasingly digital and together, through co-creation processes. Post-industrial manufacturing through digital tools such as laser etching, water cutting and CNC fabrication allows for nesting, tessellation and yield optimisation. Digital tools have been explored for their potential to bring forth personalisation or digital bespoke, with the prospect of localised production, back in the UK and elsewhere.

The last section, 4.3 Sustainable Future Leather Use, presents the Final Projects that embody my examination of materials and manufacture.

Exemplifying a despatch box, design can showcase the leather material that ages gracefully and connects with traditions. In the case of Northampton and Walsall, the connection with the intangible heritage of leather and its craft practice is rich and full of connotations of Britishness. Glove compartment lid from a zirconium tanned full hide and the door panel from waste leather fibres tests structural capability for automotive interiors and is responding to the end-of-life directive in the European car industry. Orthopaedic handle, splint and walking aids crafted with leather are enhancing access and ability. The saddle/seat with force sensors embedded directs towards applications that benefit posture and health.

To conclude, the practice has led to the curation of artefacts in a display and a handbook illustrating the practice. It developed object-oriented practices, and examined the potential of a closer relationship of leather technology and design.

Chapter 5

Discussing Leather Futures: from Experiments to Guidelines

5.1. Research Questions Revisited

Leather in the circular economy, its various issues and the scale of waste were described in the literature review. It presents a leather technologists' view, in that they seem to be assured of their ongoing practice of leather manufacturing based on scientific principles (Covington 2009, 2020). Contrary to this, designers consider the emerging landscape of structural biopolymers and materials from natural fibres as an opportunity to re-evaluate traditional materials and waste as the raw material for future creations (Franklin and Till 2018); through exploiting the organic waste and by-product matter, designers are "sweating the resources" we have already access to and transform these, through crude, mainly mechanical experimentations (ibid., p.44). Thus, Rose (2017) argues that "a slow, studied and skilful engagement of the new generation of materials craftspeople" is prerequisite for the application of green and new materials and their translation into new products. However, the leather expert communities perceive making of "leather alternatives" and "bio fabrication" would be a challenge to existing manufacturing practice of the industry (Buljan and Kráľ 2019).

To answer the research question, it was necessary to identify the material, applications and uses. Having reviewed the catalogues of leather artefacts (Waterer 1946; Amberg 2017a & 2018), it is found that there is scope to include new practice that is in pursuit of a better future relationship with materials. As for the practice of contemporary designers who are working with leather, reviewed in chapter 3, the work of Amberg, Hasan, Recht and ten Bohmer's practice utilise the existing systems more economically, environmentally and socially sound. This is achieved through a thorough understanding of the craft and the material.

Turning our attention to the area of textile, its discourse is much more advanced; I learned, in particular, from the work of designers on the circular economy for textiles (Earley 2016 & 2017).

The case-study approach that she adopted helped my understanding as to how I can utilise the circular economy thinking framework in the leather industry that shares a similarity in terms of globalised supply chains and environmental concerns. In addition, other common features included offshoring and the retaining of local skills by associating with the luxury goods industry. My investigation resulted in a range of new insights through participant-observation in a tannery environment and by engaging design students through experimentations.

The work by Ashby (2009) on sustainable material and properties was selected to clarify the position of leather material in relation to other natural fibres. Ashby makes a brief reference to leather being one of the selected sustainable materials. He considers that only very few of the materials used today would qualify as “truly renewable”. Here, he hinges this view in terms of (early) man being “part of a natural ecosystem and its closed-loop cycle” (2009: 240). Thus, he makes reservations for materials like timber based upon diminishing renewability of source and various operational processes involved in the making and transporting the material. He exemplifies this by stating that a “tree … is a diminishing source with the operations of cutting, drying, chemical treatments and transportation which all have some non-renewable consequences.”

If I were to apply Ashby’s definition of ‘sustainable materials being part of a natural ecosystem and its closed-loop cycle’, I need to pay attention to what the implication would be for leather. This leads me to question and address sustainability of leather by reviewing not only the operational issue, but also the chemical treatments and transportation in the making of leather.

First of all, the leather trade has been mapped through visualisation. The relationships of stakeholders in the UK, India and Japan have been compared. This gave me an insight into the key stakeholders, the relationships, and the role of education. This provided diverse data, with eight country categories developed, of which, three countries were investigated in depth through fieldwork. The making of leather has been drawn out as a visual process map [Figure 5.1], containing thirteen processes, of which, four were detailed in the practice; namely, finishes, upcycling waste, alternative tanning agents and digital manufacturing. I explored the potential of invention using the method of design thinking, by experimenting, making and collecting leather. Three design categories were developed for the material and its use, from the perspective of circularity and closed loops. Through ethnography, I sought the evidence of circular practices by observing the makers and the interactions of the laboratory with the designers in Italy and Japan.

The circular model that I devised was discussed with the technologist and the academics. The practice part of the research was grouped in three categories; material experiments, applications and final samples. Consequently, the research question was answered by systematically bringing and relating through fieldwork, processes, and skills which were collected.

I have raised the question of what can be the role of "design" to drive the process towards a sustainable future in leather? Buljan and Kráľ (2019) and Costello (2020) provide insights into the role that design can play to drive the process towards a bio-based understanding of the industry. I took note of waste and emerging green chemistries inside the tanning process; considering approaches of how these could be combined with waste streams from other industries. A diagram illustrates this thinking [Fig.5.1]. When it comes to the leather process, the skin itself can already be considered 'recycled' in the sense that it is a by-product, so we are already off to a good start. Decarbonisation of leather making means reducing the carbon intensity and emissions. The design of the chemical process is critical, because the way chemicals are synthesised needs to be rethought if we are to convert to a fully decarbonised supply chain. If the chemicals can be supplied with high bio-based content, then this generally does not affect the process design, unless it is a disruptive technology that changes the process. Being able to minimise energy consumption is necessary for a sustainable future, given that self-energy generation methods like solar panels are not always enough to drive high energy processes, so process design is critical. As I have demonstrated in my practice, the recycling of leather waste from the tanneries and their re-use either in the tannery or elsewhere is also a key aspect of design.

5.2 Interconnected Themes of Sustainability, Community and Technology

This section brings together three key themes in the emerging landscapes of leather futures. As described in the previous chapters, the insights are the outcome of my endeavours through literature, my observations in the field and my practice through creative explorations. The three themes which predominantly arose from my research are closely linked to sustainability, connected communities and technology (which includes traditional craft practices and considers future bio fabrication). This section discusses the key insights, centred on the circular economy model of minimising waste towards closed loops. It also outlines possible ways to keep leather as a relevant material for the future by designers, as well as by the wider communities of practice who are working with the material, supply chain and end users alike.

5.2.1 Sustainability Matters

To recap, sustainability has been defined as ‘endurance of living system’ (Brundtland and Khalid 1987), with the considerations to meet the needs of individuals, communities and the environment. Issues around animal use and environmental impact through livestock had been considered. In line with the hypothesis of the inherent sustainability of leather (Redwood 1990; UNIDO 2004 & 2012), I consider that the skins which would otherwise go to waste have, and will bring, value to mankind for a foreseeable future.

As mentioned in chapter 3, I encountered waste in the tannery and in the leather goods manufacturing processes which I explored in my practice. Using the model of life cycles, I propose systemic changes of how leather is made and waste used, utilising first of all a) leather shaving waste; b) utilising plant based waste streams to create the tanning agents [Figure 5.1].

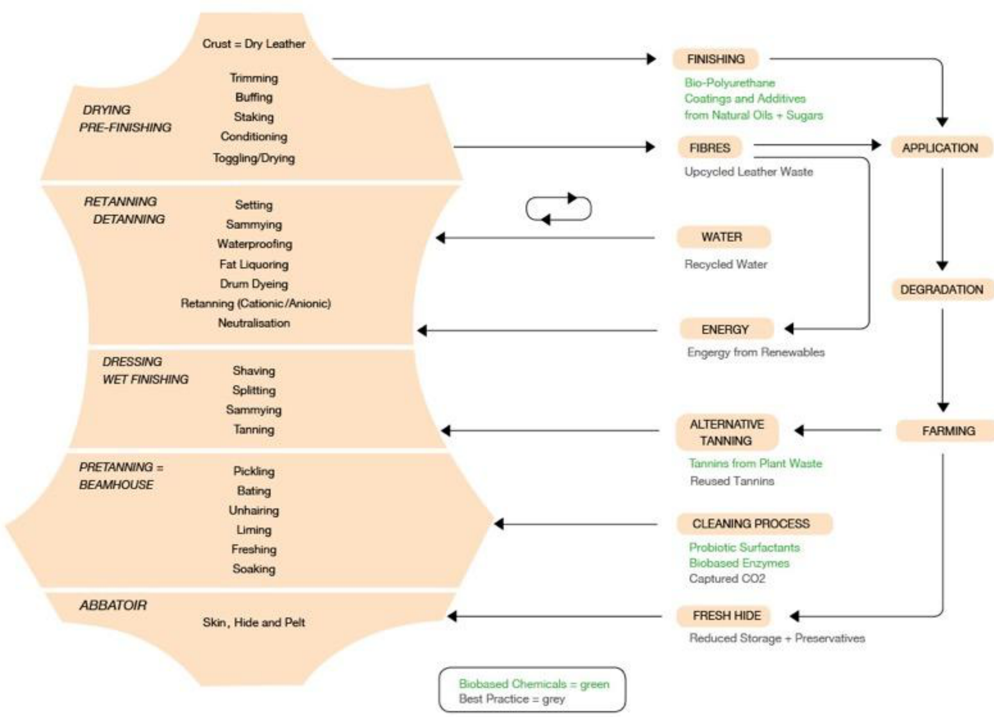


Figure 5.1 Future Leather Processing Map.

My research outcome indicated several factors that can attribute to sustainability. Firstly, it is possible to reduce the leather waste through making use of waste fibres from the shaving process.

I can reduce waste by upcycling the fibres into a new substrate for new applications, and by creating a new recycled material with many of the attractive and useful properties of leather. There is a greater potential than I had originally anticipated in the making use of leather off-cuts created in leather goods manufacture, thus creating value; the sheer quantity of the waste was much larger than anticipated. In terms of tanning, other waste streams, such as tea, hop or coffee waste, can be future tanning agents as they contain natural phenols.

Whilst such benefits have currently been investigated, there were many challenges that I encountered:

- Collection of waste needs to be developed, incentivised or regulated;
- Current waste goes either landfill, thermal processing, collagen industry, or fertiliser, where value has been lost or diminished;
- In the global industry, the majority of processing is undertaken outside Europe, including developing countries for low cost. Recovery of waste is currently a low priority.

However, this research demonstrates that leather fibres can be used as raw materials both for natural and waste based composites. Based on small samples created in a lab setting, my test results confirm that my bonded fibres are, first of all, lightweight, and secondly, they have structural properties that can further be enhanced through finishing treatments. The properties can also be enhanced by blending with plant fibres. These fibres can be derived from other waste streams, resulting in enhanced performance and aesthetic properties for new designs.

Based on my investigation on the crucial role of tanning in leather processing, it is found that we can work towards “closed looped leather processing” through vegetable tanning extracts from plant waste streams, utilising spent plants that retain tannins (plant-based phenols) that offer new design opportunities and narratives [see Figures 4.22 & 5.1]. These results build on existing evidence regarding the potential of vegetable tannins for tanning processes (Heidemann 1993; Covington 2009; Dos Santos 2014; Davis & Quang, 2019). However, this research also provides a possibility of developing a series of tanning agents from certain food wastes, such as spent tea, hops or coffee ground, that have a story, which is an extremely attractive prospect from the environmental point of view. This result thus contributes to the creation of further closed loops.

Limitations

The general application of food wastes as tanning agents is limited due to the fact that vegetable tanning is a slow process, and the tanning agent requires fortifying through the distillation process. Likewise, traditional pit tanning processes are very time-consuming as tanning liquor has to convert the skin into leather. It is possibly to facilitate speeding up the process through drum tanning technology, which is energy intensive due to heated tanning liquors.

In addition, the tannin has to be extracted first. However, some of the required energy can be won through renewable sources such as solar panels, biomass and so forth. Most importantly, the majority of leather making is taking place in the developing world. Thus, the application of such tannins needs to take account of local need and the availability of feedstock.

My tests with waste fibres indicated that I did not achieve any comparable tensile strength results to that of the newly developed natural fibres such as pineapple fibres. Future research may be undertaken with hydrolysis, micro fluidiser – a technique to further homogenise the waste fibres including grinding apparatus. One important insight was that the reconstituted material should display its own special characteristics which ought not to be disguised through the application of polyurethane coatings and use of embossings to mimic the grain structure of leather.

5.2.2 Connected Communities

In line with my research aims, I considered leather-making communities that are connected through a material and shared practice. Case studies and analysis based on a network model and actor network theory identified correlations and relationships amongst the data. The result demonstrated that the network has mutually benefitting aspects of collaboration and competition intertwined in the hubs and spokes [see Figure 5.2]. For example, the materials research and network maps in chapter 3 [see Figures 3.6 and 3.7] clearly points out that the leather expertise, although centred around the Midlands and Northampton, is closely linked to London with design, as well other locations in the areas of brands, research design, education and leather making.

Such relevant stakeholders and their respective connections, both through collaboration and competition, help not only by identifying the gap in my research, but also confirm how the leather community in Northampton is only a part of larger systems. The data collected from my fieldwork in other localities both in the UK and elsewhere in the world, e.g. in the Netherlands, Italy, India and Brazil, suggests a worldwide interconnection of the leather industry in terms of leather production and education.

My research also confirms the challenges that the leather industry is still facing. The UK leather industry remains small in its scale and currently only thirty tanneries and other members are counted by the UK Leather Federation. The industry was labour intensive, and thus underwent globalisation, leaving many of manufacturing sites unoccupied at the present time. This was because production was moved abroad to developing countries, where there was already a supply of economically viable labour and, at the time, fewer environmental restrictions.

Contrary to my original assumption, the research also showed that designers in general, except for a very small community of designers already engaged in their practices, are not very familiar with the material and locations of leather making.

Collaborative practice undertaken with students, briefed by a client in the leather industry in India, aimed to present new designs of footwear for the poor. This workshop led to the realisation that there is a large informal sector in the developing world, where the use of offcuts through the appropriate technologies of leather craft can create value that sustains these communities. The results confirm that, in order for items to be repaired and customised, they have to be durable. The works of the handicraft cottage industry in India – the ecocraft Jaipur case study (Schaber 2013b), the exhibitions (Sustain RCA) and trade fairs (Brookes Saddles) further demonstrate social aspects of sustainability (Thackara 2005; Papanek 1984) enabled through different levels of technologies.

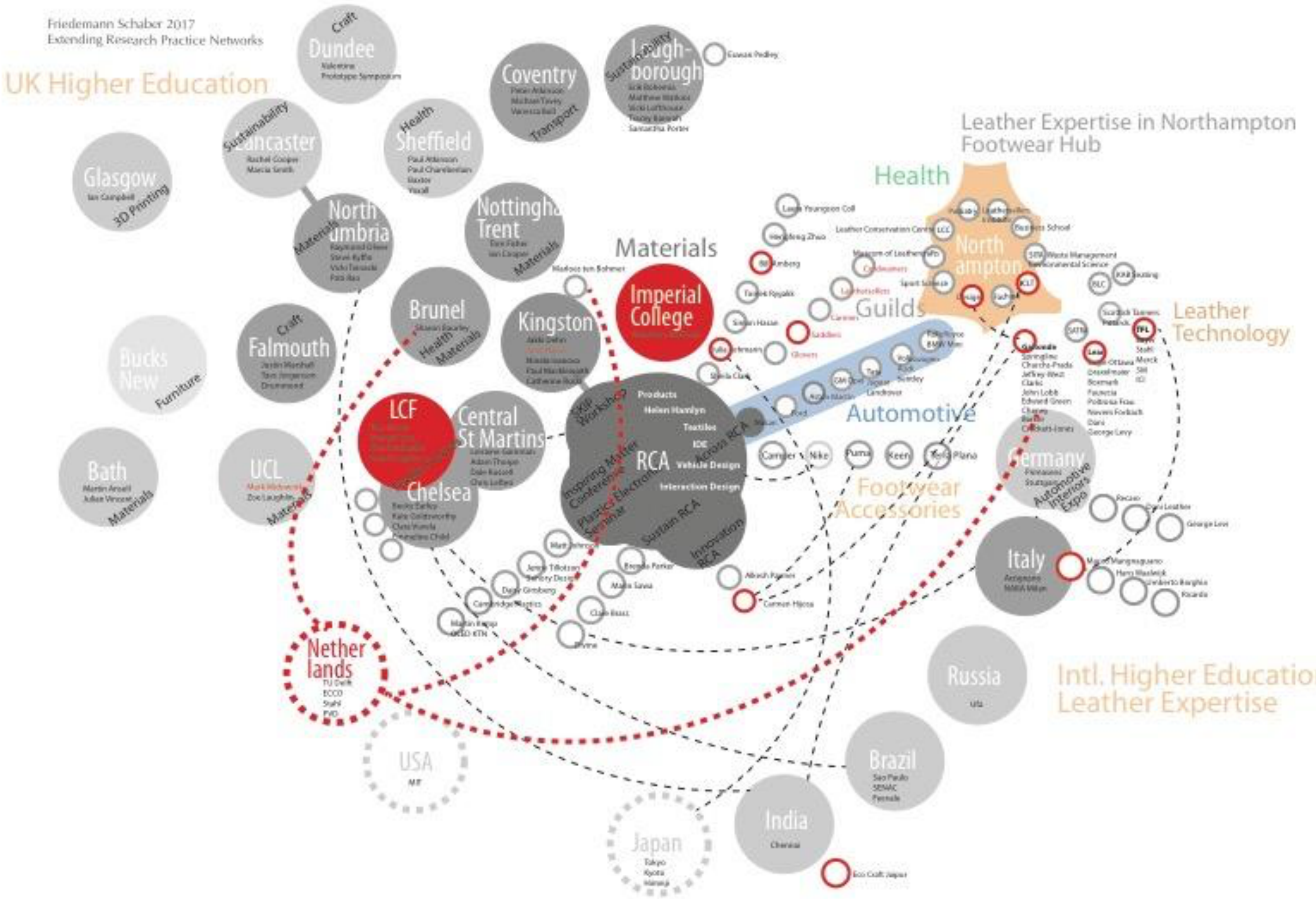


Figure 5.2 Materials Research Network Map. Highlighting transactional links (in red) with partners in the Netherlands, London College of Fashion and Imperial College.

This research identified collaborative communities which were drawn out by constructing an actor network map [Figure 5.2]. It extends from leather makers and users to other stakeholders. An atlas of locations of leather making demonstrates that industrial districts with a similar expertise congregate in a geographical proximity; for example, shoe making, saddlery and glove making industries. This pattern is also found in other countries. As for learning from leather offcuts and scraps, this project highlights co-designing circular processes with students and partners in the leather supply chain.

I also investigated the use of low grade leather, designing and creating an antique effect despatch box, presented in the display of practical work [Figure 4.16]. This demonstrated, by using distressing techniques, that leather retains desirable uses and properties and is an exceptional natural material suited for a wide range of physically long lasting and 'enduringly appealing' designs. My examples are inspired by precedents from the Victorian era. Luggage, saddlery and footwear are still produced in the British Midlands and they appeal to global audiences; the visible marks of craftsmanship, design and the reference to a notion of 'Britishness.' (Lloyd and Schaber 2019; Church & Co (Footwear) Ltd., no date)

As noted, creating value from leather supports a diverse community that is involved in the supply chain, including artisans and farmers. Furthermore, the actor network map emphasises the importance of education as a factor for consolidating the leather network. Educational pathways and the role of chemical companies in them are shown to be one of the forces of maintaining the integrity of the network. There is a growing importance of design hothouses to link design and leather; Lineapple (2019), Milan's international leather fair has recently introduced an *innovation square* that offers a platform where designers are invited to discuss the future trends as seen in other industries, especially of the textile industry.

Designers make the connection with leather makers and leather education, and innovate collaboratively, by experimental making and prototyping. Leather chemists devise and follow scientific methods, and the technologists apply these methods. The scope of innovation was explored in multiple ways, not only within leather making, but also through brands that develop a vertical supply chain with integrated leather factories (e.g. Ecco; Hermes).

5.2.3 Technology

Through practice-led research, prototype examples were produced using recently developed technologies such as rapid prototyping. These artefacts when put to use and tested, reveal new ideas and research opportunities. I developed through practice a knowledge base for leather and requirements for potential applications.

My research investigated not only traditional practices of making and working with leather, but also, importantly, new processes and techniques. Although I was familiar with the vocabulary and the practices of the traditional leather industry, I was prompted to go beyond the sphere of craft tradition. Hence, application of scientific leather chemistry, i.e. leather technology, became an integral part of my research. As a result, I was able to explore and test some of the modern practices of processing leather.

Leather making has always been explained through linear models from raw hides to the finished articles (Daniels 2013; Fuchs 2010; and, Heidemann 2009). When examining the linear model from a designer's perspective, however, a gap became apparent in terms of knowledge and leather manufacturing. Thus, my endeavour was to re-examine the processing map by shifting from a linear perspective towards circular approaches by connecting the manufacturing process to more current manufacturing systems such as biofabrication, digital manufacturing, composite fabrications, and smart material. Essentially, I was bringing the expertise, with which I am familiar in a design research at a university setting, to an industry that is considered "traditional" in terms of age-long practice. In the process, however, my perception of this industry had to change.

It is possible to map out leather futures from processing to biofabrication in a circular arrangement, and to consider circular approaches [Figure 5.3]. The taxonomy map in chapter 3 [Figure 3.4] clearly points out where to situate new practices, and technologies that are not covered within the finishing processes in leather. Emerging technologies were demonstrated through my "Sensing Chair," a saddle/seat with force sensors embedded directly towards applications that benefit posture and health. In my view, this design is a step towards 'smart' leather surfaces that offer a functional property. This correlates to the embedding of functional properties in materials, which we see in wearable technology, covering areas from health to a wide range of applications. My work demonstrates that these are important not only for the discourse of design research – materials acquire a new agency and interactional possibilities – but are also applicable for the leather industry.

Perceived quality is important to the industry and thus leather is widely used. By integrating new properties such as stretchable electronics, a number of controls can be integrated, resulting in weight reduction, reduction of components, added functionality and increased user acceptance. Manufacturing industry may require the basic structural material to also become the interface or carrier of sensors. This may well be the way ahead for a number of electronic goods and appliances.

Figure 5.3 Extending Leather Processing to Collagenic Fabrication.

The challenges that I encountered were that, whilst leather technologists and designers have some shared practices, we have different skill sets and objectives. The leather technologists rely on scientific knowledge, with an emphasis on measuring and repeatable results. As a result, I had to acquire skills in finishing and tensile testing to determine strain over elongation of leathers and new composites; learning to work with Scanning Electron Microscopy (SEM) to understand the underlying structure within mycelium and skin and new fibre compositions; and, various standardised testing methods to determine the physical properties and performance of my materials (SATRA, no date).

Franklin and Till (2018) emphasised material innovation as a crucial factor for overcoming the current linear ‘take-make-discard’ relationship with materials. I have selected innovative material research in recent years which encompass a number of areas including printed electronics (York *et al.* 2016), 3D bioprinting (Mayer 2017), bio fabrication of collagen (SLTC 2017) and vegetable tanning (Silvateam 2020).

Practical material experiments that I undertook related to the themes of sustainability, community and technology, and led to useful insights. Inspired by Montalti’s (2013 & 2017) work on the structural and decorative properties of fungi mycelium and use as an alternative to plastics, I positioned my own quest for sustainability with an ecological approach for design experiments with the binder resin that amalgamates the fibre wastes. In order to make a material that has a degree of performative properties, my sampled offcuts and leather fibres require a level of adhesion. This would cover a wide range of glues, starches, bio or synthetic polymers such as polyurethane resin, which is already used in some man-made materials that are referred to as ‘vegan leathers.’ Here, my attempts were to find and apply binders that are themselves biodegradable and are made from natural sources; there is a growing literature on deep eutectic solvents as binders (Abbott *et al*. 2017) and on starch adhesives for wood-based composites (Rudi *et al*. 2017).

This approach led me to a series of experiments with natural fibre combination which I presented early in section 4.1. Here, I discuss an experiment for the potential of chitin of which the fungal cell walls are composed (Abo Elsoud and El Kady 2019). Mycelium is the fast-growing, vegetative part of fungi, consisting of a tight network of interconnected filamentous cells (Montalti 2013 & 2017) instead of adhesives that are commonly used.

Figure 5.4 Mycelium *Fomes Fomentarius* Blend with Leather Shaving Waste Fibres: Growth on Day 16, 18 and 34, 2020.

I used Mycelium as a mixing agent for leather waste fibre and an experiment indicated that a new chitin cellulose collagen mixture can be a way forward to combining these materials to strengthen their properties, and yet is biodegradable [Figure 5.4]. Such a process led to the development of novel material concepts and qualities.

5.3 Findings

In order to overcome 'the barriers to transformation', The Circular Economy White Paper (no date) emphasised the need for "fundamental understanding on interactions between systems – environmental, economic, social, cultural, legal and regulatory, technological and behavioural" for specific resource flows. Thus, this research presents approaches for the circular economy covering the use of new designs, materials and technologies suitable for reuse, repair, remanufacture and recycling.

Cultural reference systems prescribe the material's contexts, procedures and applications deemed correct by society. Established materials for making are imbued with cultural references that sometimes date back thousands of years (Ashby 2009, quoted in Lohmann 2016: 84). Through my research with Northampton shoemaking, I found traditional practices of working with leather and understood that the eco strategies of durability, reparability and longevity can be applied.

A key insight is that leather's suitability for repair and its longevity makes it a sustainable choice, evidenced richly in the artefacts in collections and museums of transport. This is supported by Evans and Cooper (2010), arguing that product longevity is a key aspect of sustainability; thus, they promote an extended lifetime of products as a way in minimising environmental sustainability impacts.

Rognoli's tentative map of *Intelligent, Connected and Smart* (ICS) materials (Karana *et al*. 2015) is very interesting because there is a potential to consider leather to have properties that would suit as an ICS material. As demonstrated in this review and in case studies, the performance properties of leather can be enhanced in various ways, for instance as a carrier of thermochromic pigments. Some enhanced products have been commercialised by several chemical specialist companies (TFL 2012; Stahl 2017). The new characteristics move it into the domain of a reactive material, which includes smart materials or combinations of inactive materials with smart material components, e.g. thermo-chromic inks. A degree of self-healing properties can be assigned, inherent through its

3D collagen bundle matrix as it is derived from a living material, i.e. collagen based skin. Examples are products used in shoe repair or polish. Breathability and waterproofness can be introduced and controlled. These are a state of higher technological complexity, with a degree of smartness and interactivity. Experiments around conductivity resulted in black carbon leather and embedded force sensor matrices (Appendix III) that fall within the domain of an augmented computational material, akin to e-textiles. The processes used are beyond the typical current set-up and competencies of a tannery or leather manufacturer. The results can be repeated and have been achieved in a laboratory environment and through cross disciplinary work with programmers and material scientists.

At the Leather Conservation Centre, I observed the distinct strategies of conservation and restoration where I learned about assessments and different methods of repair, the use of polyurethane resins and colour matching. Through visits to chemical companies (in Italy and in the Netherlands) I came to understand that polyurethane coatings are applied to both leather and manmade fibre products, thus improving performance, but potentially diminishing distinctiveness.

Revisiting the research question of “How can leather be used as a sustainable material of choice for the future?” Through my research, I found traditional practices of making and working with leather, and applied eco strategies of durability, reparability and longevity. Through prototyping, I explored and tested modern practices of processing and handling leather. Through observer participation, it became evident that:

1) the leather industry is affected by developments and movements in the global supply chain, including automotive and luxury goods / apparel;

2) skills gap; whilst there are country-specific education routes such as work-based learning, apprenticeship models are scarce, with few institutions offering access courses, top-ups or degrees. It was noted that tannery staff are trained and upskilled by chemical suppliers;

3) the emergence of design ‘hothouses’ and ‘appreciation’ courses for creatives and opinion makers, provided by leather consortia, chemical companies and brands;

4) and, leather makers have an ongoing challenge to respond to environmental pressures and regulations in many locations, with certification processes and consortia to change perceptions of the trade and product, exemplified by Tuscany Vegetable Tanners in Italy, Leather Naturally in the UK, and Hyogo Leather and Tatsuno Leather Corporation in Japan.

Collaborative practice has been demonstrated by me with leather technologists, fibro science and papermaking; it demonstrates the role of leather knowhow. Through the making of prototypes, I have accessed tacit knowledge and have come to an understanding of how that knowledge has been accessed by material researches and creatives.

The prototypes created by me, ranging from chrome-based, zirconium tanned, vegetable tanned and engineered composites material, will be examples of what could be done going forward with the research outcomes:

- Development of a Handbook/Glossary
- New material and sustainable design solutions of leather and its by-products
- Extending an understanding of leather in the circular economy

To summarise, I investigated the conceptual ideas necessary for prototypes, questioned social and cultural histories of the material, and perceptions of existing alternatives. I mapped processes of leather making, the usage and outlet, and asked: can new leathers be produced to respond to increasing or changing usage?

The research aligns with, and critically evaluates an increasing interest in creating, tinkering and designing with new materials (Karana *et al*. 2015). Of note here is the growing of materials from living organisms (Collett 2017) and creating active composites by embedding electronics into materials (Vallgårda *et al*. 2016). My contribution to the practices of design is to add to a positive social, environmental and to economic and political change (Drazin and Küchler 2015).

The research investigated leather material, its applications and usages. In the process, I have sought for evidence of industry regeneration through design innovation, with particular reference to the contracted UK leather supply chain. For this purpose, comparative studies were undertaken in Italy and Japan, which I selected because of accessibility and the supportive research community. In these particular societies, I found an interplay of innovation and tradition. For the UK, I co-presented research surrounding the 'commodification of heritage', exemplified by the fashion house Burberry and Northampton shoemaking, which demonstrates 'Britishness' as an intangible element of cultural heritage (Lloyd and Schaber 2019).

In my literature research, I considered the areas of sustainable design, eco-design, co-design and design management, and connected them with insights from eco-informed material choice, leather technology and making (Ashby 2009; Covington 2020; Pye 1968; Sennett 2009). My aim is to introduce new practices, with guidelines to support the future practice of collagenic fabrication. I discuss the claim for new knowledge and why it is a contribution to the areas of material driven design, emerging materials, and material-enabled cultures around design and production.

The leather innovations by companies and designer makers and their relation to my own material explorations/artefacts are discussed in a comparative table 5.1. Of note here are 1. The upcycling of leather waste fibres and 2. the vegetable tanning or 'wet green' technologies developed by Ecotan, which is a brand owned by Silvateam SPA in Italy. Also, Olivenleder from Germany recently launched a wet-green leather tanning agent from by-products of the Mediterranean olive harvest, which has been Cradle to Cradle certified product standard (C2C). The listing of my own final artefacts [sections 4.6-4.13 in Table 5.1 below] complete my practice review. I compare the relation to the work of others and their significance for the research through a comparative table between my material explorations/artefacts and other leather innovations.

Chapter Ref.	Material and process explorations/artefacts	Other leather innovations. Acknowledgment of other companies and researchers, with dates	Contribution	Positioning of my practice / Significance	Doc. of development Appendix No.
4.1	**Creation of Bonded Fibres from Leather Waste** 1. No Binder. Leather fibres interlink without binders; 2. Latex + Leather mixed with natural rubber as adhesive; 3. PVA + Leather mixed with adhesives (PVA); 4. PLA + Leather mixed with bio polymer; 5. Leather shavings mixed with Rice Starch Japanese traditional glue; 6. Leather shavings coated with Japanese persimmon; 7. Mulberry (Kozo) + Leather blended with Japanese mulberry from papermaking; 8. Palm Oil Fibre Blend + Leather mixed with waste from palm oil fabrication; 9. Leather shavings entangled with a textile backing; 10. Mycelium; leather shavings as feedstock for structural fungi such as Fomes Fomentarius.	Leatherboard, 19th C. innovation; bonded waste fibres using mainly natural binders to obtain a sheet material that shows leather-like qualities. E-Leather Group, Peterborough, markets leather fibre material that is hydroentangled with a backing matrix. Patents 2001, 2005 and 2013. Kollamat by Bader GmbH & Co. KG, Göppingen, collaboration with Arburg Injection Moulding with 2003 Patent: Process for the production of a material using leather waste and moulded article. Nordic walking stick handle by Leki has been made from Kollamat. **Leather-like innovations from natural fibre waste streams** Nataša Perković and Fibro Science Lab at Kyoto Institute of Technology, Palm oil fibres 2018. Carmen Hijosa RCA Pinatex, Pineapple fibres 2014.	There are considerable environmental benefits by using leather, by-products and waste efficiently. New material and sustainable design solutions of leather and its by-products Appropriating the Washi Japanese paper making process Investigating the creative and commercial potential of blended natural fibres. Processing of collagenic fibres laminated with biodegradable polylactide, experiment to strengthen the fibres.	Leather shaving blends with plant fibres. Adding to the catalogue of green composites – i.e. composites from natural and waste-based sources. Experiments towards circular systems that I have devised to use leather waste and offcuts. Extending an understanding of leather and its by-products in the circular economy.	APPENDIX III Creation of Bonded Fibres from Leather Waste
4.2	**Recycling of Leather Off-Cuts** 3D Relief Effect with Calcium Chloride. Embossed effect through CaCl Screen printing Dyeing experiment with mycelium collaboration with Ninela Ivanova 2017 Leather waste fibres as feedstock for mycelium	1. Jorge Penades, Structural Skin 2018. Leather off-cuts are cast into a mould with animal glue. 2. Julia Lohmann RCA MA, Ruminant Bloom. 2004. Lamps from Sheep Intestines. 3. Billie van Katwijk Cow Stomach Handbags. 2017 4. Elisa Palomino, Gustavo Adrian Defeo and Lotta Rahme Fish Skin Lab 2018. 5. Benjamin Malatrait, Ictyos, Salmon skin, LVMV Start-up incubator 2018. 6. Tom Leech, MA RCA 2018 Experiments with off-cuts and waste shavings.	Prototyping circular practices using leather production waste through hands-on investigation in a design laboratory. Samples created by collaboration with Dr Ninela Ivanova in Dying with Fungi through facilitated workshops.	Leather Fibres + Cellulose Feedstock for Mycelium. Prototyping circular practices using leather production waste through hands-on investigation in a laboratory using structural fungus Fomes Fomentarius. 3D Relief Effect with Calcium Chloride. Trials to apply three dimensional effects onto leather and to propose a tactile material suitable for embedding sensors. Use of CaCl salts to imbue new	APPENDIX III Recycling of leather off-cuts

		7. Elvis and Kresse. RCA MA Leather off-cuts 2014. 8. Maurizio Montalti's experimental fungal mycelium-based technologies 2017. 9. Alexander Taylor MA RCA and Heleen Sintobin MA RCA CNC machined leather. 10. Alice V Robinson. MA RCA 2018 Sheep No 11458 Documentation of the entire process from slaughter to tanning. 11. Amy Wright 2018 RCA MA etched leather. 12. Bill Amberg. Stacks, leather floor tile, from off-cuts. 2018		functional properties. Its importance is to 1) embed smart material properties; 2) to create a decorative two-tone effect, and 3) to increase surface area to influence acoustic and thermal insulation properties.	
4.3	**Plant Matter (Waste) as Tannins** Samples from tanning experiments on the reuse of plant waste. Alternative tannages from plant matter, farm and forestry waste that contain phenolic tannins. Experimental tanning of rawhide with 1. cider apple pulp, 2. alder tree and foliage, 3. chestnut 4. cherry tree shavings and bark, 5. spent coffee ground waste 6. hop plant waste	1.Ecotan i.e. a brand owned by Silvateam SPA (2020), Piemont, Italy. Silvateam SPA (2020) and Eric Poles (Silvateam technical manager) research on vegetable tannage, referenced in chapter 4. 2. Eliza Chidsey Axelson. Leather diplomacy. Traditional tanning. RCA MA 2014 local leather, rawhide, oil tanned deerskin, sage, vegetable tanned cowhide, oak bark, alum tanned goatskin, sumac. 3. Olivenleder, Reutlingen, wet-green leather tanning agent from by-product of Mediterranean olive harvest. 4. Proctor, The Principles of Leather Manufacture 1922.	Practical experiment to use plant waste from cider apples and forestry cuttings of alder tree alnus and cherry tree prunus. Tanning effect has been observed but inferior to commercially traded mimosa and chestnut extracts. Extraction and distillation has been sought for future trials.	Coffee Retanning: Designing Leather that fits the Circular Economy. Proposal to innovate and evaluate sustainable leather making based on a retanning process with hydrolysable phenolic tannins that are extracted from spent coffee ground and valorise this waste feedstock. Plant matter rich in natural phenols traditionally used as a bittering agent in brewing. Tannins distilled at ICLT Northampton.	APPENDIX III Plant Matter as Tannins
4.4	**Digital Tools for Fabrication** Tableau with sample of offcut, optimisation through nesting and tessellation for a design of mascots and playthings resembling animals Elephant Design Lasercutting and Engraving	1. Affalterbach, Embossing dyes. 2. Trumpf, Keyence, Lasercutting and etching technology. 3. CNC cutting Gerber, Zuend. 4. Lectra, Yield optimisation and digitising tools. 5. Woodash Northampton, leather cutting dyes 6. Fenix Lasercutting Service, Brazil 7. Guy Bingham. Digital Tools. Loughborough PhD.	Lasercutting and engraving of mascots. Elephant Design. Contoured with perforations for stitching and assembly. Cut from full thickness bovine hide and logo applied for merchandise and promotional events.	Practicals to gain an appreciation of the scientific and technological needs of the automotive, fashion, footwear and allied leather industries. Understanding new and traditional leather processing techniques and to expand the possibilities of how leather can be used.	APPENDIX III Digital Tools for Fabrication

4.5	**Collagenic Fabrication** Mouldmaking on display at RCA Work in Progress Show WIP 2019.	Richard Hollinshead Sculpture. Silicone mouldmaking and casting of figurative sculpture 2018.	Mouldmaking and spray coating application of collagenous fibres with and without resins, binders and foils for upscaling of production	Demonstrates the structural capability of a collagenic fibre blend with biodegradable binders.	APPENDIX III Final Project
4.6	**Door Panel**	Sheila Clark 2016 Mould making door panel. Application of natural fibres and bio resin	Demonstrates the structural capability of a collagenic fibre blend with biodegradable binders.	Potential to substitute self-skinning polyurethane in non-loadbearing automotive interiors applications. Responding to the end-of-life directive in the European car industry.	APPENDIX III Final Project - Car Door Panel
4.10	**Despatch Box**	UK Government design red despatch box. Victorian era. 19th C and 20th C designs manufactured in London by Barrow, Hepburn and Gale.	Featuring a distressed finish, scars and surface defects; demonstrating leather material that ages gracefully.	Design for repair and longevity. Eco design strategy of emotional durable design explored and tested.	APPENDIX III Final Project - Despatch Box
4.11	**Glove Box from Leather Waste Fibres**		Self-supporting structural capability through mould-making process demonstrated. Applications of collagenic fibres with and without binders and resins, and foils demonstrated, spray coating for upscaling of production.	Potential to substitute self-skinning polyurethane in non-loadbearing automotive interiors applications.	APPENDIX III Final Project - Glove Compartment
4.12	**Medical Splinting Device**	Prosthetics 16th - 20th C designs Wellcome Trust collection.	Universal handle for a client with cerebral palsy following wrist reconstruction. Co-design with Occupational Therapy of a polymer cast of a forearm, saddlery leather and goatskin which has hypo allergenic properties, is breathable. Comfortable to touch and reduces pressure points.	Medical device innovation. Use of local material and skills.	APPENDIX III Final Project - Medical Splinting Device
4.13	**Saddle with Force Sensors**	Brooks Saddles, Birmingham. Hermes and Ideal equestrian saddles, vegetable tanned. Mr Ma, RCA IDE MA bicycle saddle with sensors 2017. Lisa Pape RCA MA embedding sensors in footwear 2017.	Embedded in vegetable tanned embossed cowhide and wired to Arduino Micro Controller, displaying pressure distribution, with potential benefits for posture and health.	It adds leather to the new practice of intelligent responsive materials and clarifies responsible usage of vegetable tanned leather for the benefit of designers and users.	APPENDIX III Final Project - Saddle Seat with Force Sensors

Table 5.1 Comparative Table between my Material Explorations/Artefacts and other Leather Innovations.

The comparative table references my work in the Appendix III. Other companies and researchers are listed in Chapter 3.2.4 Creation of a Taxonomy of Processes and Material. I also discuss the principles of my new practice and reposition leather and its by-products in the circular economy, leading to Chapter 6 with conclusions, future directions and implications.

5.3.1 Scaling-up and Quality of Production

Here, I consider the material investigations of leather waste fibres, fabrication including mycelium, alternative tannages and digital fabrication. In terms of quality of production, it is exemplified how my samples will be developed to meet the high-quality needs of the industries discussed, including mycelium. For this purpose, I describe below the TRL levels of my prototypes and then describe the risk approach to then commercialise/develop – highlight e.g. investment needs, stakeholders relevant industries.

I intend to focus on vegetable tanning - designing leather to fit the circular economy.
A working prototype of a coffee tanned leather has been developed at ICLT with a concept at Technology Readiness Level 3 (Proof-of-Concept). The aim is to refine the established work (TRL 3) and achieve a successful scale up to confirm TRL 5, then to develop new leather products to explore user acceptance and motivation. This would demonstrate on a local scale a commercially viable circular economic model, which rethinks leather processing using sustainably available plant waste. A funding or knowledge transfer application to UKRI would strengthen scaling-up and quality of production. A possible avenue for future funding could be the EU Green Deal and the Creative Program of the EU's Innovation Council.

My research questions relating to mycelium covers the following: Can collagen be feedstock for mycelium composite to build a lightweight matrix? Would mycelium help to convert fibres to a voluminous body with structural properties? Would upcycling be otherwise considered waste?

Would chromium be indigested by mycelium? What would be a possible way to fabricate with protein ingesting mycelium without posing a danger to workers and its users? Experimenting with a natural and living material such as mycelium in new ways would also expose leather technology to new materials tinkering with a view towards biofabrication.

Turning our attention to alternative tanning projects, below is a work plan [Table 5.2] that illustrates how I would mitigate the risks that would arise from a new product development. Cocreated with the ICLT, scientific methods and rigorous project management are applied to assure a funding partner and industry.

Project start Project Team initial meeting. Protocols and dissemination plan	Ethics Compliance. Dissemination and communication strategy detailed in Workplan.
Liaison with suppliers and feedstock delivery. Extraction of tannins	Lab and spray dryer set-up. Extraction of tannins from waste coffee solids and product drying
Characterisation of extracted tannins	Laboratory analysis of the dried extract to include: FTIR spectroscopy, size exclusion chromatography, tannin content, extract pH, qualitative tannin identification
Tannery trials	Development of the leathering process to suit the needs of the applications defined by industry partners. Production of prototype leather for product manufacture. Interim Report
Leather laboratory testing	Physical and chemical testing of prototype leather to confirm compliance to expected standards from industrial partners. The biodegradability of produced leathers is to be determined.
Prototype design and manufacture	Prototype manufacture to be outsourced to industrial partners. Product lines to be developed and marketed by the beverage and other associated industries.
Product user testing, sale & measure of user acceptance, perceived quality, and impact	Public display. Products to be trialled/offered for sale are to be accompanied by a questionnaire to probe market acceptance / customer decision
Project end and report preparation	Evaluation. Final Report. Dissemination of findings.

Table 5.2 Work Plan of Coffee Ground Vegetable Tanned Leather Towards TRL 5.

5.4 Handbook of Terms and Practice for the Design Community

The purpose of the Handbook is twofold. Firstly, for the thesis component, the handbook describes the glossary of terms and practice that this research is concerned with. Secondly, it is intended for the non-expert community that uses leather, in particular the product designer and the 'connoisseur' consumer or user. It offers an update on material innovation and sustainable practice of leather. To meet the needs of the envisaged users, a range of leather glossaries and other guidebooks have been sampled. Relevant information to answer the research question has been selected and updated. The handbook includes current terms including alternative tannages and circularity. Layout, content and range have been selected and through consultation with graphic designers, and the illustrations and terms verified by leather technologists. The usefulness has been tested through test prints and handouts to several designers that I have interacted with and resulted in a synthesised second and third updated version.

This illustrated glossary contains 99 entries of relevant terms and processes from accessories to zirconium tanning (see Glossary section). It contains a small working vocabulary and definitions in alphabetical order. It also covers a list of leather trade locations where fieldwork has been undertaken and introduces communities of practice, i.e. practitioners. It is an outcome of the research undertaken on new and innovative uses of leather, it is also a record of leather workshops that I participated in. The glossary/handbook defines terms, conventions and processes for a non-expert community that appreciates, works with and uses leather. The glossary aims to guide designers and to help them to disseminate this knowledge to consumers. In doing so, the reader is engaging with the leather trade and is negotiating/clarifying somewhat different use of terms and conventions by various communities of practice. Illustrations such as photographic images, diagrams and graphics are visualising data, giving insights and communicating specific manufacturing and chemical processes. In an exhibition, material swatches will accompany the glossary.

Previously, the 'International Glossary of Leather Terms' had been prepared by the International Council of Tanners to serve the needs of the leather-producing industry and the public using leather. The scope of the glossary is governed by the following principles: The terms included are all of potential interest to tanners, and/or their customers, and/or the general public. Terms, the meaning of which is self-evident (e.g. football leather, upholstery leather etc.) are not included. In the 'Inter-national Glossary of Leather Terms', processing terms are not included, except for a few terms where it was necessary in order to clarify the definition of a type of leather. Primarily, this glossary will include and illustrate processes and terms related with leather in mobility and design led applications. The larger section, with around 100 entries in alphabetical and thematically grouped order, features key concepts and processes in the leather trade. Major processes and common products are described. New technologies are being introduced here for the first time to a non-expert audience. The entries contain links and references, and cross references are included to link to related content. A range of applications are featured, mainly through photographic images. A second section highlights leather trade locations that were visited and have some importance in the industry. These range from ancient industrial districts, where tanneries cluster, to places linked to manufacturing, design and retail. In this section, key manufacturers and suppliers are named.

5.5 Claim for New Knowledge

My claim for new knowledge consists of three major and several minor contributions to the advancement of knowledge that have been grouped in A, B, C and D as below:

Major claims to the advancement of new knowledge

Firstly, through my research I gained a new understanding of tacit craft. This I have decoded and am making available in guidelines, in the form of a Handbook.

Secondly, I have decoded leather processing knowhow. This knowledge I am presenting in a systems map.

Thirdly, I have extended sustainable thinking. This knowledge I am presenting in a leather processing diagram with closed loops.

The followings describe these major contributions in detail:

1. My findings identified collaborative communities which were drawn out in three areas: an actor network map, a leather processing diagram with closed loops and an atlas of locations of leathermaking.

2. I produced a framework and an accompanying glossary to inform future practice with leather, including composite fabrication and digital manufacturing.

3. In the practice part of this research, several artefacts have been created, demonstrating a potential process for undertaking circular product design.
4. A body of findings resulting from this research was categorised and presented in guidelines aimed at supporting future practice.
5. Physical leather samples and upcycled composite materials from leather shaving waste tested the validity of my proposals. Here, the studies demonstrate circular systems for production and reclaiming production by-products, through experiment and prototyping.
6. One outcome of this research is to highlight the relevance of leather as a material for the circular economy – this is communicated through a handbook that illustrates terms and processes, which is hoped will inspire makers and users.
7. The value of this research for design practice is in its exploration of sustainable manufacturing methods and uses of leather, exemplified by providing samples, as well as the creation of the illustrated handbook.
8. For the academic community, its consideration lies in developing design and reframing the position of leather and its by-products in the circular economy, which unlocks value from the reuse, repair, remanufacture, retrieval and recycling of products, components and materials (this concept has been framed in the Circular Economy section 2.5).

Minor claims to the advancement of new knowledge

A) Upcycling waste fibres

A prototype of composite material from collagenic fibres and mulberry fibres. The processes included the blending of leather fibres from production waste with a plant fibre, and optimising fibre composition in the Fibro Science Lab at Kyoto Institute of Technology.

A prototype of composite material from collagenic fibres with palm oil fibres, from another waste stream, investigating the creative and commercial potential of blended natural fibres.

A prototype of a blend of collagenic fibres, cellulose and fungal mycelium Fomes Fomentarius

B) Upcycling of leather off-cuts

Breadline shoe design with several samples created in an Indian community context using appropriate technologies with offcuts from shoe and leather production.

C) Saddle/seat with force sensors embedded in vegetable tanned embossed cowhide and wired to an Arduino Micro Controller, displaying pressure distribution, with potential benefits for posture and health.

D) Material: aspects and samples of alternative tannages, wrinkle shrinkage technology to embed smart material properties, as contribution to the advancement of knowledge.

New knowledge has been claimed and tested through peer review and scrutiny in two grant applications and pitch events as a direct outcome of this research, as follows:

- Shortlisted for UKRI joint funding application to UKRI Circular Economy Hub; for feasibility study (40k for coffee tanning demonstrator), titled: Vegetable Tanning – Making Leather to fit the Circular Economy.
- Shortlisted for Terra Carta RCA + Sustainable Markets Initiative for Coffee Leather – designing leather to fit the circular economy.

5.6 Ethics and Authorship

The issue of authorship in co-design and collaborative work is addressed in chapter 3 design research approaches, clarifying own contribution to collaborative projects that precede the practice. The RCA Ethics Checklist within the Code of Practice for Research Ethics applies to the work I undertook as part of this research. My work involved the active and passive involvement of other participants. Whilst discussing leather practice with informants, a record of feedback via structured and semi-structured questionnaires was limited to students only which were involved in curricular activities.

1. Whilst considering environmental issues, such as landfill, also economic and social elements of sustainability, I have not quantified ways in which sustainability can be identified and measured in the leather industry. LCA tools for leather have been studied through literature.

2. Academic bias is declared when conducting research when undertaking research with colleagues and students at the University of Northampton, through the involvement of student projects.
3. I am the creator of prototypes from leather waste fibres and lignocellulose. These were created using a laboratory and supported by staff based at Kyoto Institute of Technology during a residential in Japan.
4. I am the creator of prototypes and finishes from leather. These were created using a tannery and laboratory, supported by staff based at the Institute of Creative Leather Technology ICLT. Other work was undertaken during a residential at an Italian leather testing laboratory.
5. Scanning Electron Microscopy SEM photographs of composite specimens were taken by me, and subsequently were evaluated at the University of Northampton. Dr A. Lama and Mrs T. Hayes set up the equipment and prepared the specimen with Sputter Gold Coating Technology for Electron Microscopy.
6. I am the creator of the embedded force sensors in a seat. A program was devised utilising *Instructables* tutorials and Arduino Open Source and Creative Commons license. The screen interface was created in Processing 3 software by Ms S. Zarakani (written consent was obtained via email). The code is recorded in the Appendix III.
7. Coffee and hop tanning processing and an analysis of tanning content have been conducted by Dr Stefan Davis and Mr Ashokkumar Baskar at the ICLT.

Chapter 6

Conclusions and Feed Forward for Future Investigators

6.1 Conclusions

This research has demonstrated new approaches for how leather can be used as a sustainable and desirable material. The key findings are that leather has a future if we enhance its inherent sustainable properties, develop the communities that work with the material, and apply technologies that give leather new forms and purpose. Through a design-led methodology, this research developed knowledge and guidelines for new sustainable practice in this traditional industry. It has resulted in an understanding as to how leather can be a material for sustainable future consumer experiences and for manufacturing.

This PhD by practice is a novel approach with leather material and practice. Following Rust (2007), exploring knowledge through making, the focus has been on insights won through interrogating artefacts and processes, and I considered leather production waste as a raw material for the creation of my artefacts. I used off-cuts, waste from the shaving process, and also plant waste from tanning processes, resulting in a curated collection of new artefacts and a display. The benefits of this approach have led to new insights combined with drawing out existing embodied knowledge in leather manufacture, and the interrogation of the materials through prototyping. Guided by knowledge transfer mechanisms and the review by Cox on Creativity in Business that calls for collaborative approaches between university and industry, I am introducing design thinking methods to the scientific discipline of leather technology.

My methods are visualisation, graphically drawn out networks, and drawing out the framework which connects leather technology with other practices, such as papermaking and digital manufacturing. New forms of fabrication were tested, such as growing mycelium to bind leather fibre waste. The framework presented in my research is the outcome from my experience with leather manufacturing processes. The diagram represents not only the individual process, but new ways of fabrication, such as new composite fabrication and digital manufacturing. These processes are standalone, but my diagram illustrates the interconnections as a possibility of embedding new properties to leather.

The research investigated what leather can be, beyond a material for footwear, garments and high-end design applications including vehicle interiors, upholstery and luxury products. Intrinsically, it has unique properties that can age gracefully. It is because leather is a renewable natural material that its inherent longevity and reparability make it a perfect fit for the circular economy.

It is of concern how much waste is produced in the leather industry in the form of shavings and off-cuts. It is, therefore, a paramount task both for the communities related to the leather industry and a new generation of designers to consider a variety of ways of turning the waste into a potential raw material, which can then be converted into artefacts and products, using new forms of technology that complement the traditional ways of processing.

The key points of the research which have been developed are as follows:

- Creation and applications of composite materials from leather fibre wastes;
- It is possible to use a wider range of digital technologies to complement traditional leather manufacturing;
- Creation of the framework for future leather practice which will include other practices, such as 3D printing, composite and bio fabrication;
- Artefacts that show a concept towards smart materials through functional and responsive surfaces;
- And, a handbook is presented as a visual thesaurus of the terms of practices in leather making.

Through interrogating the material, the practitioners, the communities and technology, I re-evaluated the practices of handling leather in this industry which have been developed over the centuries. For example, vegetable tanning is a traditional practice that can be used today using alternative tanning-agents, by distilling extracts from plant wastes such as coffee ground remains, hop plant wastes, or, apple waste. This in itself is a further contribution to sustainability.

Thus, the use of feedstock from other waste streams can close loops and work towards waste-free manufacturing, as is seen in traditional oak bark tanning; we can transfer this knowhow to new systems. My final artefacts (a door panel and a glove compartment) demonstrate the upcycling of leather wastes into bonded collagenic fibres, which addresses the end-of-life directive in the automotive industry.

The research has proposed leather as a material choice alongside other materials that have ecological considerations. Circular practices using leather were prototyped through hands-on investigations in a design laboratory and tannery environment, both in the UK and elsewhere including Japan and Italy. My research demonstrates circular product design by utilising leather production waste as a raw material; the prototypes created reflect new insights that I gained from a series of the experiments by recomposing leather off-cuts, through applying different processes of cutting, forming and laminating. Furthermore, appropriation and adaptation of manufacturing techniques used in papermaking and leather technology to develop artefacts has also been undertaken.

Investigation also identified collaborative communities, which were drawn out in three areas: these are an actor network map, whereby communities connected through the practice of leather are represented visually; an atlas of leather-making locations; and, an illustrated handbook – aimed at the design community – clarifies the terms of current practice and informs future practice with leather.

The technology of leather-making is captured and updated in a leather processing diagram with closed loops. A new framework of collagenic fabrication repositions the understanding of leather processes. In a circular visual format, the framework incorporates new practices such as digital manufacturing, composite fabrication and bio fabrication, changing our conventional understanding of linear process models into a circular fabrication model.

In the practice part of this research, several artefacts demonstrate circular product design covering the fabrication of designs from leather fibres. Automotive applications of door panels and glove compartments test the structural capability of a collagenic fibre blend, demonstrating circular systems for production and the reclamation of production by-products.

A body of findings resulting from this research were categorised and presented in guidelines aimed at supporting future practice. In support of the guidelines, physical leather samples and upcycled composite materials from leather shaving waste were tested and verified. An outcome of this research highlights the relevance of leather as a material for the circular economy. This is communicated through a handbook that illustrates terms and processes, and it is hoped that it will inspire makers and users.

The value of this research for design practice is in its exploration of sustainable manufacturing methods and uses of leather, exemplified by providing samples, as well as the creation of the illustrated handbook. These samples were created from inferior leather, off-cuts, leather fibre waste and tanning plant fibre waste. For the academic community, its consideration lies in developing design and reframing the position of leather and its by-products in the circular economy, which unlocks value from the reuse, repair, remanufacture, retrieval and recycling of products, components and materials.

The United Nations' Sustainable Development Goals demand the instigation of change through collaborative approaches by scientists, businesses and researchers from varied backgrounds, to address "wicked problems" and bring forth systemic change. Design Thinking approaches have been tested by innovating for sustainable development in the leather industry.

6.2 Feed Forward for Future Investigators

Leather fibre waste, in conjunction with other natural fibres and binders as a green composite material, should be developed by future research. Papermaking techniques have been found to involve suitable manufacturing processes that can be adapted, together with new forms of bioprinting.

The wide use of leather has been encroached by synthetic materials and imitated by man-made materials that display characteristics which are inherent in leather. There are, therefore, narrowly defined standards that are intended to protect leather. New collagenic materials offer opportunities and should be brought to market, named and classified for the benefit of consumers and communities working with these emerging material categories.

The complex natural system of collagenic fibre bundles and orientation within skin has been explored using a scanning electron microscope. This can be interpreted in future research by designers and imitated in digital processes such as 3D printing, developing the recent design area of Biomimetics, which focuses on adapting biological systems.

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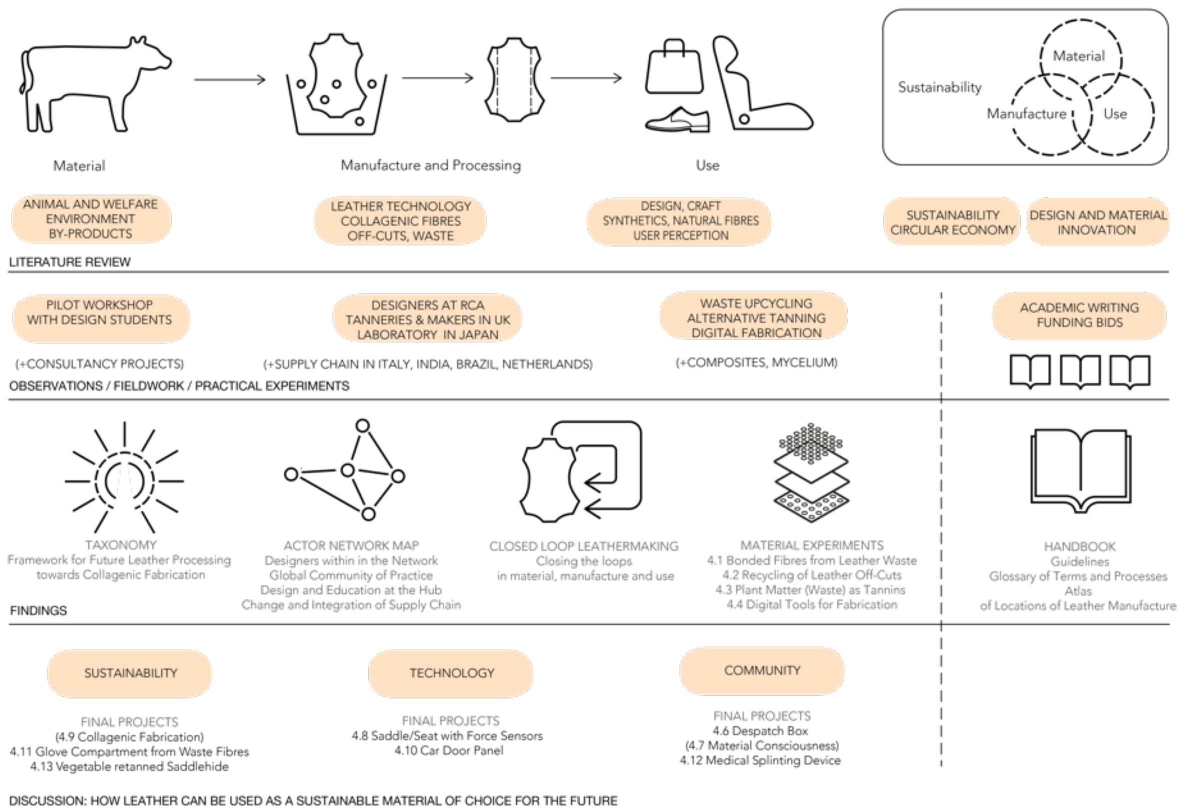
APPENDICES

APPENDIX I

Overview of Thesis Structure



Leather Futures: How leather can be used as a sustainable material of choice for the future

Chapter 1. Introduction

- Introduces the **purpose** of this research by practice, addressing the question as to how leather can be used as a sustainable material of choice for the future.
- Describes the **motivation** behind the current research, that is to offer design innovation so to regenerate the contracted shoe and leather industry in the UK.

- Presents **key concepts** that are inherent to this research, which are the circular economy and the science & technology of leather.
- Lastly, this chapter illustrates how the thesis part relates to the practice.

Chapter 2. Literature Review

- Highlights current issues relating to natural fibres and man-made materials in the context of the three facets of sustainability (Papanek 1984) and the circular economy (McDonough and Braungart 2002).
- Reviews craft, design, network and practices of working with leather (Waterer 1946; UNIDO 2010; Amberg 2018).
- Identifies the knowledge gaps through the literature review regarding materials, the manufacturing and the applications.
- Discusses how the findings of this literature reviews underpins the scope and practice of my research – new materials in design (Franklin and Till 2018), eco-informed material choices (Ashby 2009) and fundamentals in leather science (Heidemann 1993; Covington 2009 & 2020).

Chapter 3. Research Design Approaches

- Discusses a design-led methodology (for practice-based research part), such as prototyping circular practices using leather through hands-on investigation in a design laboratory and tannery environment.
- Presents ethnography documenting detailed observations of communities of practice (network mapping) through fieldwork in the UK, Italy and Japan. The purpose of this is to understand the link or discrepancy between theory and practice.
- Shed light on the leather community through practical understanding of the global industry's state and goals.

Chapter 4. New Experiments and Research

- Illustrates practical material experiments undertaken for upcycling waste fibres and off-cuts with creation of composites.

- Examines sustainable manufacturing and processing through alternative tannage (zirconium, reuse of plant waste); use of digital tools, conductivity and collagenic fabrication.
- Presents the final projects that demonstrate sustainable future leather use including prototype creation and curation of a display.

Chapter 5. Discussing Leather Futures: From Experiments to Guidelines

- Revisits research questions.
- Reviews the role of the designer for industry and as a critical curator.
- Discusses how to innovate for sustainable development.
- Closing the loops: this section examines the circular economy through my cross-case analysis of material, processes and use.
- Presents *A Handbook of Terms and Practice for the Design Community* in terms of locations, actors, modes of knowledge transfer/patterns of learning/communication.
- Examines the limitations of the research.
- Presents a claim for new knowledge through prototyping new material and approaches.

Chapter 6. Conclusions and Feed-Forward for Future Investigators

- Proposes design tools in the leather supply chain.
- Emphasises the environmental imperative with shifting roles of manufacturer, designer and consumer.
- Shares my feed-forward for future investigators.

APPENDIX II

Illustrated Handbook, Glossary of Terms

Leather – A New Illustrated Glossary

Friedemann Schaber
Royal College of Art
Vehicle Design Research
June 2021

99 Entries of Terms and Processes
from Accessories to Zirconium Tannage;
Leather Trade Locations
and Communities of Practice

Introductio and scope

The purpose of the Handbook is twofold 1. For the thesis component the handbook describes the glossary of terms and practice that this research is concerned with. Secondly, it is intended for the non-expert community that uses leather, in particular the product designer and the 'connoisseur' consumer or user. It offers an update on material innovation and sustainable practice of leather. To meets the needs of the envisaged users, a range of leather glossaries and other guidebooks have been sampled. Relevant information to answer the research question has been selected and updated. The handbook includes current terms including alternative tannages and circularity. Layout, content, and range have been selected and through consultation with graphic designers, and the illustrations and terms verified by leather technologists. The usefulness has been tested through test prints and handouts to several designers that I have interacted with and resulted in a synthesised 2nd and 3rd updated version with a list of contents, thematically arranged in the sections L Leather Terms, T Tanning, B Bio Fabrication, A Applications, K Knowledge Base, S Sustainability.
This illustrated glossary contains 99 entries of relevant terms and processes from Accessories to Zirconium Tannage. It contains a small working vocabulary and definitions in alphabetical order. It also covers a list of leather trade locations where fieldwork has been undertaken and introduces communities of practice, i.e. practitioners. It is an outcome of research undertaken on new and innovative uses of leather, it is also an output of doctoral studies undertaken at the Royal College of Art and workshops participated at the University of Northampton from 2011 to 2017. The glossary/handbook defines terms, conventions and processes for a non-expert community that appreciates, works with and uses leather. The glossary aims to guide designers and help them to disseminate this knowledge to consumers. In doing so, the author is engaging with the leather trade and is negotiating/clarifying somewhat different use of terms and conventions by various communities of practice. Illustrations such as photographic images, diagrams and graphics are visualising data, giving insights and communicating specific manufacturing and chemical processes. In an exhibition, material swatches will accompany the glossary. Previously, the 'International Glossary of Leather Terms' has been prepared by the

Illustrations and photographic record

Leather Diplomacy RCA MA

Image by Eliza Axelson Chidsey

International Council of Tanners to serve the needs of the leather-producing industry, of all users of leather and the public using leather throughout the world. The scope of the glossary is governed by the following principles: The terms included are all of potential interest to tanners, and/or their customers, and/or the general public. Terms, the meaning of which is self-evident (eg. football leather, upholstery leather etc.) are not included. In the 'International Glossary of Leather Terms' processing terms are not included, except for a very few terms which it was necessary to define in order to clarify the definition of a type of leather. Primarily this glossary will include and illustrate processes and terms to do with leather in mobility and design led applications. The larger section with around 100 entries in alphabetical order features key concepts and processes in the leather trade. The author encountered these in the course of his research including fieldwork and workshops. Major processes and common products are described. New technologies are being introduced here for the first time to a non-expert audience. The entries contain links and references, and cross references are included to lead to related content. A range of applications are featured, mainly through photographic images. A second section highlights leather trade locations that were visited and have some importance in the industry. These range from ancient industrial districts, where tanneries cluster, to places to do with manufacturing, design and retail. In this section, key manufacturers and suppliers are named. Finally, a listing and portrait of designers, artisans, chemists, technologists and educators who supported this investigation. These represent this community of practice and are the actors in this network.

Illustrations and photos are by the author, otherwise referenced.

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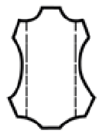

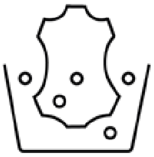

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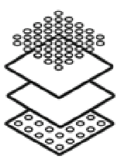

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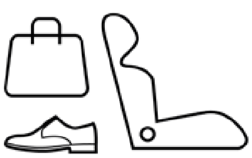

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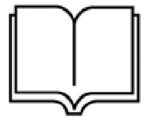

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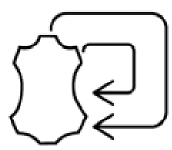

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Qualitative research methodologies: ethnography

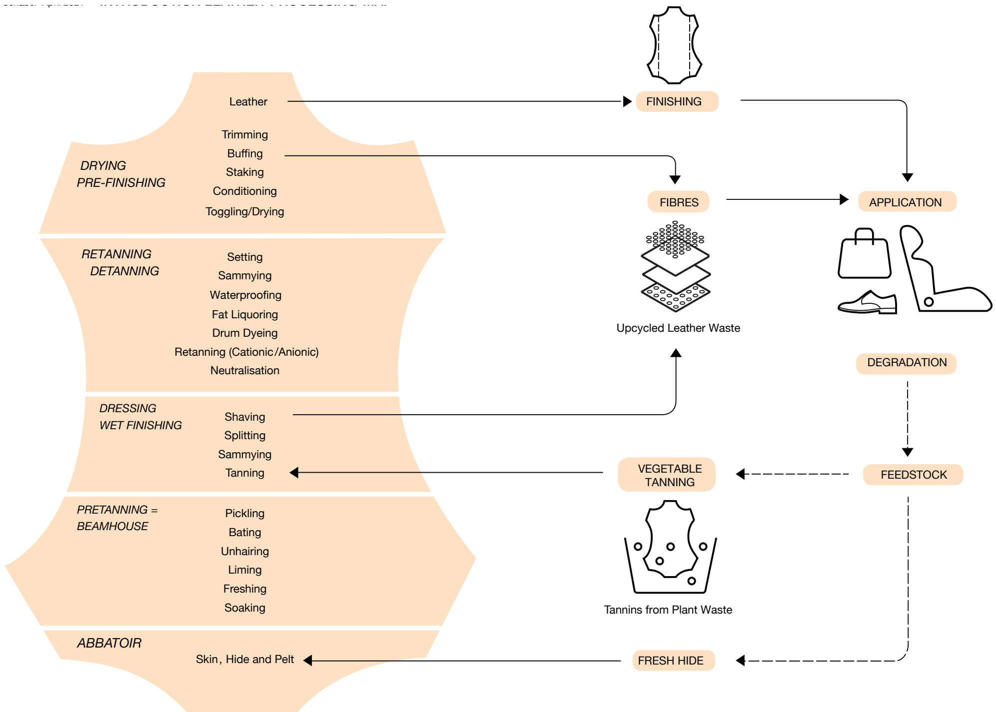
Leather Diplomacy, Oil Tannage
Image by Eliza Axelson-Chidsey

Ethnography is a qualitative research method: studying social interactions, behaviours and perceptions that occur within groups, teams, organisations, and communities. In order to document the culture, perspectives and practices of the people in these settings, I used the participant-observation method of aiming "to 'get inside' the way each group of people sees the world" (Hammersley 2017). Ingold (2014: 388) describes the progression from meeting people when conducting our research and 'encountering the world' to 'observing from the inside', as an 'education by attention.' My principal research field work was carried out in locations both in the UK and in Japan amongst leather manufacturers, very often by interacting with practitioners. The rationale was to shed light on the contribution of design and networks in the transformation of the shoe industry and leather industry, which are different trades related by a common material. In Japan, I undertook observations in districts where tanneries cluster, and two locations relating to manufacturing, design and retail. To complement a logbook and sketchbook, following Aldersley et al. (1999), video and photographic recording devices were used for some observations of practitioners. The output of fieldwork is sampled in this handbook with assorted artefacts as part of my practice, and is on display.

(Hammersley 2017; Ingold 2014)

Leather Processing Map

The infographic lists and names several production processes from the raw material to the finished item, in steps from the rawhide to a crust. Icons illustrate tanning and finishing processes. Ordered and simplified the manufacturing steps, included closed loop material flows, green chemistry and manufacturing terms



Framework of Leather Processing and Collagenic Fabrication

A circular shaped diagram of leather process and collagenic fabrication that includes new domains of fabrication. Includes stages to do with finishing, composites, fibres, forming, moulding, 3D printing, digital manufacture, smart materials and biofabrication. This illustration helps explain the transition from a current thinking of leather processing, to a future for leather that includes collagenic fabrication and new biomaterials from natural or reconstituted collagen

Accessories

A small article or item of clothing carried or worn to complement a garment or outfit, such as hat, gloves, bag or shoes. These items are commonly made from leather and described as leather goods. In the mid 20th century the term leather fancy goods was used by the trade and designers such as John Waterer.
(Oxford Languages 2021)

Aldehyde

Washable leather which in its natural state is white, usually prepared from sheep or lamb skin splits or degrains and tanned with formaldehyde or other aldehydes.
a term in Chemistry, i.e. an organic compound containing the group —CHO, formed by the oxidation of alcohols. Typical aldehydes include methanol (formaldehyde) and ethanal (acetaldehyde). Origin in Mid 19th century: shortened from Latin alcohol dehydrogenated 'alcohol deprived of hydrogen'.
(International School of Tanning Technology 2021; Oxford Languages 2021)

Alum, aluminium salts

General term for aluminium (iii) complexes used in tanning. The stiffening effect of aluminium (iii) is useful for suede leathers, and it has often been incorporated into complexes with other metal salts.
Tawing is a method that uses alum and aluminium salts, originally potash alum, used to be on making white gloving leather. Strictly this process is not tanning and is known as tawing. This white leather is functional, but the effect may be reversed it get wet. Exposure and aging may cause slight yellowing over time.
(Covington 2020)

Alternative Tannages

Alternative tannages are used instead of chrome tannages. They are enzyme activated. Olive oil residues have high perfomance properties.
(ICLT 2017)

Aniline

A colourless oily liquid present in coal tar. It is used in the manufacture of dyes, drugs, and plastics, and was the basis of the earliest synthetic dyes. Origin Mid 19th century: from anil 'indigo' (from which it was originally obtained), via French and Portuguese from Arabic an-nīl (from Sanskrit nīlī, from nīla 'dark blue'). Oxford dictionary Depending on the thickness of the applied pigment layer, smooth leather is referred to differently. Aniline leather has no pigment based top colouration. Little pigmentation, but hair pores still well recognisable: Semi-aniline
(Lederlexikon 2021)

Tanner fleshing an animal skin with traditional tools. When fleshing, connective tissue and meat residue are removed from the flesh side of the skin. In the past, drawknife and beam were used by the tanner. Nowadays this stage is done with rotating scraping rolls.

Pigmentation - To make leather more durable, more stain-resistant and permanently water-repellent, a layer of a binder-pigment-mixture is applied to the surface of smooth leather that has already been completely pre-coloured with aniline dyes.

Measuring anionic pigments
TFL Arizigniano

Animal

Leather is a by-product - the main sources of raw material for the leather industry world-wide are cattle, sheep and goats, which are reared specifically for the production of meat, wool and dairy products. Typically, the value of cattle hides, sheep and goat skins represents in the region of 5-15% of the market value of an animal. The leather industry utilises hides and skins which would, if the industry did not exist to process them, create a waste disposal problem with the attendant health hazards. Sustainability of production is a fundamental value for the global tanning industry represented by the International Council of Tanners (ICT). The welfare of animals from which the industry's raw material derives, in every moment of their life, is considered as a prerequisite. Protection of Animals on Farms, Protection during transportation of animals, Protection of animals at the time of slaughter and killing
(International Council of Tanners 1967;
Manifesto for Animal Welfare)

Anionic Pigments

Dispersion mechanism - Ionic dispersing agents act by coating the surfaces of inorganic mineral particles as the result of an attraction to the positive charges that develop on particles when in contact with water, a process known as 'adsorption'. Adsorption imparts a net negative charge to the particle surface so that the particles are repelled from each other. When a mineral is dispersed in water using Dispex products, this negative attraction reduces the interaction between particles, thus lowering the viscosity of the mineral slurry or paint mill-base. The slurry then remains fluid until a fairly high quantity of the mineral has been added (70 - 80% mineral). The Dispex addition gives the slurry better flow properties and it remains stable for longer. By making the polymer chain more hydrophobic, interaction with minerals such as TiO_2 and ZnO is improved, as is the water-resistance and gloss of a formulated coating.
(BASF 2016)

Artico leather

A new generation of imitation leather used by Mercedes is called "Artico leather" with the added comment "man-made leather". This material description does not appear to be in compliance with EU standards.
(Lederlexikon 2021)

Authenticity

The quality of being authentic. Synonyms: genuineness, originality, reliability, dependability, trustworthiness, truth, veracity, verity, faithfulness, fidelity, authoritativeness, credibility Oxford dictionaries. Walter Benjamin (1936) states that the presence of the original is "the prerequisite to the concept of authenticity" and that a work of art, in principle, has always been "reproducible" and "man-made artifacts could always be imitated by men." Design research (Nidderer 2015) questions the meaning of authenticity in the context of emerging digital practice, "how can we authenticate the digital and how might makers address genuineness, the ownership of ideas, designs and claims to uniqueness, in a world of instant copying, sampling and the habitual plagiarism of images?"
(Benjamin 1936; Nidderer 2016)

Automotive Leather

Used in transport interiors, to a high specification defined by car manufacturer, conformity tests of lightfastness, rubfastness, consideration of thermal stability, fogging, used are mainly bovine leather with often corrected grain and PU finish in a wide range of colours. Mainly bovine hides due to large panel sizes. Set covers require different leathers as for dashboard, side panels, steering knob, bellow, steering wheel cover, headrest, consideration of end-of-life regulations. Evolved from Coach-making tradition with upholstery craftmanship. Specified by carmakers through design departments in Interior design, Color and Trim, added value to car, opportunity to personalise a car without tooling costs. Seat cover, armrest, steering wheel, door trim, instrument panel, gearshift knob or boot produce the perfect custom solution for every application. This includes leather finishing and custom cutting to the flawlessly stitched final cover.

Bead Tannage

Xeros Technology Group, a UK start-up that has developed a patented polymer bead system that it claims can save large volumes of water in leather production, has been working with the university since the start of 2014 to adapt its technology, which it says works well in dry cleaning applications, to leather production. In May 2015, Xeros entered into a partnership with major leather chemicals manufacturer Lanxess, saying it hoped this would lead to its being able to use its bead technology to process high-quality "on a commercial and scalable basis".
(http://www.aplf.com/en-us/leather-fashion-news-and-blog/news/26868/leather-bead-technology-water-free-future-tanning)

Beam House

The steps in the production of leather between curing and tanning are collectively referred to as beamhouse operations. They include, in order, soaking, liming, removal of extraneous tissues (unhairing, scudding and fleshing), deliming, bating (including puering), drenching, and pickling.
(Lederlexikon 2021)

Biopolymers

Biopolymers are polymers that occur in nature. Carbohydrates and proteins, for example, are biopolymers. Collagen is the most abundant protein found in mammals. Gelatin is denatured collagen, and is used in sausage casings, capsules for drugs and vitamin preparations, and other miscellaneous industrial applications including photography. Casein, commercially produced mainly from cow's skimmed milk, is used in adhesives, binders, protective coatings, and other products.
Polyesters are produced by bacteria, and can be made commercially on large scales through fermentation processes. They are now being used in biomedical applications.
(www.sda-uk.org/materials/popups/plastics/what_are_biopolymers.htm To find out more about Biopolymers visit - http://greenplastics.com/green-materials.html)

Beamhouse operation - Liming pit at Baker Tannery

Oakbark tannage in pits at Baker Tannery, Colyton

Baker Tannery in Colyton, Devon. Managing Director Mr Parr and pits with coppiced oakbark from Cumbria. Image by Andrew Shaylor

Dressing the tanned hide with fish oil at Baker Tannery

Oakbark tanned bovine hides, clicked for shoe soles

Biofabrication

Biofabrication
Grow collagen from living cells alike natural protein found in animal skin. Assembling this collagen into a sheet material and then finish it in a simplified tanning process.
(Williamson and Redwood 2017. http://www.modernmeadow.com)

Boarding

A leather production process designed to reinforce and emphasise the grain of the leather. The tanned and dyed leather is rolled under pressure over an edge. The grain side is thereby on the inside (facing the board) and is compressed. The resulting folds in the leather are as durable as an embossing. The leather can be boarded from several directions, thus giving different grain textures.
(Lederlexikon 2021)

Brand

The term brand refers to the unique marks burned into the hides of cattle to distinguish the animals of one owner from those of another. A brand is a distinguishing symbol, mark, logo, name, word, sentence or a combination of these items that companies use to distinguish their product from others in the market. Legal protection given to a brand name is called a trademark. A brand is seen as one of its company's most valuable assets. It represents the face of the company, the recognizable logo, slogan, or mark that the public associates with the company. In fact, the company is often referred to by its brand, and they become one and the same. A company's brand carries with it a monetary value in the stock market (if the company is public), which affects stockholder value as it rises and falls. For these reasons, it's important to uphold the integrity of the brand.
(Brand - Investopedia)

Bycast

Bicast leather is a lower cost material made with split leather as a backing, commonly used as sidepanels for seating. A polyurethane coating is applied to the surface and then embossed.
(ICLT 2017)

Craft demonstration at Mulberry, Mayfair

Chamois leather in drum

Chamois

(1) Suede finished leather made from sheep or lambskin, from which the grain has been removed by frizzing, and tanned by processes involving the oxidation of fish or marine animal oils in the skin, using either solely such oils (full oil chamois) or firstly, formaldehyde and then such oils (combination chamois). In France and the U.S.A. the term "chamois", without any qualification, is restricted to the flesh split of sheep or lambskin tanned solely with oils.
(2) Leather made from the skin of a mountain antelope or chamois (such leather is rare). Chrome Retan Leather which has been first chrome tanned throughout its thickness and subsequently further treated or tanned with vegetable and/or synthetic tanning agents and/or resin filling materials, these agents penetrating notably, but not necessarily completely, into the interior.
(British Standards Institution, 1983)

Chrome tanning

Leather tanned either solely with chromium salts or with chromium salts together with quite small amounts of some other tanning agent used merely to assist the chrome tanning process, and not in sufficient amount to alter the essential chrome tanned character of the leathers. Chrome 3, Chrome 6, low-salt pickle, hydrotropic effect
(British Standards Institution, 1983)

Chrome tanning yard with drying conveyor belt. Image Con. Mastrotto

Circularity

The circular or circle economy (CE) is a transformation of our linear or throwaway economy, into one where waste is eliminated, resources are circulated, and nature is regenerated. The model is characterised by closed-loop or circular flows of nutrients from the biosphere or technosphere, in a process from making, use and waste management. Circularity is a radical re-think in how we use resources, how we design products and services, the business models used to provide those products and the systems required to keep products, materials and components in circulation at their highest value for the longest period. Instead of liner through-flow of materials, a circular economy aims to preserve and rebuild stocks of man-made and natural capital and reduce resource consumption, create more jobs and promote a different type of growth, where waste and pollution is designed out at the outset.
(Circular Economy Hub 2021; Weetman 2021; McArthur Foundation 2021)

Collagen

A group of fibrous proteins that occur in vertebrates as the chief constituent of connective tissue fibrils and in bones and yield gelatin and glue upon boiling with water. Collagen, in the form of elongated fibrils, is mostly found in fibrous tissues such as tendons, ligaments and skin. The name collagen comes from the Greek kólla), meaning "glue", and suffix -, -gen, denoting "producing". This refers to the compound's early use in the process of boiling the skin and sinews of horses and other animals to obtain glue. cosmetics, gelatine for food. Collagen also has many medical uses in treating complications of the bones and skin.
(Merriam Webster 2021)

Composites - Cell Collagen Silicia Composites

Cell-collagen-silica composites and methods of making and using the same. A composition comprising: at least one biological material; a tuned collagen material comprised of individual fibril branches, and having an inner portion, and an outer portion, wherein the inner portion is configured to at least partially encapsulate the at least one biological material; and a silica layer, wherein the silica layer is coupled to the outer portion of the collagen material.
(https://www.google.com.na/patents/WO2016172365A1?cl=en)

Color and Trim

The designer defines and designs the ambiances, colors and materials for the interior of a car, in coherence with the brand image and the trends, while integrating the economic and industrial constraints. A trend expert, the « color and trim » car designer is responsible for the research and development of the ambiances, materials, colours designed for the interior and exterior of a vehicle.
(https://www.strate.education/color-trim-designer)

Conductivity

Leather is an insulator and non-conductive. This property can be altered so to use touch-screens with a glove. Materials composed of a conductive and an insulating content undergo three phases in which the movement of electrons inside the matrix may or may not happen, this feature is governed by the distance between the conductive particles. Polymers characterized by high amount of conductive carbon black show a proper contact between the filling particles, the movement of electrons is promoted by the continuous conductive structure inside the matrix, the conductivity is mainly affected by the carbon black conductivity particles and their contact.
(Galiotto 2017)

Connollysation

Many years ago there was a leather producer, Connolly Leather, that provided the leather for Rolls Royce, Bentley, Aston Martin, Ferrari and many other luxury automobiles and high quality leather furniture. In time they discovered that after some time the finish on their leathers began to deteriorate. As they looked deeper into this they also discovered that the underlying leather itself was still in good condition so from this came a process called Connollisation. Conollisation is basically cleaning an existing finish, stripping it slightly and reapplying a new finish. If this is done soon enough before the leather itself has deteriorated it will result in a auto seat, couch, loveseat, chair or whatever that looks almost like new. So that is what leather restoration is, it is the refinishing of leather. I
(Pioneer Leather 2021)

Corium

Corium - the middle layer of the skin
The longest running alumni of Northampton university dating back over 100 years. It is primarily for students studying leather, for a diverse amount of students from all over the world, Taiwan, Kenya, India, Pakistan, South Africa and Italy. The aim of Corium club is to help students integrate and create friendships across all years of the leather course, but also help create friendships with students from other disciplines.
(ICLT 2017; Northampton Union 2021)

Corrected Grain

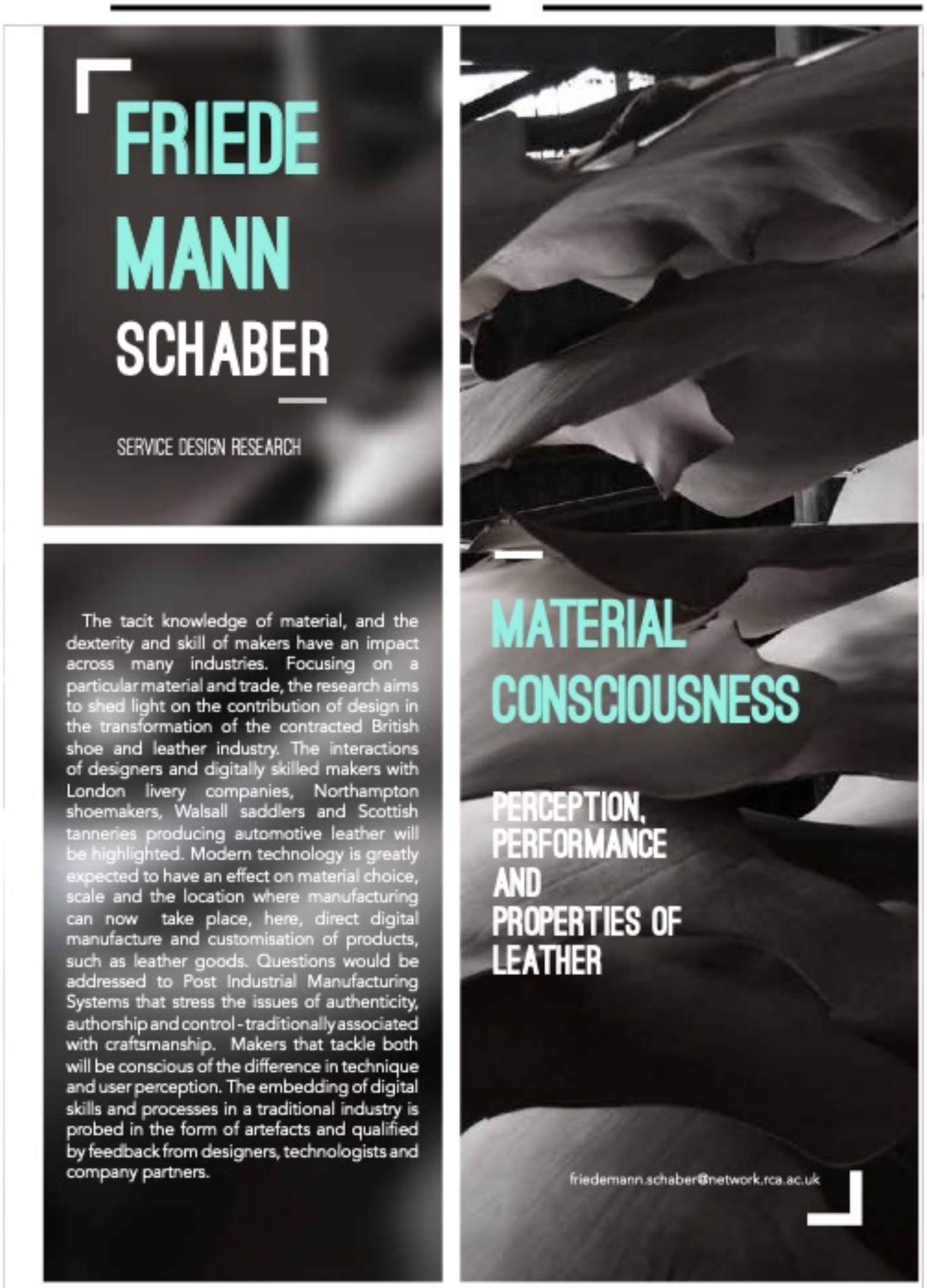
In preparation for embossing smooth leather, the leather is frequently sanded (buffed) first on the grain side to obtain a uniform surface and to make skin damages invisible. Subsequently, a binder-based colour layer is applied and a uniform grain embossed. Such leather is then referred to as “Corrected Grain”. It is cheaper and feels stiffer and colder due to the thick colour layer and the fibre compression of the embossing. It is also less breathable than porous leather. There are also corrected grains, which are only slightly sanded and embossed and feel soft and warm.
(Lederlexikon 2021)

Craft

Activity that “involves making something in a skillful way by using your hands, an activity that requires special skill”. David Pye’s notion of workmanship draws the boundary to design: ‘design proposes, workmanship disposes’.
(Merriam Webster 2021; Pye 1968)

Corporate Social Responsibility

Abbreviated CSR, Corporate Social Responsibility is a form of corporate self-regulation integrated into a business model. Related terms are corporate citizenship, corporate conscience and responsible business)
(Sheehy 2015)


FRIEDE
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SCHABER
SERVICE DESIGN RESEARCH
The tacit knowledge of material, and the dexterity and skill of makers have an impact across many industries. Focusing on a particular material and trade, the research aims to shed light on the contribution of design in the transformation of the contracted British shoe and leather industry. The interactions of designers and digitally skilled makers with London livery companies, Northampton shoemakers, Walsall saddlers and Scottish tanneries producing automotive leather will be highlighted. Modern technology is greatly expected to have an effect on material choice, scale and the location where manufacturing can now take place, here, direct digital manufacture and customisation of products, such as leather goods. Questions would be addressed to Post Industrial Manufacturing Systems that stress the issues of authenticity, authorship and control - traditionally associated with craftsmanship. Makers that tackle both will be conscious of the difference in technique and user perception. The embedding of digital skills and processes in a traditional industry is probed in the form of artefacts and qualified by feedback from designers, technologists and company partners.
MATERIAL
CONSCIOUSNESS
PERCEPTION,
PERFORMANCE
AND
PROPERTIES OF
LEATHER
friedemann.schaber@network.rca.ac.uk

Design

Industrial Design is a strategic problem-solving process that drives innovation, builds business success, and leads to a better quality of life through innovative products, systems, services, and experiences. Industrial Design bridges the gap between what is and what's possible. It is a trans-disciplinary profession that harnesses creativity to resolve problems and co-create solutions with the intent of making a product, system, service, experience or a business, better. At its heart, Industrial Design provides a more optimistic way of looking at the future by reframing problems as opportunities. It links innovation, technology, research, business, and customers to provide new value and competitive advantage across economic, social, and environmental spheres.
(World Design Organization)

DNA labelling

Applied DNA Sciences is a bio-tech company specialising in the use of botanical DNA for anti-counterfeit and security applications. Applied DNA Sciences is a bio-tech company specialising in the use of botanical DNA for anti-counterfeit and security applications. Applied DNA Sciences are the creators of unique botanical DNA-based tagging and authentication systems which have been successfully implemented to improve supply chain management, protecting textiles, electronic components, cash, vehicles and many other assets. The leather industry supply chain is complex and there is currently no complete and reliable system for managing traceability. DNA labelling could provide the solution to secure the entire value chain, from the farm to the retailed product.
(International Leathermaker 2017)

Drum

Commonly used tanning equipment that is superseding pits. Hides would be loaded in a drum and immersed in a float containing the tanning liquor. Described in Proctor's treatise on the conversion of skins into leather both practical and theoretical, while the drum slowly rotates about its axle, the tanning liquor slowly penetrates through the full substance of the hide.
(Proctor 2018)

Dye

Pigments are based on organic and inorganic colorants with or without casein to cover and match the color required. We have both cationic and anionic pigments in many shades. The advantages of cationic pigments are without compromising on the natural feel the defects are covered to some extent and also imparting a brilliant appeal.
Dye Solutions are used to colour the crust as per the users exact shade requirement. For many decades we are the front runners in this category. We have brilliant colours with different concentration which can be used on any type of leather right from shoe upper to garment leather or suede to nubuck to get exact colour as per the choice of the customer. They give good colour fastness and migration properties. We have both anionic and cationic dye solutions. These products are helpful to maintain the natural feel of leather and also

Tanning Drum

Dye, colour matching

cover the defects in the leather to some extent.
(CEL Leather Chemicals, 2017)

Eco Label

The EU Ecolabel was established in 1992 by the European Commission. The EU Ecolabel helps to identify products and services that have a reduced environmental impact throughout their life cycle. Recognised throughout Europe, EU Ecolabel is a voluntary label promoting environmental excellence which can be trusted. The Eco Label index filters and compares ecolabels.
(Eco Label Index 2017; EU Ecolabel, 2021)

E-Leather

Made with natural leather fibres is a cost effective, strong & durable alternative to leather, for Aviation, Bus & Rail upholstery & interiors. Manufactured using leather off-cuts that would otherwise end up in landfill, E-Leather reduces the costs both environmentally and economically of producing high-quality, upholstery material. Discarded leather is upgraded in a patented process, which physically interlinks the fibres without the use of adhesives. The manufacturing process uses state of the art techniques which close loop recycles 95% of the process water, and converts its own waste streams into energy which is fed back into the process.
(E-Leather Group 2014)

Embossing

The art of producing raised patterns on the natural grain of an animal skin. The design is created by pressing rolling, or stamping. Embossments can cover the entire surface of a skin or just selected areas. Another reason for embossing hides is to obscure natural markings on leather. Therefore, the surface is sanded and repaired before embossing. Such leather is called 'corrected grain'. Embossing is used to hide insect bites, injuries, illnesses and other damages on animal skins and to create a uniform grain. This reduces wastage, as the entire surface of a skin gets a uniform grain pattern. All parts of a set of furniture or car interiors will be identical. Minor flaws and irregularities of the natural grain can be balanced and must not be circumvented when cutting the leather.
(Lederlexikon 2021)

Effluence, Common Effluent Treatment Plant

Small scale tanneries can not afford to have their own effluent treatment facilities and therefore, combined effluent from all tanneries are to be brought to a centralized place for treatment. This facility is called a Common Effluent Treatment Plant (CETP). For operation and maintenance of CETP, small scale tanners formed a co-operative society. The expenses for operation and maintenance of CETP are being shared by participating tanneries. Wastewater management for the cluster of small scale tanneries was studied in details and various measures were incorporated to improve performance of the CETP and also to improve treated effluent quality to confirm

Embossing press

Embossed vegetan and chrome tanned bovine leathers

standard prescribed by regulatory agencies.
(National Environmental Engineering Research Institute 2017)

End-of-life vehicles producer registration

The End of Life Vehicles Regulations place responsibilities on producers of passenger cars and light goods vehicles. Producers and importers of vehicles must register with Department for Business, Energy and Industrial Strategy (BEIS), state the brands of vehicles for which you are responsible for meeting recovery and recycling targets. Free take-back of end of life vehicles. As a vehicle producer you are required to make a convenient network of facilities available. End of life vehicles can be taken to these facilities for dismantling and recycling at no cost to the final owner.
(UK Government Regulations 2015)

Enzyme

One of the oldest applications of industrial enzymes is processing hides and skins for leather. Hides and skins contain proteins and fat in between collagen fibres and before tanning; these substances should be partially and fully removed. The proteins can be removed by proteases and lipases as well as other chemicals can remove the fat. Today, proteases and lipases are mainly used for soaking, bating and enzyme assisted un-hairing. Using lipases to dissolve and remove fat is a recent development and lipases are now extensively used for leather processing in many parts of the world.
(Maps Enzymes 2017)

Exotics, CITES

Exotic leathers are either made from relatively rare animal species or from skin parts of animals that are rarely processed into leather. Some exotic leathers are protected by the CITES (Convention on International Trade in Endangered Species of wild fauna and flora). Crocodile or snake skin leathers are commonly addressed as leather. However, other exotic leathers like fish leather, leather from chicken legs or from cow belly/stomach also exist. Depending on the culture, the definition of exotic leather, can differ. Alligator lizard, Ostrich leather Sealskin leather Snakeskin, Yak leather, Zebra hide. The Washington Convention on the Protection of Animals (CITES - Convention on International Trade in Endangered Species of wild fauna and flora) is an international agreement between 164 countries, which is to control the global trade in plants, animals and products made from them. The aim of the agreement, signed by eighty governments in Washington in 1973, is the protection of endangered species from extinction. The agreement contains three lists of endangered species of plants and animals whose trade, even in processed form, is totally prohibited. This includes exotic leather, especially reptile leather, monitor lizard species, giant snakes, cobra varieties and peccary. On importation, such goods are confiscated by customs.
Lederlexikon 2021; Convention on International Trade in Endangered Species of Wild Fauna and Flora 1973)

Epidermis

Exotics: Crocodile

Exotics: Ostrich

The upper or outer layer of the two main layers of cells that make up the skin. The epidermis is mostly made up of flat, scale-like cells called squamous cells. Under the squamous cells are round cells called basal cells. The deepest part of the epidermis also contains melanocytes.
www.medicinenet.com

Epi leather

A style of pressed leather. It is made by stamping a pattern into vegetable tanned leather that is dyed, and finished with a water resistant, protective coating. Its characteristic look is a horizontal, textured pattern. Epi leather is most often used in Louis Vuitton handbags.
https://www.libertyleathergoods.com/epi-leather/

Finishing

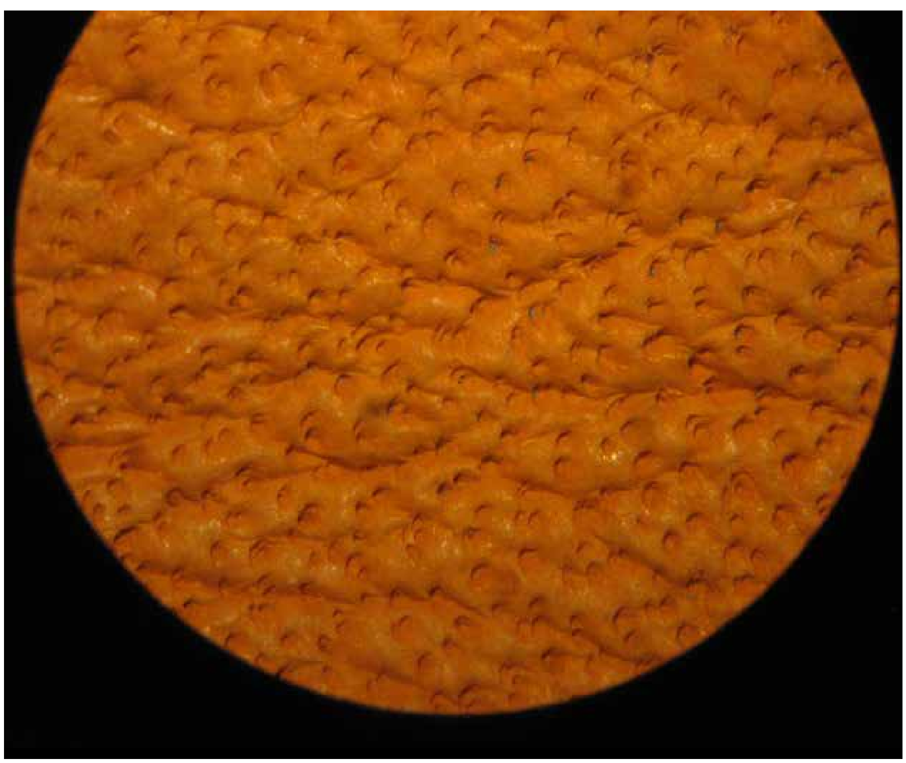
Application of a basecoat and topcoat of usually polymers but may be protein, to protect and enhance the grain, to allow aesthetic effects to be created. Finishing may also be applied to suede surfaces. Processes include feeding, tipping, spraying, coating, staking, burnishing, glazing, toggling, drying, rotary ironing press, base coating, corrected grain, Airless spray coating
(ICLT 2017; Covington, 2020)

Genotyping

Process of determining differences in the genetic make-up (genotype) of an individual by examining the individual's DNA sequence. A method to differentiate leather from different animals.
(BLC Eurofins 2016)

Glazing

Epidermis with bovine patterned hair follicles under light microscope



Leather which has a very bright or glossy (glass-like) appearance. The leather surface is compressed by strong friction pressure so that it becomes smooth and shiny. To achieve a particularly high gloss finish, non-thermoplastic binders are applied to the leather surface, which prevent the leather from becoming soft and sticky during this process. Mostly, casein-based binders are used. The process is carried out by a glazing machine. Nevertheless, the manual effort for the glazing is enormous, which increases the cost of production. High gloss crocodile leather, lizard leather, snakeskin, turtle leather or ostrich legs are mostly glazed. Glossy leather is otherwise extremely water-sensitive and especially for shoes, a waterproofing final lacquer is applied to make the leather, water-repellent.
(Lederlexikon 2021)

Grain texture

The outer layer of the hide or skin, the more valuable part comprising the corium minor and the enamel outer surface. The pattern characterised by the pores and unique to the animal concerned, visible on the outer surface of a hide or skin after the hair or wool and epidermal tissue have been removed. The grain side refers to the smooth, grained surface facing the hair side (or the outside, if no hair is present) in leather. The grain pattern can be changed by embossing and colouration. A natural leather grain varies across the skin surface. In the middle of a skin the leather is mostly fine grained, while towards the edge it has a coarse grain. When cutting seating surfaces for furniture and vehicles, the customers value a uniform grain structure. Due to the uniform embossing, the grain structure is identical across the hide.
(Covington 2020)

Handle, haptic

The abundance of leather describes how full the leather feels. The leather is “filled” by large-scale retanning substances and hence feels fuller and heavier.
Haptic relates to the sense of touch (feel), as well as the look of an object, with regards to its material characteristics, surface structure and consistency.
The term “grip” is also used to describe the feel of a leather. “A buttery napa leather,” a “waxy” grip of a fine aniline leather, the “plastic-like” grip of strong coated leather, or the “parchment-like” grip of an old, dry, thin leather are all used to describe the feel of leather. Also, theand stiffness, elasticity, warmth and coldness of a material come under the haptic properties.
(Lederlexikon 2021)

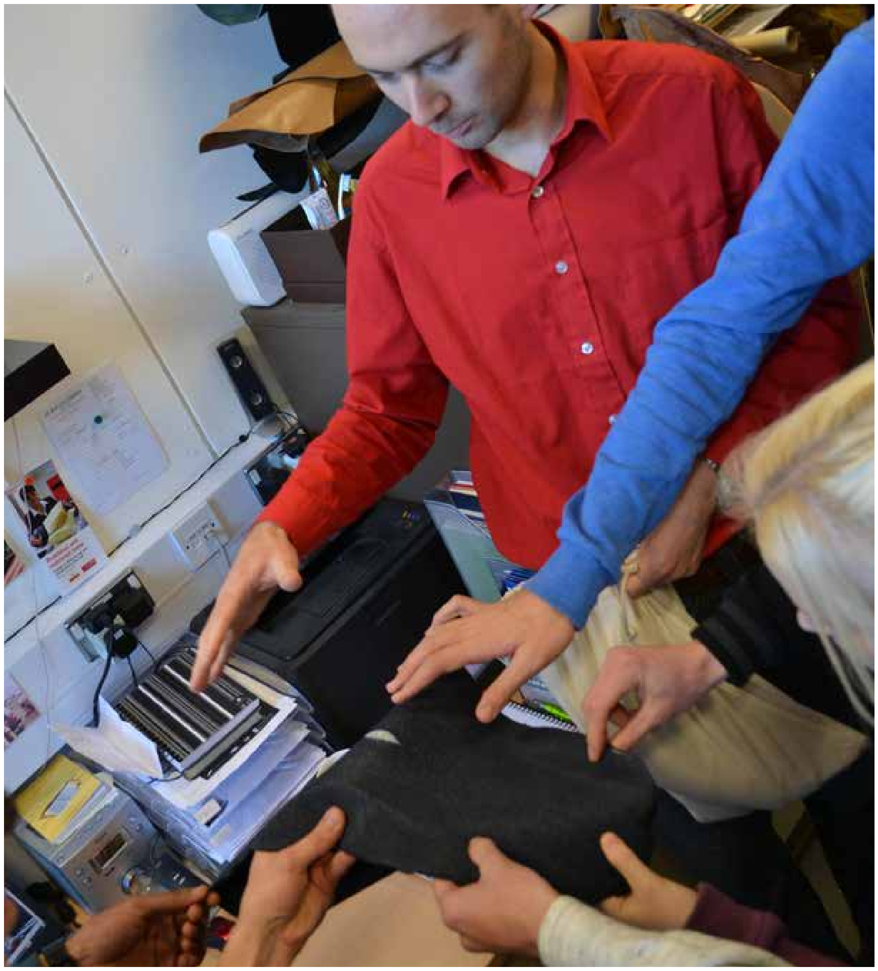
Heat reflective coating

Smart material properties in topcoat finish, visible under infrared light
(TFL 2012)

Hide

Glazing through friction pressure

Tanning drums



Handle of shagreen (stingray)

Moulded leather - saddlery

Vegetable tannin extract fabrication - chestnut

The outer covering of a mature or fully grown animal, typically adult bovine animal
(ICLT 2017)

Imitation leather, faux, vegan, leatherette

There are many expressions for imitation leather. Faux leather', fake leather, leatherette, synthetic leather, artificial leather, man made leather or skai are just some of them. Modern synthetic leather has a polyurethane coating instead of the PVC coating. Therefore the name PU imitation leather is also used. In parts of China, imitation leather is known as PU leather, while the Portuguese call it napa and there are many varied expressions in other countries. Some names are used in an attempt to disguise the fact that the material is not genuine leather. Names like Coskin, like leather, textile leather, pleather, vegan leather, vegetarian leather or Pellissimo and many more expressions are used to make the material sound more valuable. Advantage is is cheap, producers on the roll with high cutting efficiencies, legally cannot be described as leather, different handle properties to leather, synthetic, non-circular and non-renewable.
ICLT 2017; Lederlexikon 2021)

Innovation

The action or process of innovating. 'innovation is crucial to the continuing success of any organization'. A new method, idea or product
(Oxford Languages 2021)

Intellectual property

Business will own some form of intellectual property (IP) and protect these assets, trade marks, patents, copyright, designs and confidential information. The UK Government Intellectual Property office advices on licensing, intellectual property protection and franchising .
(Intellectual Property Office 2016)

Injection moulding

Leather fibers and biopolymers are combined to create a high-quality injection molding material that combines the look, feel, and moisture-regulating properties of leather, with the potentials offered by synthetic materials. Kollamat provides optimal heat and sound insulation along with significant variability in durability and density. There are also ecological advantages to using Kollamat such as low production-related energy consumption (maximum 160 °C) and the substitution of mineral oil-based plastics with leather - a natural resource.
(Bader Leder 2021)

Knowledge transfer (KT)

A term used to encompass a very broad range of activities to support mutually beneficial collaborations between universities,

Upholstery, Fleming & Howland at 100% Designshow

Dr Martens shoe fabrication, Wollaston

businesses and the public sector. KT is a 'contact sport'; it works best when people meet to exchange ideas, sometimes serendipitiously, and spot new opportunities
(www.cam.ac.uk/research/news what-is-knowledge-transfer)

Leather

A general term for hide or skin with its original fibrous structure more or less intact, tanned to be rot-proof. The hair or wool may or may not have been removed. Leather is also made from a hide or skin which has been split into layers or segmented either before or after tanning. However, if the tanned hide or skin is disintegrated mechanically and/or chemically into fibrous particles, small pieces or powders and then, with or without the combination of a binding agent, is made into sheets or other forms, such sheets or forms are not leather. If the leather has a surface coating, however applied, or a glued-on finish, such surface layers must not be thicker than 0,15 mm.
(ICLT 2017; European Directive no. 94/11/ CE and the Italian D.M. 1996)

Leather Manufacturing Process

The use of hides and skins, tanned or untanned, as useful articles has been with us for thousands of years. The Oxford Dictionary refers to leather as "material made from the hide or skin of an animal by tanning". Tanning, in simple terms, refers to the treatment of raw hides and skins with tanning substances to render the material immune to bacterial attack, i.e. to produce leather. Additional changes introduced in the process of tanning are secondary and are related to the tanning and retanning chemicals used. There are hundreds of different leather types and tens of thousands of different chemicals to choose from when producing these leathers. The most important chemicals in the tanning process are the tanning agents as they define the process of leather manufacture as a whole. In this modern day and age, tanners will choose tanning chemicals based on price, convenience of use, environmental issues, and by matching the physical and aesthetic properties introduced by the tanning chemicals to the desired leather properties of the end product. A basic knowledge of the general processes involved in leather production, the tanner's true raw material ie collagen, the pretanning, tanning and retanning chemicals used in the production of leather, and the mechanistic interaction of tanning chemicals, are all factors which are important in order to appreciate just part of the intricate process of leather manufacture.
(The Leathersellers Company 2016)

Luxury goods

Luxury goods, synonymous with upmarket, superior goods and Veblen goods are goods for which demand increases more than proportionally as income rises. As the consumer gets more income, he consumes more of both goods but proportionally more of one good (the luxury good) than of the other (the necessary good).
(Varian 1992)

Nappa

Soft and full grain gloving or clothing leather made from unsplit sheep, lamb, goat or kid

Innovation - Conductive leather

Morgan Motors - Muirhead Leather

skins. It is usually tanned with alum and chromium salts and dyed throughout its substance.
(International Council of Tanners 1967)

Nubuck

Strong hide leather on the grain-side to give a velvety surface.
(International Council of Tanners 1967)

Olive Tannage - Wet Green

The Wet-Green tanning system based on an aqueous olive leaf extract enables production of high-quality leathers suitable for applications in all kinds of areas, especially automotive, furniture for the residential and commercial/public sectors, leather goods and clothing. At the same time, the use of environmentally and health-relevant conventional chemical tanning agents like chromium (III) salts or glutaraldehyde is waived. This sets new standards regarding sustainability. The olive leaves are obtained in great quantities as a residue in connection with olive harvesting in the Mediterranean.
(Olivenleder 2021)

Patent leather

Leather one surface of which is covered with a flexible waterpreoof film, with a lustrous mirrorlike surface, produced by application of several coats of daubs, varnishes and laquers, some of which may be pigmented.
(International Council of Tanners 1967)

Performance properties, material science

Material scientice emphasises the understanding ,how the history of a material (in processing) influences its structure and thus the material properties and performance. The understanding of processing, structure properties relationship is called the material paradigm. This paradigm is used to advance understanding in a variety of research areas, including nanotechnology, biomaterial and metallurgy. Material science is also an important part of forensic engineering and failure analysis, investigating material, products, structure or components which fail or do not function as indicated.
(Ashby 2009, Singh 2020)

PeTA

The organisation 'PeTA' is internationally active and fights against animal cruelty and everything related to it. This includes mass animal husbandry, but also the use of animals as foodstuffs or the utilisation of the skin as leather, because in their opinion this leads to animal cruelty.
(Lederlexikon 2021)

Pickle

The pickling process prepares the pelt for the chrome tannage or is used as a form

Pickled sheep intestines. Image by Julia Lohmann

Nubuck sample

of long term preservation particularly for sheep skins pelts which are traded around the world in the pickled condition.
In the most simple form pickling consists of the treating the skins or hides with salt (sodium chloride) and an acid, usually sulphuric acid. To help penetration of the pickle and to provide a masking effect to aid chrome penetration, it is common to add organic acids or their salts, the most common being formic acid or sodium formate. Lime fleshed hides or skins delime more easily and if the delime process is optimised the pickling will in turn be more easily accomplished.
(TFL 2016)

Pigment

A pigment is a material that changes the color of reflected or transmitted light as the result of wavelength-selective absorption. Pigments are used for coloring paint, ink, plastic, fabric, cosmetics, food, and other materials. Most pigments used in manufacturing and the visual arts are dry colorants, usually ground into a fine powder. This powder is added to a binder (or vehicle), a relatively neutral or colorless material that suspends the pigment and gives the paint its adhesion.
A distinction is usually made between a pigment, which is insoluble in its vehicle (resulting in a suspension), and a dye, which either is itself a liquid or is soluble in its vehicle (resulting in a solution). A colorant can act as either a pigment or a dye depending on the vehicle involved. In some cases, a pigment can be manufactured from a dye by precipitating a soluble dye with a metallic salt. The resulting pigment is called a lake pigment. The term biological pigment is used for all colored substances independent of their solubility.
(ILTC 2017)

Polyurethane

Polyurethane polymers (PU) are used, both in solvents and in aqueousdispersion, in order to obtain special lacquer effects or to produce separate films, which are stuck onto the leather. Usually, these leathers have a glossy surface. PU leather is used for furniture and shoes. PU leather is a split leather that has been laminated with a polyurethane coating to make it look

Dye Drums / Green Hide. Image by Scottish Leather Group

like a top grain leather. Usually, these leathers have a glossy surface and an antique look. PU leather is used for furniture and shoes.
(TFL 2021, Lederlexikon 2021)

Proof of Concept

The Proof of Concept (POC) is a small exercise to test the design idea or assumption. The main purpose of developing a POC is to demonstrate the functionality and to verify a certain concept or theory that can be achieved in development. Prototyping is a valuable exercise that allows the innovator to visualise how the product will function, it is a working interactive model of the end product that gives an idea of the design, navigation and layout.A POC shows that a product or feature can be developed.
(Singarama and Jain 2018)

Prototyping

Connection of craft, making and prototyping, as "a prototype is an early sample, model, or release of a product built to test a concept or process or to act as a thing to be replicated or learned from" . In his keynote speech at MIT, Schrage (2010) addresses a concept of crafting interactions as the purpose(s) of 'serious play.' Fisher and Nidderer (2015) raise the need to question established understandings of making and of craft in the context of "current developments, including computer aided manufacturing and science-based ways of 'producing' craft artefacts, such as growing clothing from micro cultures." While a POC shows that a product or feature can be developed, a prototype shows How it will be developed.
(Nidderer 2015; Blackwell and Manar 2015; Singarama and Jain 2018)

Properties - Working properties

Different materials exhibit different working properties. Listed below are the key properties which determine how materials behave.
conductivity is the ability of a material to conduct heat or electrical energy
strength is the ability of a material to withstand a force without breaking or bending
elasticity is the ability of a material to bend and then to return to its original shape and size
plasticity is the ability of a material to permanently change in shape
malleability is the ability of a material to permanently deform in all directions without cracking
ductility is the ability of a material to deform, usually by stretching along its length
hardness is the ability of a material to resist wear, scratching and indentation
toughness is the ability of a material to withstand blows or sudden shocks without breaking
durability is the ability of a material to withstand wear, especially as a result of weathering
fusibility is the ability of a material to change into a liquid or molten state when heated to its melting point
http://www.bbc.co.uk/schools/gcsebitesize/design/resistantmaterials/materialsmaterialsrev6.shtml

Pull-up leather

A leather that by design, lightens in colour when stretched. Nubuck with a grease or wax finish. There are also leathers, where the surface is not sanded before greasing or waxing. They are aniline leathers. With these leathers, the

CADCAM Cutting Table. Image by Scottish Leather Group

Suede - Velvet like nap finish produced on leather by abrasive action, buffing

Splitting of leather for suede production

Suede - Denim effect

patina development is not as fast and strong as with the nubuck (sanded) pull-up leathers. Also, this version is often referred to as pull-up. Historically, grain side non-sanded leathers with a greasy finish were called pull-up leathers. There have also been suedes with a grease layer as a finish. Therefore, the term pull-up has to be questioned or examined when offered. However, the patina or vintage look is characteristic for such leathers.
(Lederlexikon 2021)

Rawhide

A hide which has only been treated to preserve it prior to tanning.
(International Council of Tanners 1967)

REACH Restrictions

European Commission Article 68(2) of REACH provides a simplified procedure which the Commission may use in relation to substances classified as carcinogenic, mutagenic or toxic.
(European Commission REACH)

Retanning

Subjecting the tanned hide to a second tanning process involving a similar, or more usually, different tanning materials. Example eco-solutions, chemicals that fix the chrome in leather
(British Standards Institute 1985)

Semi-aniline

Leather which has been anilyne dyed or stained, incorporating a small quantity of pigment, not so much as to conceal the natural characteristics of the hide.
(International Council of Tanners 1967)

Sewing and stitching

Leather specific sewing and stitching are Cricket ball stitch, blind stitch, saddle stitch, chain stitch and goodyear welt

Smart materials

The common characteristic of smart materials is their ability to undergo a predetermined (shape) change as a response to an external stimulus such as light, electricity, humidity, or heat. The change can be reversible or irreverbible.
(Bengisu, M and Ferrara, M 2018)

Smell

It is often said that leather can be recognised by the smell. Only very natural leather has a characteristic leather smell that is not transferable to artificial leather. There is not one “leather smell”, but very different leather smells. Some artificial leather manufacturers perfume the material so that it smells like leather. The smell test is therefore only an indication, among other indices, and rather a test for experienced leather experts.
(Lederlexikon 2021)

Snuffing

Leather which the top surface of the grain has been removed, usually through a process of abrasion. (See also corrected, buffed, fluffed)
(ILTC 2017)

Split

Leather slit into several layers, Leather made from the flesh split or middle split.
(ILTC 2017)

Suede

Velvet like nap finish produced on leather by abrasive action, buffing
(International Council of Tanners 1967)

Supply chain

Manufacturers sometimes refer to companies in their supply chain as tier one and tier two suppliers. The terms indicate the commercial distance in the relationship between the manufacturer and supplier. Although supply tiers can apply to any industry, the terms most commonly describe manufacturer and supplier relationships in the automotive industry.
An original equipment manufacturer, or OEM, refers to a company that makes a final product

for the consumer marketplace. For example, Ford and General Motors are OEM companies that manufacture cars, and Apple is a computer OEM. Tier one companies are direct suppliers to OEMs. The term is especially common in the automobile industry and refers to major suppliers of parts to OEMs. Eagle Ottawa is a tier one supplier of automotive leather to automotive OEMs. Tier two companies are the key suppliers to tier one suppliers, without supplying a product directly to OEM companies. However, a single company may be a tier one supplier to one company and a tier two supplier to another company, or may be a tier one supplier for one product and a tier two supplier for a different product line.
http://smallbusiness.chron.com/difference-between-tier-1-tier-2-companies-25430.html

Sustainability

The endurance of systems and processes. Aim for sustainable development goals, such as economic development, social development and environmental protection. Responsible and proactive decision-making and innovation that minimizes negative impact and maintains balance between ecological resilience, economic prosperity, political justice and cultural vibrancy to ensure a desirable planet for all species now and in the future.
(Magee et al "Reframing social sustainability reporting: Towards an engaged approach", 2013)

Tanning

The process of perishable raw hides and skins by the use of tanning materials into permanent and inputreticle objects.
(ICLT 2017)

Testing

Method to establish the material properties i.e. tear strength, tensile strength, elongation etc of leather

Titanium Tannage

Method to use titanium salts for white leathers.
(Covington, 2020).

Top Coat

A primer is first applied to promote adhesion. The top coat, a kind of clear protective coating, is then applied to the subsequent colour layer. Top coats protect the binder colour from abrasion and discolouration and determine the degree of gloss and the haptic. Crosslinkers provide improved fastness as additives. In case of particularly matt leather, a duller is added to the top coat and/or to the colour. Vehicle leather is often very matt and leather-covered dashboards must be particularly matt because of the risk of reflections in the windscreen.
(Lederlexikon 2021)

Traceability

High Street retailers and major brands are facing ever increasing demands from consumers and NGO's about where products come from and under what conditions they are manufactured. Brands and retailers,

Leather on "horse"

Top coat application with spray gun

especially in the high-end luxury segment, face serious problems with fake or counterfeit products and need to make sure that any leather products made from exotic species are all sourced legally and meet CITES rules. In recent years, human rights and environmental NGO's (Non-Governmental Organisations) as well as animal welfare campaign groups have attacked the leather industry for perceived violations in working conditions, environmental controls and its association with poor animal welfare practices. To counter these threats and to show greater transparency in the leather supply chain responsible leather makers, brands and retailers have sought to introduce traceability into their supply chains. The Traceability in the Leather Supply chain report brings together all the latest studies from other industrial sectors into a single report examing the various technologies both already in use within the leather supply chain and what could be used in the future to trace from the farm to the finished leather product.
http://www.thesauerreport.com/reportaction/ILM042017_Traceability/Marketing

Trade Organisations and regulatory bodies

The UK leather trade is regulated and represented by the Worshipful Company of Leathersellers, SLTC, COTANCE, UISLT, BSI and ITC
(ICLT 2017)

Trends

Global trends that will shape the future of the leather industry in Europe. COTANCE speakers - Mike Redwood embarked the audience into a trip into the future with regard to urbanisation, demographics and technology and how these will affect life and consequently production and consumption patterns. Paul Pearson provided an exhaustive account of global production and trade trends in leather highlighting the outlook for the trade and industry in the areas of raw materials, the allocation of resources, hide prices, leather authenticity labelling and CSR. Guido Nelissen concluded the day with a detailed picture of the vision of the largest EU industry trade union with regard to industrial policy in the EU presenting the intelligence and the recommendations collected in the organisation's Manifesto to put industry back to work.
http://www.euroleather.com/index.php/leather-2025

Upholstery

The work of an upholsterer is not restricted to providing furniture with fabric or leather covers. An upholsterer must also be able to provide seats with new padding, springs and webbing. Upholstery work also extends to automotive interiors, while the occupation of recovering car seats, carpets and other soft furnishings is called a 'trimmer', 'coach trimmer' or quite simply 'automotive upholsterer'. Casestudy: Low-grade selection (cow/buffalo) of fashionable articles
(Lederlexikon 2021)

Vegetable tanning

Hide or skin tanned exclusively with tanning products of vegetable origin or with above-said products combined with small quantities of other ingredients used only to facilitate the tanning process or to improve or modify the leather, assumed that these quantities

Drum at ITLC Northampton

Basil Kardasis, Garments from Fish Skin

cannot alter the essential characteristics of the vegetable tanning of the products. By definition vegetable-tanned leather can derive from any kind of raw hides and be destined, when finished, to any kind of use, included but not limited to leather goods, shoes, furniture, saddles, garments, nautical industry, etc. organic, but needs large quantity, biological degradable but needs accelerant, mimosa, wet white, wet blue, syn-tan, chestnut, tara, quebraco, oak bark, Tara is best for automotive leathers because of lightfasteners, rub test, re-examined, Dongola Tannage, sumac
(International Council of Tanners 1967)

Vellum

For writing and bookbinding it is made from unsplit calf, sheep or other skin, by drying out the limed skin without applying any tannage, the material being thoroughly cleansed and degreased and the grain surface being smoothened during the process
(International Council of Tanners 1967)

Waterproof leather

Leather thoroughly impervious to water, usually chrome tanned or combination tanned
(ICLT 2017)

Wet blue

Chrome-tanned pelt, it is wet because it is not usually dried before progressing to post-tanning and it is blue because of the nature of the chrome complexes bound to the collagen.
(Covington 2020)

Wet white

Non-chrome tanned leather or otherwise chemically stabilised pelt. Originally defined in terms of capability of being split and shaved. Now regarded as a tanning system in its own right; typically consisting of a combination of various syntans and usually glutaraldehyde or other aldehydic reagents.
(Covington 2020)

Yield

Guide when determining square footage requirements of leather
www.westdean.org.uk/study/school-of-conservation/blog/books-and-library-materials/tensile-testing-of-leather
http://www.garrettleather.com/hide-sizes

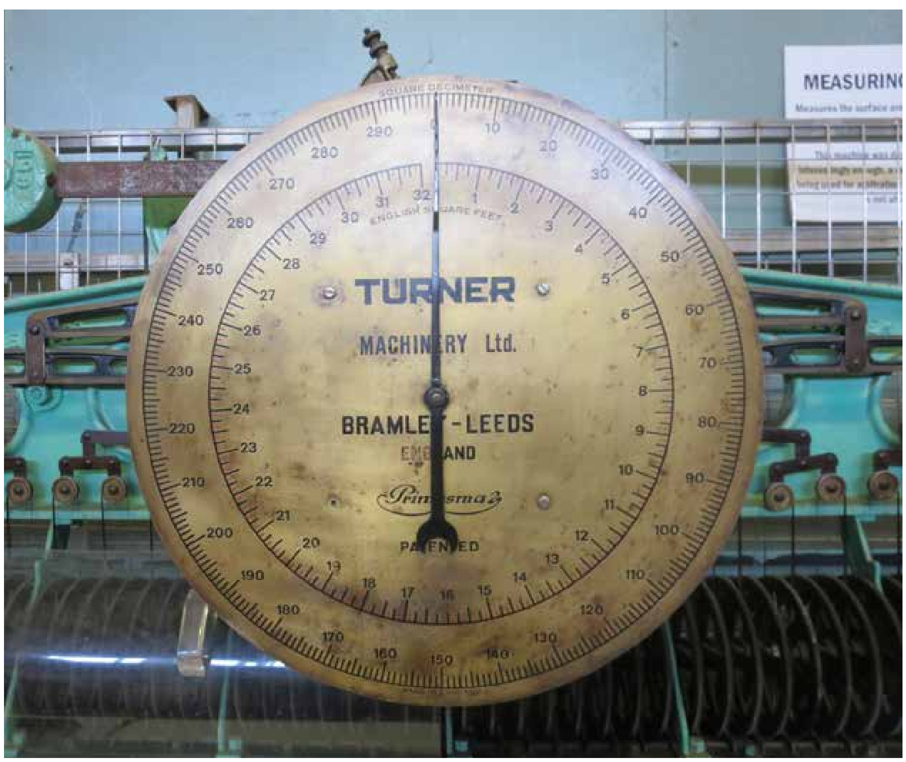
Zirconium salts

Standard products for tanning. This limited usage is due to the higher price of the zirco-nium tanning salt and due to the particular plumpness of the zirconium tanned leather.
(Covington 2020; Heidemann 1993))

Cuir Buillii vesells by Simon Hasan

Sammying of wet blue hide, removing of excess water

Measuring leather yield with Turmer pantograph



Leather Trade Locations

Fieldwork and visits 2011-2021:
Arzignano, Italy
Bridge of Weir, Glasgow
Bristol
Chennai
Chesterfield
Colyton, Devon
Crewe
Himeji, Japan
Igualada, Spain
Leeds
London Bermondsey
Milan
Northampton
Novo Hamburgo, Brazil
Oisterwijk, Waalwijk, Dongen, NL
Pirmasens, Germany
Reutlingen
Offenbach
Tatsuno, Japan
Walsall
Yeovil

Leather Goods and Tannery Expertise in the UK

Design and Manufacture

Communities of Practice, Informants

Roberto Borgia, Riccardo Centomo, Davide Rinaldi, Mauro Magnaguagno, Giulio Galiotto, Rachel Garwood, Sateesh Jadhav, Yuko Nishimura, Katsushi Hasegawa, Paula Antunes, Will Wise, Tony Covington, Karl Flowers, Mike Redwood, Dave Sherwood, Paul Evans, Marloes ten Boehmer, Jane Harris, Chris Bernard, Simon Hasan, Julia Lohmann, Jayne Nutt, Nick Cooper, Carmen Hijosa, Bill Amberg, Mike Redwood, Stephen Johnston, Claire Johnston, Sheila Clark, Jonathan Muirhead, Jeffry Guthrie Strachan, Andrew Parr, Yvonne Fletcher, Paul Richardson, Mark Wilkinson, Harrison Sears, Raimonda Navickaite, Jonathan McCoy, Georgie Tym, Ffleur, Sandra Nelson, Steven Marks, Patrick Sears, Giles Taylor, Martin Bremer, Duksha Patel, Emma Driscoll, Hervey, William and Alastair Tusting, Paul Pearson, Frans van den Heuvel, Satoshi San, Basil Kardasis, Chris Lefteri, Zoe McLaughlin, Kristina Nidderer, Hans-Peter Germann, Herr Haidle, Huub van Beieren, Udo Steiner, Eliza Axelson Chidsey, Philip Warner, Louise McKay, Catherine Garrod, Stephen Hems, Debbie Carter, Luc Vogtlander, Eric Poles, Michael Costello

Nick Cooper, Northampton Shoemaker

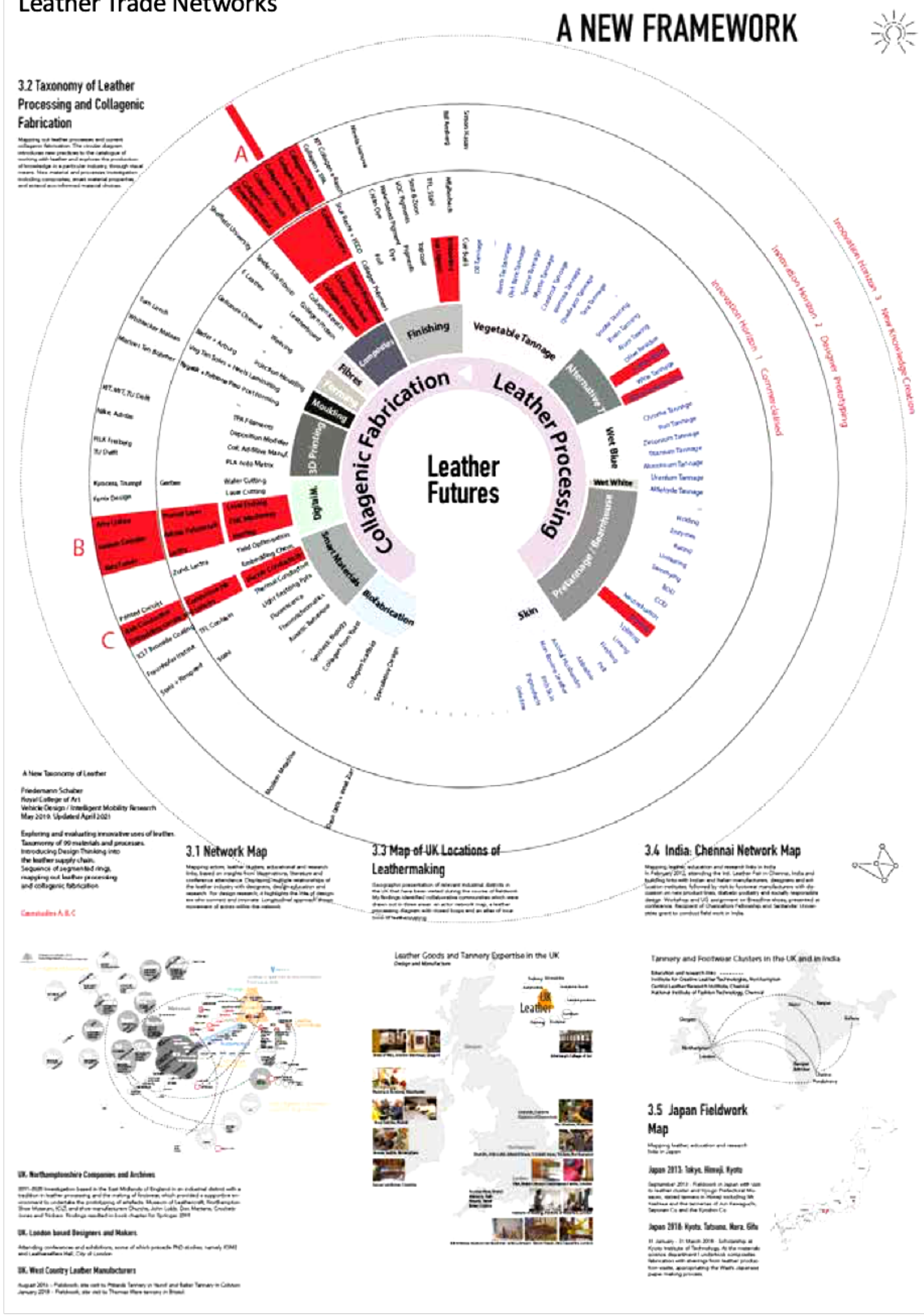
Davide Rinaldi at TFL Chemicals Arzignano

Ideal Saddlery Walsall

Himeji Tanner, Image by Katsushi Hasegawa

Tatsuno Tannery, Himeji

Framework of Leather Processing and Collagenic Fabrication, and Leather Trade Networks



We can observe companies and their relationships by taking a network perspective and relate these to the industrial districts found in Europe, Asia or in South America - that is: a core of more or less equal enterprises bound in a complex web of competition and cooperation. Markusen (1996) suggests a typology of industrial districts, a useful concept to help us understand the overlap between purely local networks and the wider network in which firms and industries are placed. This holds true to Northampton, a town renowned for its tradition of shoe-making. In support of its core industry, teaching institutions were established, namely, the Colleges of Art and Technology. Today, this expertise is part of the University of Northampton. Within the fashion department, a footwear and accessories provision evolved, engaged in knowledge transfer in support of the London based fashion industry. New links and collaboration with French and Italian luxury good brands can be observed with students benefiting through placement opportunities. For over a century, its British School of Leather Technology is educating staff for the global tanning business. Since the 1920s Indian tanners have been trained at the school and this three-generation old relationship provides insights. The author's research maps past, existing and emerging networks around leather in the UK. Local universities are found to be at the hub of networks of people, London livery companies, material scientists, designers such as Bill Amberg and Zandra Rhodes, the makers of Kinky Boots, Jeffery-West or Church's shoes. We consider professional design networks which are defined through membership of a guild or society, such as the Worshipful Guild of Leathersellers, Cordwainers, Drapers, The Institute of Leatherchemists. Furthermore, we find informal or formal creative communities evolving from the craft around leather in an industrial district in which whey are physically located or are associated with. Global networks emerge as local companies manufacture or trade with abroad, or are part of luxury goods market. For example Churchs' is now a part of Prada and John Lobb a brand within the portfolio of Hermes. New links and collaboration with French and Italian fashion houses can be observed with MA and UG students benefiting through placement opportunities.

APPENDIX III

Practical experiments for this project

Creation of Bonded Fibres from Leather Waste

This is the work done to inform the project over the period from February 2018 to June 2020.

Technical evidence of the creation of bonded fibres from leather waste through measurements, protocol, and photographic record and testing to document and demonstrate findings from residency at Kyoto institute of Technology. Washi Paper Lab at the Fibro Science Department. Fibre samples were created, measurements of samples of Bonded Fibres from Leather Waste during 7 lab sessions between 8 February – 28 March 2018. Scanning electron microscopy of selected samples at ICLT Northampton in 2018. Tensile Tests undertaken of 7 assorted leather and 6 Blended Leather shaving waste Fibres, on 5 September 2019 with results listed as tensile testing graphs and data in table results.

Photographic Record of Fibro Science Lab Set-up and Experiments, 9 March 2018.

Fibre Generation in Fibro Science Lab with vacuum sieve apparatus and food processor

Date	**Prototyping Process of Bonded Fibres from Leather Waste**
8 Feb 2018	Induction. Resident researcher and Lab technician (*Shiki san)* were consulted about corresponding processes used within their studio practice. Assorted leathers and fibres were inspected, waste leather shavings were subsequently sourced from a tannery in Tatsuno, Hyogo Prefecture (Chrome) and ICLT Northampton (veg).
8 Mar 2018	Grinding and shaving of assorted leather fibres to size, acquisition of traditional binders – *nori* Japanese rice starch paste as adhesive.
9 Mar 2018	In *washi* studio with leather shaving fibre, pulp 5 samples, acquire scooping technique, with small papermaking frame. Samples 1), 2)and 3) 100x65mm, 1g, beige colour, no binder, vegetable tanned shavings, water, hand scooping process, overnight drying in conditioned chamber, Sample 4) 100x65mm 1g, off-white colour, bonded with 30% kozo fibres, after drying half of surface brush coated with Japanese persimmon coating. Sample 5) rectangular specimen cut for inspection with SEM and scatter coating.
19 Mar 2018	In *washi* studio with leather shaving fibre pulp 5 samples veg tan shavings. Mid size scooping frame. Subsequently (2019) one (large Mat) has been stabilised and coated at ICLT by M Evans. 3 sheets have been folded, cut and laminated to one stack of 6 layers, 16g, with PLA (Pl-1005) adhesive. Sample turned out to be brittle and broke in half when manually flexed. Assessment is that of inferior flexibility and haptics Lab technician (*Shiki san)* created 2 x matting with vacuum filter apparatus. Advised on fibre length and adhesion.
20 Mar 2018	In washi studio with leather shaving fibre pulp 3 samples, 3 layered composites with PLA, 1x palm oil fibre 50%.
22 Mar 2018	Several samples, persimmon applied on 4 samples, applied and melted PLA with hot iron, laminated to 6 layers
23 Mar 2018	Four samples with vacuum sieve apparatus. 1 fabric bag mesh with pulp on reverse side, 1 fabric bag mesh with PLA on back, cotton handkerchief on back, 1 sample with 30% *washi*, 10% palm oil fibre, 60% leather fibres. 10 x samples 140x100 3g 1 x 140x100 4grm PLA added and ironed.
28 Mar 2018	130x100mm 3grm vegetable, no binder for SEM Chrome shavings from Japanese tannery applied, several leather fleeces to optimise fibre size. Sample with 40% *washi* 60% chrome leather fibres. Sample with 50% chrome 50% vegetable tanned fibres. Labelling of fibres and boxing for scientist's future use.

Summary of the Experiments in Japan: Creation of Bonded Fibres from Leather Waste; record of date, measurements, dimensions, weight, substrates, application process

Tensile Test Results (5 September 2019) of several sample leathers, natural fibres and composite

Specimen Label	Average value of maximum load (N)	Average extension of maximum load (mm)	Average Area (cm^2)	Average Tensile stress at maximum load (MPa)	Percentage Elongation
Pineapple fibre NWOI Warp	9.08	42.38	0.23	0.38	
Mulberry Kozo	24.53	13.63	0.8	3.06	27.27
Zirconium	622.74	26.34	5.2	11.91	52.68
Composite Matrix	54.54	22.54	2	2.72	45.09
Veg Fibre	7.03	1.96		1.00	3.92
Veg Fibre 2	9.59	3.68		1.37	7.37
Test Matt	334.79	25.48		20.92	50.96
Palm oil fibre	7.22	3.50		0.48	7.01
Upholstery leather	326.90	38.57		23.35	77.15
Veg Mimosa 1	252.64	28.14	2	12.63	56.29
Veg PLA Fabric 2	15.07	10.49		0.33	20.99

Veg Mimosa Vegetable (mimosa) tanned bovine leather

Tensile Test (5 September 2019) and Young's Modulus Calculation
The test parameters are set to comply with IUP (SLP 6)
(Measurement of Tensile Strength and Percentage Elongation).
Method: SLP 6_Basic_Prompted.im_tens

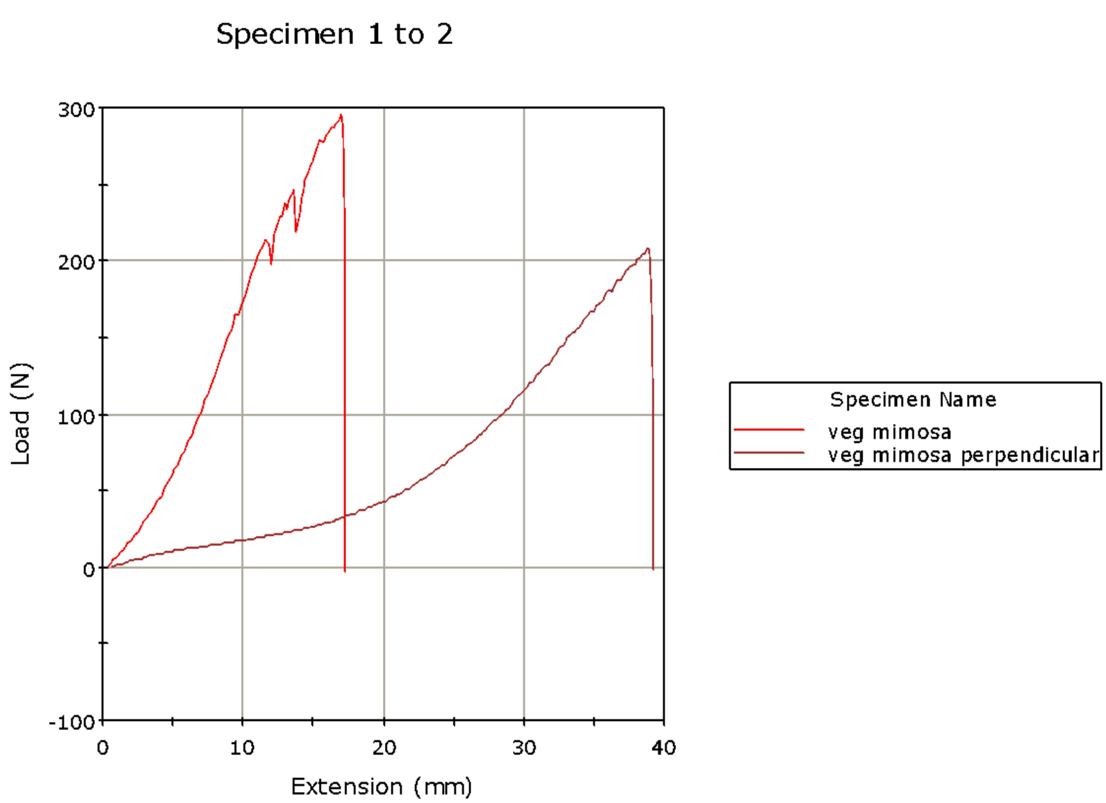
Dimension: Length	50.00 mm
Dimension: Width	10.00 mm
Test: Control mode 1	Extension
Test: Test Speed	100. mm/min

Mean Measurements

Maximum Load (N)	Extension at break (standard) (mm)	Width (mm)	Thickness (mm)	Tensile stress at Tensile strength (MPa)	Percentage Elongation
252.64045	28.14750	10	2	12.63202	56.29500

$$\frac{252.64045 / (10\times2)}{28.14750 / 50} = \frac{12.6320225}{0.56295}$$

MPa = 22.43897771 MPa   0.02243mm GPa



Kozo Chromium tanned bovine leather shavings, blended with jap. mulberry (kozo)

Tensile Test (5 September 2019) and Young's Modulus Calculation
The test parameters are set to comply with IUP (SLP 6)
(Measurement of Tensile Strength and Percentage Elongation).
Method: SLP 6_Basic_Prompted.im_tens

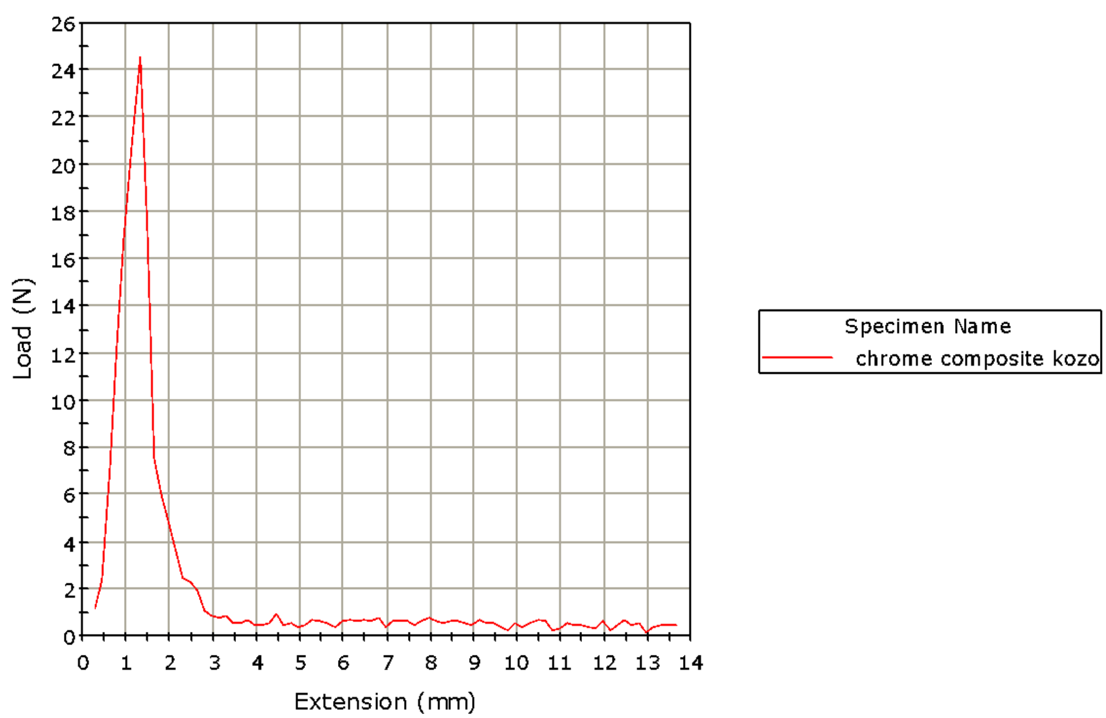
Dimension: Length	50.00 mm
Dimension: Width	10.00 mm
Test: Control mode 1	Extension
Test: Test Speed	100. mm/min

Mean Measurements

Maximum Load (N)	Extension at break (standard) (mm)	Width (mm)	Thickness (mm)	Tensile stress at Tensile strength (MPa)	Percentage Elongation
24.53850	13.63581	10	0.8	3.06731	27.27161

$$\frac{24.538 / (10 \times 0.8)}{13.63 / 50} = \frac{3.06}{0.2726} \text{ MPa} = 11.23 \text{ MPa} \quad 0.01123\text{mm GPa}$$

Specimen 1 to 1



Composite Matrix Vegetable tanned leather shavings, backed with a textile matrix, PLA adhesive

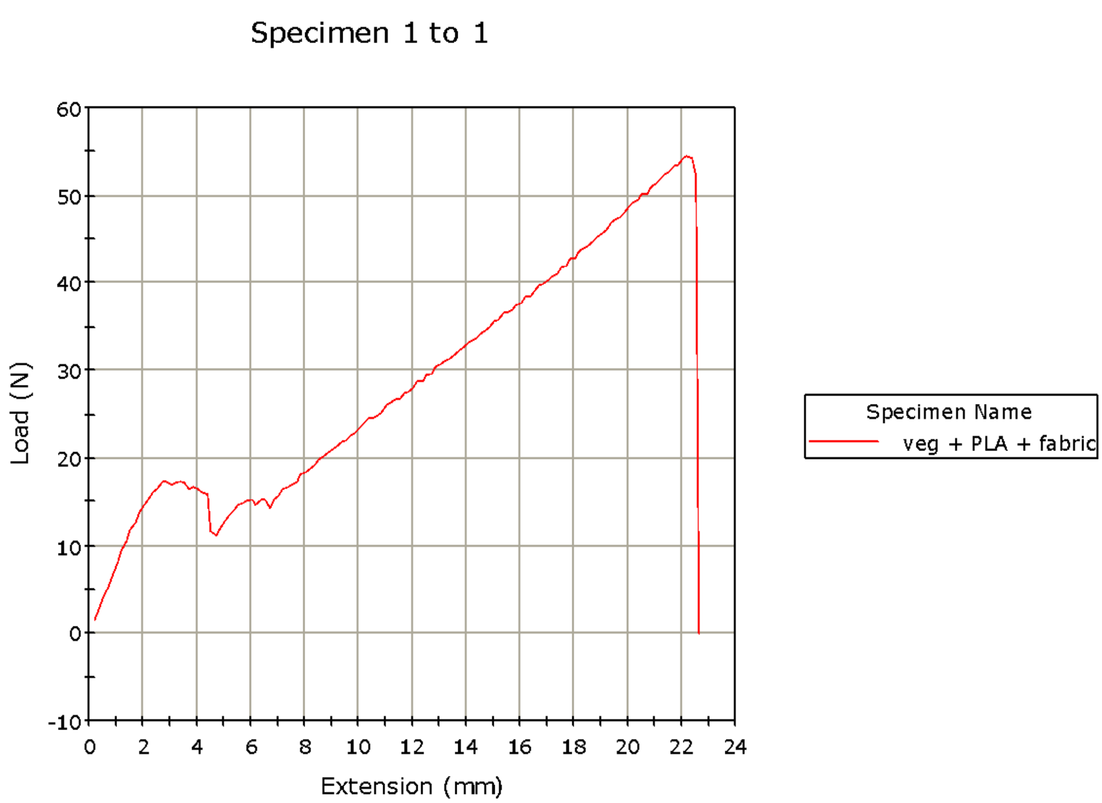
Tensile Test (5 September 2019) and Young's Modulus Calculation
The test parameters are set to comply with IUP (SLP 6)
(Measurement of Tensile Strength and Percentage Elongation).
Method: SLP 6_Basic_Prompted.im_tens

Dimension: Length	50.00 mm
Dimension: Width	10.00 mm
Test: Control mode 1	Extension
Test: Test Speed	100. mm/min

Mean Measurements

Maximum Load (N)	Extension at break (standard) (mm)	Width (mm)	Thickness (mm)	Tensile stress at Tensile strength (MPa)	Percentage Elongation
54.54088	22.54752	10	2	2.72704	45.09504

54.54088 / (10 x 2)
__________________ = 2.727044
22.54752 / 50 __________ MPa = 6.047325826 MPa 0.006047325826 GPa
0.4509504



Zirconium Zirconium tanned bovine leather

Tensile Test (5 September 2019) and Young's Modulus Calculation
The test parameters are set to comply with IUP (SLP 6)
(Measurement of Tensile Strength and Percentage Elongation).
Method: SLP 6_Basic_Prompted.im_tens

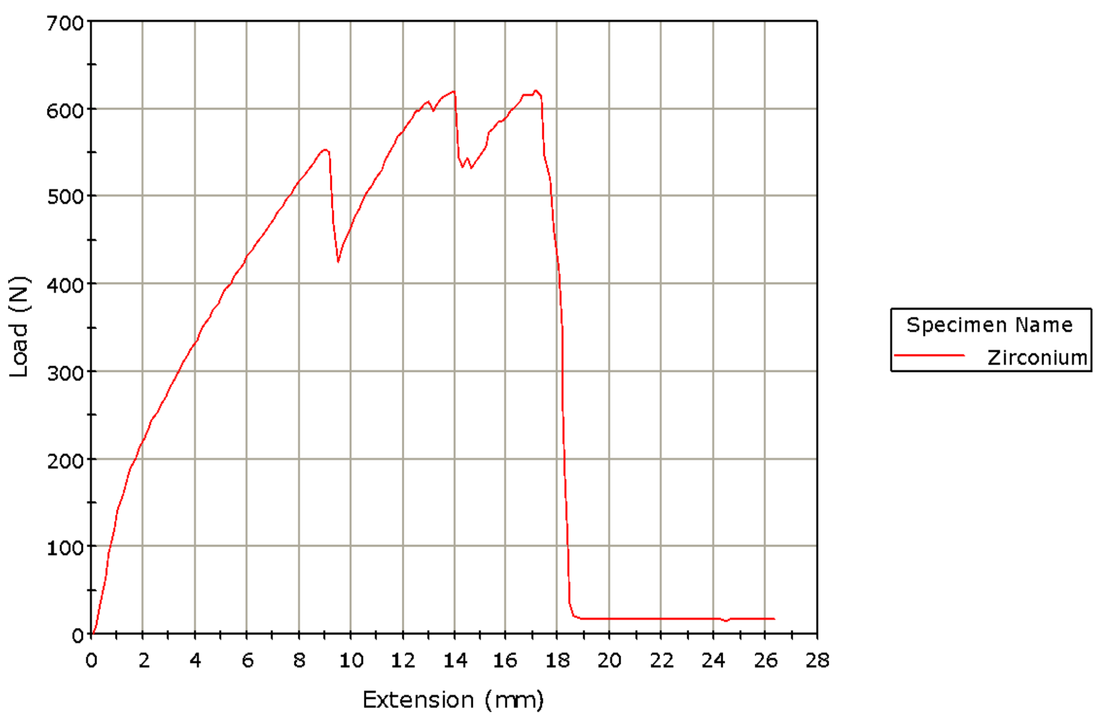
Dimension: Length	50.00 mm
Dimension: Width	10.00 mm
Test: Control mode 1	Extension
Test: Test Speed	100. mm/min

Mean Measurements

Maximum Load (N)	Extension at break (standard) (mm)	Width (mm)	Thickness (mm)	Tensile stress at Tensile strength (MPa)	Percentage Elongation
622.74674	26.34499	10	5.2	11.91420	52.68998

622.74674 / (10 x 5.2)
____________________ = 11.97589885
26.34499 / 50 ____________ MPa = 22.72898727 MPa 0.02272898727 GPa
0.5268998

Specimen 1 to 1



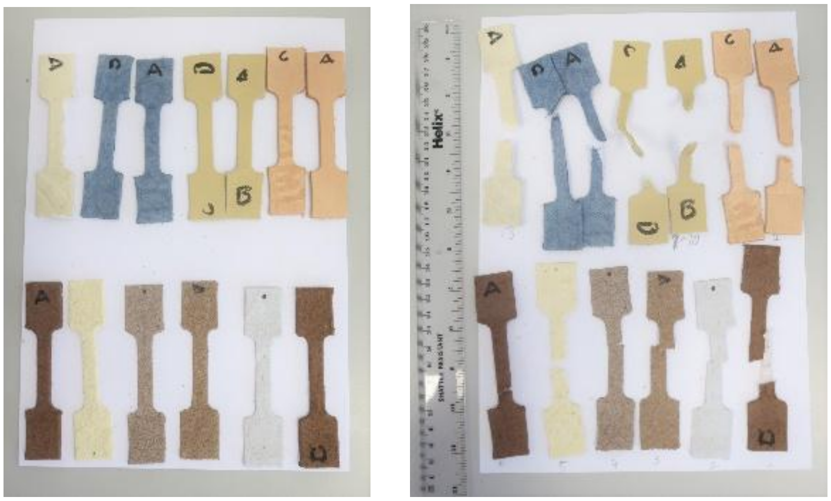


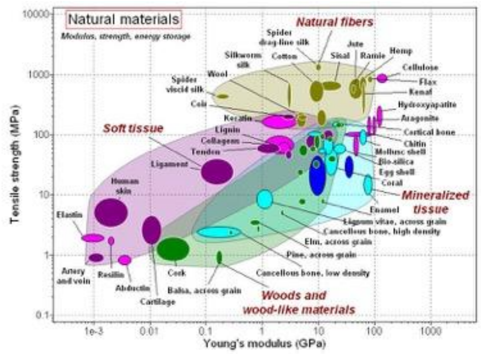
Figure IV Tensile Testing of Leather (7 in Upper Row)
and Blended Leather Fibres (6 in Lower Row).

1 top, from left	Zirconium Zirconium tanned bovine leather
2	2 chrome tanned denim style suede
3	2 chrome tanned denim style suede, treated with CaCl
4	Upholstery leather chrome pigmented , commercial
5	Upholstery leather chrome pigmented , commercial
6	Veg Mimosa Vegetable (mimosa) tanned bovine leather, with dye
7	Veg Mimosa Vegetable (mimosa) tanned bovine leather

1 bottom, from left	Bonded Veg tanned shaving waste, no binder
2	Bonded Veg tanned shaving waste with kozo, no binder
3	Kozo Chromium tanned bovine leather shavings, blended with jap. mulberry (kozo)
4	Kozo Chromium tanned bovine leather shavings, blended with jap. mulberry (kozo) (perpendicular dye cutting)
5	Bonded chrome tanned shaving waste fibre with palm oil fibre, no binder
6	Bonded Veg tanned shaving waste fibre with palm oil fibre, no binder

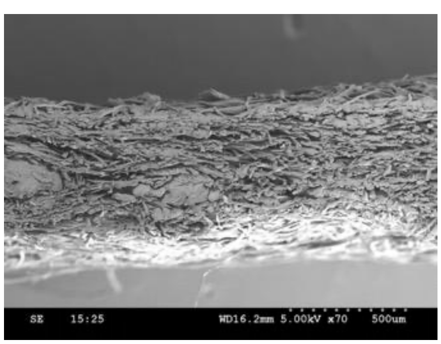
7	Composite Matrix Vegetable tanned leather shavings, backed with a textile matrix, PLA adhesive

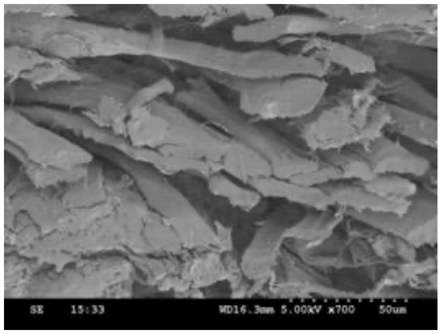
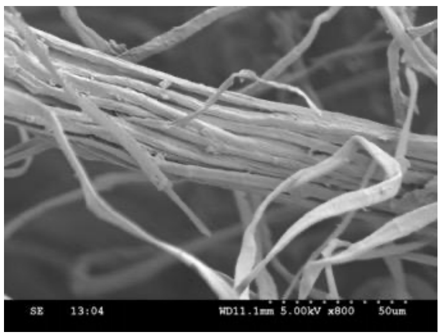
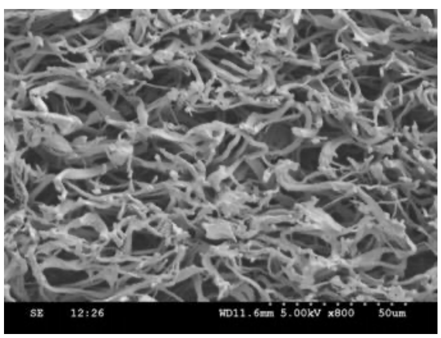
Natural Materials. Source: M. Ashby CES Edupack Database, 2008



Tensile Strength Testing Apparatus

SEM of selected Kyoto Samples and other materials on 18 September 2018

Scale	Photographs of the Specimen	Description
a) 70 X		Specimen of vegetable leather and mulberry fibres blended without binder and persimmon coating applied. At x 70 enlarged the horizontally layered, loose network of fibres is noted.

b) 700 X		No discernible difference between leather and mulberry fibres, with denser fibre bundle on bottom left. Some nanofibers were noted of low density without wider entanglement.
c) 800 X		Pineapple fibre bundle, tangled and loose strands; horizontal orientation noted.
d) 800 X		Mycelium rhizome is evenly distributed throughout the entire specimen. No directional orientation or layering of density noted.

Scanning Electron Microscopy of Blended Leather and Mulberry Fibres (a & b); Pineapple Fibres (c) and Mycelium (d).

Recycling of Leather Off-Cuts and Application with Mycelium

Undertaken October 2017 – May 2020

Background

The potential of *Fomes fomentarius* fungus as base for mycelium composites has been demonstrated by designers (Amadou Leather, Ninela Ivanova, Sebastian Cox). Fabricating with fungi leads to novel materials. User perception and sensory response to active growing materials are of interest for future consumer engagement (EKSIG Rotterdam, 2017). The recycling of leather off-cuts and application with mycelium was inspired by Ninela Ivanova's innovative investigation into material applications for mould and fungi, during a practice-based research training workshop held at Kingston University 2013. Subsequently received updates on her practice at the UKRI materials innovation convention (Coventry Ricoh Arena 2014), Digital Resistance Seminar (London College of Fashion 12 July 2017) and Design Frontiers at Somerset House (London Design Festival 18 - 24 September 2017). Nina's collaboration with Sebastian Cox 'MYCELIUM + TIMBER: Exploring biofacture' resulted in a collection of grown furniture, made using mycelium (fungus) and wood, which was presented at a temporary laboratory of biofacture. These encounters led to the concept of a) chitin-leather composite with protein collagen as feedstock, and b) prototype of vegetable leather that has been coloured/dyed with essences from fungi such as *phaeolus schweinitzii*, known as Dyer's Polypore. The aim was to create materials and surface treatments in new ways and in new places, so to expose leather technology to new 'materials tinkering'.

Research questions

Can collagen be feedstock for mycelium composite to build a structural, lightweight matrix? How can we convert leather fibres into a voluminous body with structural properties? Can we upcycle leather shavings what would be otherwise considered waste? Would collagen and tannins within leather be indigested or hinder the digestion process? An earlier question posed to Carmen Hijosa was: 'Have you tried to blend your pineapple fibres with animal fibres so to enhance material properties, with wool or leather shavings from shoe production?'

Growth on Day 16, 18, 34 and when Growth was Terminated, Display at Viva Stage 2021.

Lab experiment of mycelium based composite

Wheat grain was inoculated with mycelium *fomes fomentarius* and blended with leather shaving waste from wet-blue tanning production, mixed in equal measures and water added to a pulp of 200ml, grown in dark, in sealed 500ml plastic tub at room temperature of 20 degrees. Fully dried, the specimen shrinks 20% to 80mm dia., 18mm height and 40g weight. Noticed an uneven off-white appearance and firm structure with little flex and a velvety surface. A sample has been extracted for visual inspection (SEM and light microscopy). It could be determined that the mycelium network somehow binds grain and leather fibres together. It could not be seen if any leather fibre substrate has been indigested, as feedstock.

Findings

Mycelium is strengthening loose leather fibres into a matrix or 3D objects that can be formed. There is scope for functional composites from leather waste fibres and complementing the material investigations by designers Suzanne Lee, Myco Works, Myco Make by Evocative Design and Carole Collett’s Design and Living Systems Lab, developing the circular economy through laboratory made organic materials including fungi.

Plant Matter as Tannins

Technical evidence and testing of plant matter as tannins to document and demonstrate findings.

Protocol for cider apple, alder, cherry vegetable tanning processes

Date	Prototyping Process
12 August	Plant waste was collected, and this was then shredded with water using a food processor and was bottled, which was referred to as "tea"; at this stage, this tanning content was to be determined via bell test.
19 August 1	Tanning experiment with cherry extract and bovine pelt of 1.7kg weight with a pH of 3. Preparation of a solution of 85g Sodium Chloride salt (NaCl) + 1.7l H2O to suppress swelling. For apple tannage, a bovine pelt of 440g in an Italprogetti laboratory drum was set-up. Then, 50g NaCl in 1000ml H2O was added to suppress swelling with 10 mins drum action, followed by 20g NaCl and drum action for 10mins. Added were 4.4g NS syntan substance with drum running for 1 hour. Then 1 l of apple puree was added.
2	Bring the pH to 4.5 with adding of 1% (17g) TRUPOTAN NS, a neutralisation syntan, which is to assist the penetration of tanning agents (Trumpler 2013).
3	Once the solution achieved a pH of 4.5, added 1l cherry tea + 300g cherry chippings to the drum and commenced with continuous drum action until 3 September.
22 August	During the process, on several occasions the tanning tea was topped up so as to increase the concentration; pH measured and physical test was undertaken, through cutting the leather's edge to observe the cross section for the level of penetration of tanning agent [Figure 4.13]. Added were 4.4g NS syntan substance with drum running for 1 hour. Then 1 l of apple puree was added and with continuous drum action until 3 September. pH testing 3.5, topping up of extract, cross section showed poor penetration just below the pelt's surface.
3 September	Measure apple pH 3.5 and cherry pH4. In order to achieve pH to 3.5, formic acids were added and the drum was left to run for 20 mins. Finally, 1% of antimould solution was added, and then the hides were removed from the drums and were washed, with leather hung onto a frame. Drum action was halted on day 20 (3 September) and partially tanned hides removed for washing and drying.
5 September	The result was reviewed by a tannery manager. The samples were then tested with the Iron 3 indicator method, but no reaction was noticed. Results deemed unsuccessful for cherry and apple. Six pieces of skins were dried on toggle frames for collection, and these have been cut to size and incorporated in the display.

Tannins extract from Coffee Waste

Lab data generated by Ashokkumar Baskar at ICLT 2021

Coffee Waste (CW)
Weight of wet coffee waste: 2396g
Weight of dried coffee waste: 994g
% weight of moisture/volatiles present: 58.5%
Weight of dried coffee waste taken for extraction: 990g
Weight of extracted dried solid from coffee waste: 111g
% yield of extracted dried solid from coffee waste: 11.2%
25g tannins/ kg dry coffee waste (2.5%) chestnut is 30g/kg (3%)
Assuming a salt-preserved goat skin = 2kg
11kg of coffee solids needed for 1 goat skin
Assuming a salt-preserved hide = 25 kg
Need the extract from 137.5 kg coffee solids needed for 1 cattle hide

Coffee Waste (CW) Extract - Tannins estimation			
Parameters	**Mimosa ME**	**Coffee Extract**	**Difference**
% Tannin	70.2	21.8	-48.4
% Non Tannin	22.5	35.4	12.9
% Insolubles	3.4	40.9	37.5
% Moisture	3.9	1.9	-2

Spot test analysis for tannins presence in CW (with reference Tara & Mimosa)

CW – Significant darkening colour was observed

Spot test: Condensed Tannins
CW – No significant change in colour was observed

Spot test: Hydrolysable Tannins
CW – No significant change in colour was observed

Data for hide powder and hide powder treated with fresh coffee extract for 24hrs (with and without fixing).

Data for hide powder and hide powder treated with fresh coffee extract for 48hrs in a water bath at 30^{0}C (with and without fixing).

Spot test analysis for tannins presence in Fresh Coffee Extract (FCE) (with reference Tara & Mimosa)
Spot test: Hydrolysable Tannins
FCE – No significant change in colour was observed

Findings

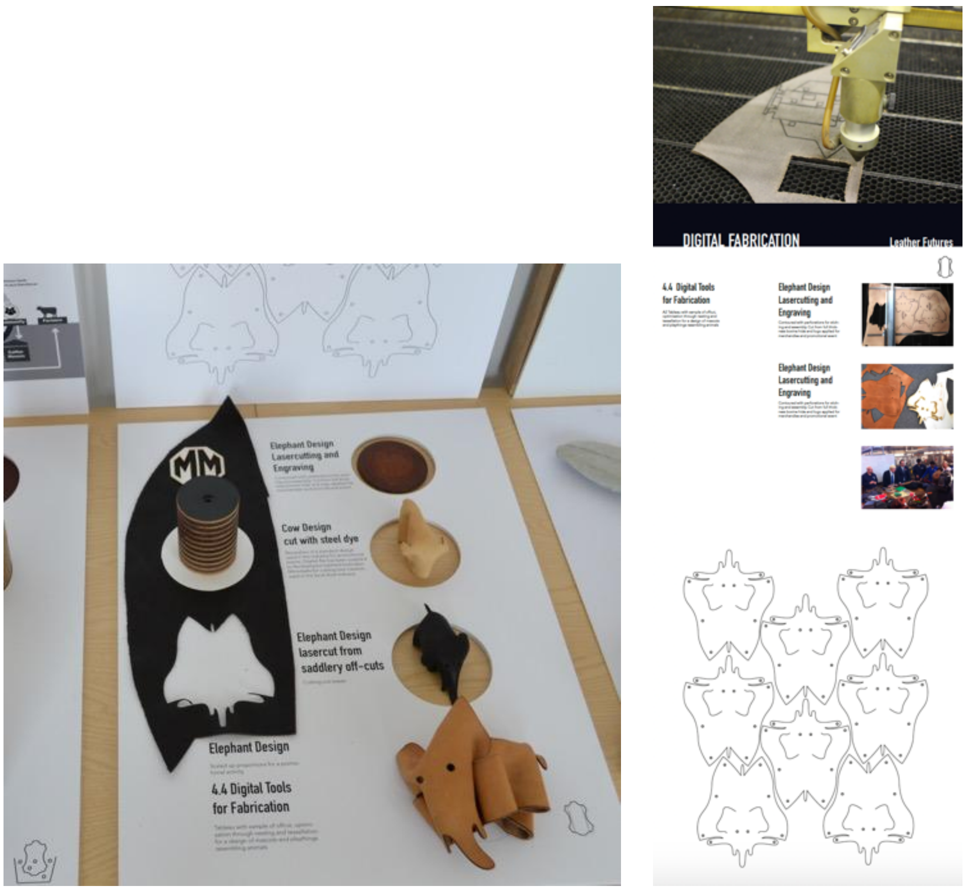
i) Based on my investigation on the crucial role of tanning in leather processing, it is found that we can work towards “closed looped leather processing” through vegetable tanning extracts from plant waste streams, utilising spent plants that retain tannins (plant-based phenols) that offer new design opportunities and narratives [see Figures 4.22 & 5.2]. These results build on existing evidence regarding the potential of vegetable tannins for tanning processes (Heidemann 1993; Covington 2009; Dos Santos 2014; Davis & Quang, 2019). However, this research also provides a possibility of developing a series of tanning agents from certain food wastes, such as spent tea, hops or coffee ground, that have a story, which is an extremely attractive prospect from the environmental point of view. This result thus contributes to the creation of further closed loops.

ii) Vegetable tanning is suited for micro tannery operations, supporting sustainable rural communities by offering local processing and value to their by-products, that can complete the circle from food to leather. A range of leather goods that are designed, produced and marketed as “Made in England.”

iii) Innovation of new leathers with plant waste from the beverage industry (beer and coffee) concludes my explorations to create and demonstrate a zero-waste manufacturing process. Set up as a co-design approach through collaboration with leather technologists and farming communities, hop plant fibres and ground coffee beans (Davis and Tran 2019) are being developed into sustainable feedstock for the tanning of cowhides. My proposition is that this will be an attractive circular material of choice for fashion and designers alike.

Digital Tools for Fabrication

Technical evidence (Adobe Illustrator files and measurements of mascots) and photo records that document and demonstrate findings of nesting and tessellation. Illustrator cow images, photos of nesting, cutting, etching and embossing.

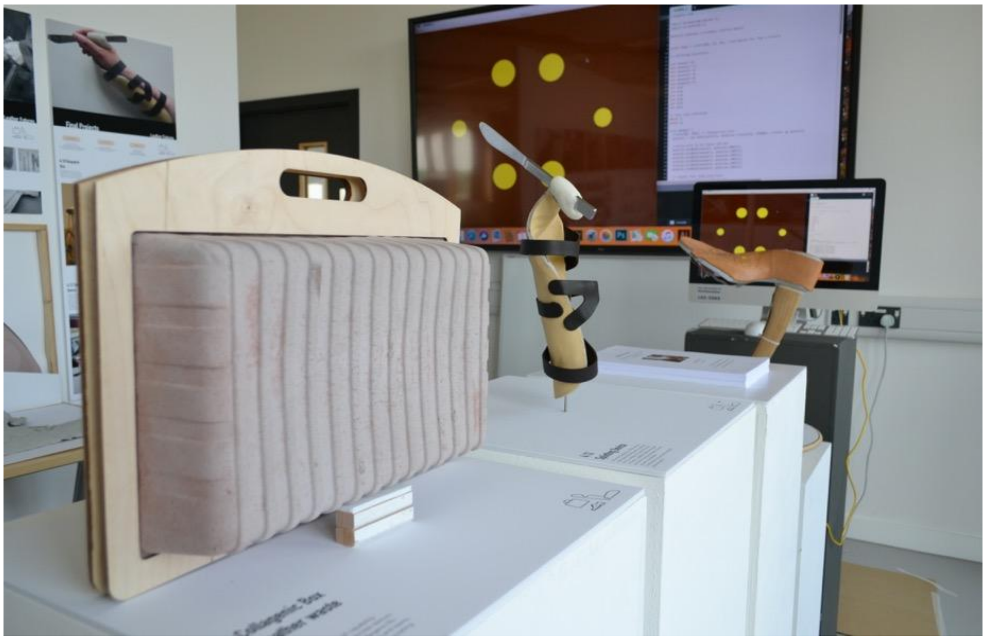


Digital Tools for Fabrication Display at Viva Stage 2021.

Final Project – Car Door Panel

Car Door Panel Display at Viva Stage, 2021.

Final Project – Glove Compartment Box

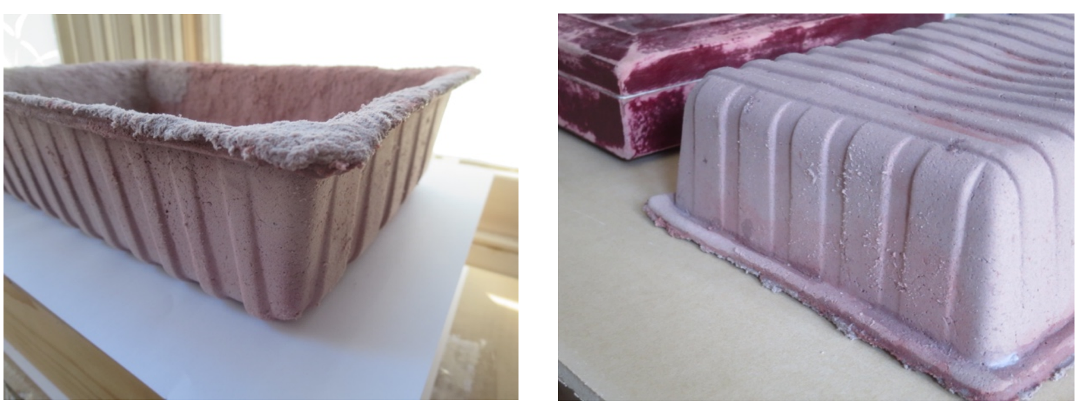


Glove Compartment Box Display at Viva Stage 2021.

Technical evidence and testing to document and demonstrate findings.

370 x 285 x 90, 815g

2-part 3mm thick plywood frame.



Series of Photos from Mouldmaking, 2021.

Final Project – Despatch Box

Despatch Box Display at Viva Stage 2021.

Technical evidence and testing (measurements, protocol, photographic record from Private View at RCA Biennale 2013

295x225x70, 1975g

The artefact alludes in form and colour to a UK government design of a despatch box, Brass handle and fittings, distressed finish to a bovine hide that covers a wooden frame, RCA royal crest laser engraved.
My final project Text for RCA Research Exhibition catalogue November 2012
Practice-led Research - 'Leather and collagenic fibres in transportation interiors' Creation of a range of prototypes presented at RCA Research Exhibition "Disruption" Upper Gulbenkian Gallery.

My response to the research exhibition call is to investigate and disrupt the behaviour of my primary research material i. e. bovine leather, its form and surface, also, distorting traditional processes. Key concept is 'distressing', methods to produce an appearance of age and wear. In distressing, the object's finish is intentionally destroyed or manipulated to look less than perfect. These artefacts may be featuring distressed finish, inherent or induced surface defects such as branding, scars, or microbial attack. Thus, they challenge perceptions of tactile interface, maximum durability and recycling properties.

Despatch Box, opened at Viva Stage 2021.

Significance

Through this project I apply materials knowledge to the specific arena of apparel and automotive interior manufacture. In these industries, quality control and the specifications lead to avoidance of surface defects, which in turn lead to significant waste and off-cuts.

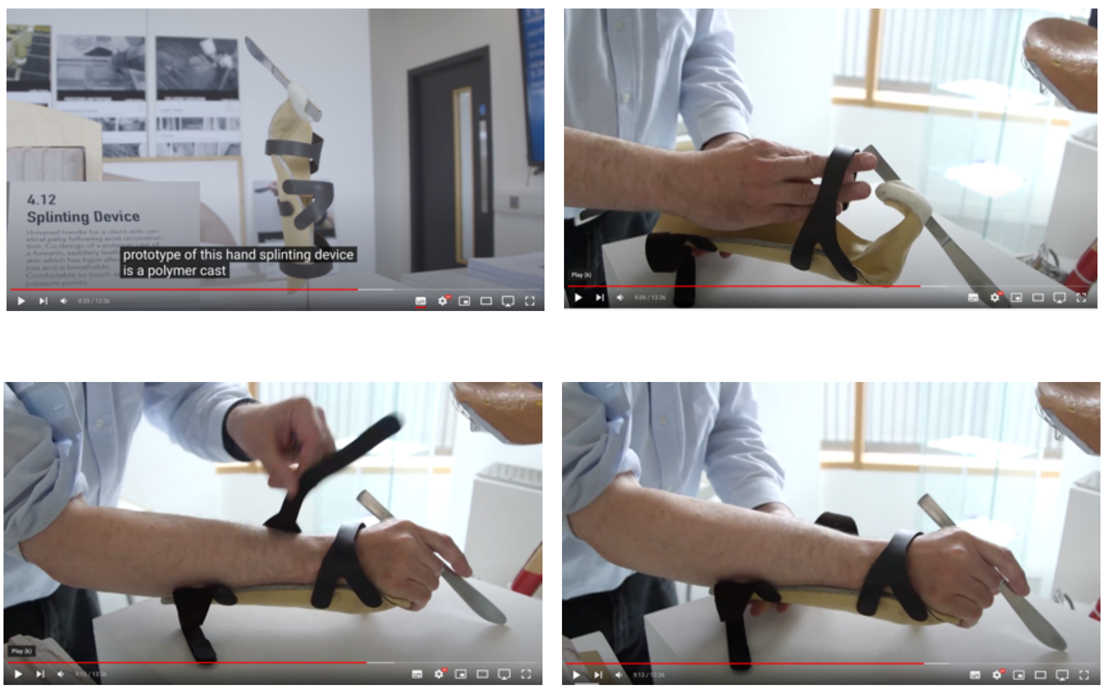
Final Project – Medical Splinting Device

Technical evidence and testing to document and demonstrate findings.

Splint 290 x 110 x 85mm 186g

PLA Polymorph polymer splint, leather cover (sand colour), 2 sets of Velcro fitted leather straps (coffee brown) 255 x 70 mm strap x 20 mm wide

Universal handle for a client with cerebral palsy following wrist reconstruction.



Screenshots of a Youtube Video https://youtu.be/obLrJqqZp-o is Recording of Fitting and Use of Splint at PhD Viva Stage, 2021.

The project is a co-design approach with the Occupational Therapy Subject Group, to develop customised cutlery handles for a client with cerebral palsy to use – following surgery and wrist reconstruction. Here, design and craft skills are demonstrated in the making process of a customised medical device. The splints utilise locally processed animal hide and leather off-cuts;

the artefacts help enhance the user experience, thus contributing to the user's well-being as a result. The items are orthopaedic universal handles, medical splinting devices crafted with leather that enhance comfort, access and ability.

The featured prototypes of this hand splinting device is a polymer cast of a forearm, covered in leather. The material was sourced locally and partly came from saddlery off-cuts. This material has hypo allergic properties and it is breathable. It is comfortable to touch, it reduces chafing from the user's body and acts like a glove.

Evaluation

This project shows engagement with user, Occupational Therapy, OT, Footwear and a medical device company

Helped facilitate wider and better-informed engagement with medical device technology partners, alongside access and engagement with medical device innovation.

Developed understanding of the positive and potential impact design can have on people with needs, a small business and opportunities for future research.

Final Project – Saddle Seat with Force Sensors

Technical evidence and testing to document and demonstrate findings.

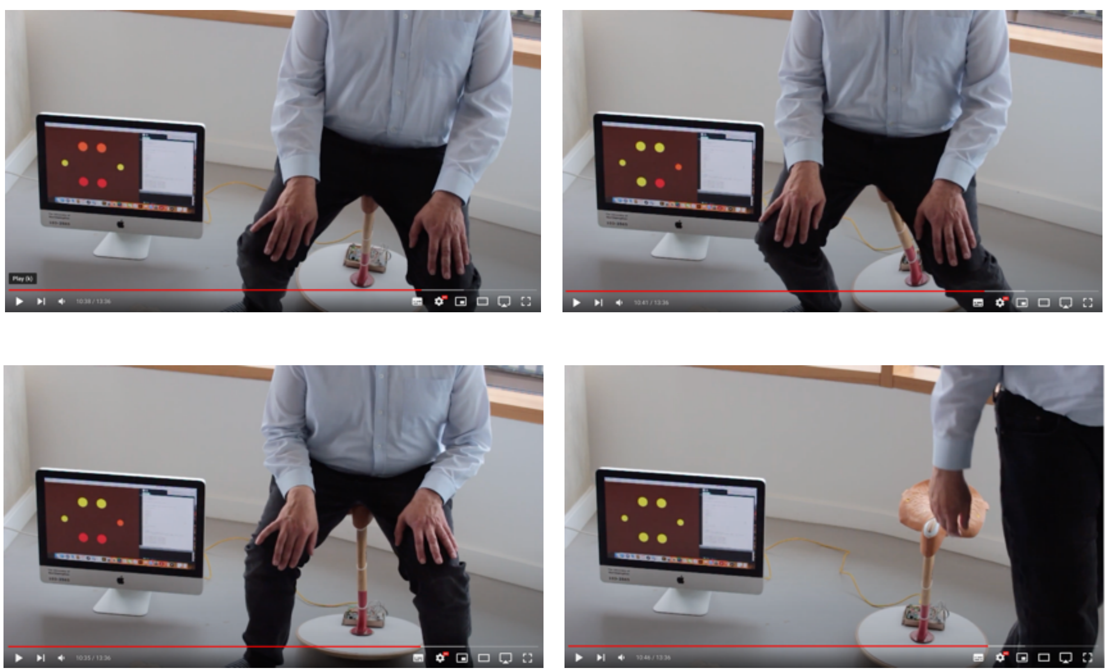
520x390 mm 4500g

Description and Measurements: 520 mm high 390 mm diameter,

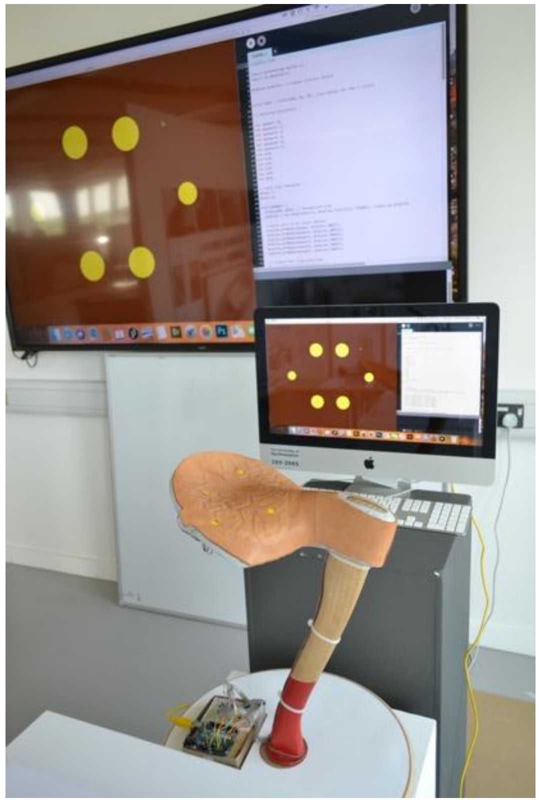
Video on Youtube being tested, Photo from talk at RCA SoD PGR event in Darwin LH1

Private view at WIP

Technical evidence of Creation of Bonded Fibres from Leather Waste through measurements, protocol and photographic record and testing to document and demonstrate findings.



Embedded in Vegetable Tanned Embossed Cowhide and Wired to Arduino Micro Controller, Displaying Pressure Distribution, with Potential Benefits for Posture and Health. The Youtube Video https://youtu.be/obLrJqqZp-o is a Recording of the Working Prototype, 2021.



Arduino and Processing 3 Code on Display for WIP Work in Progress Exhibition and Display at Viva Stage, 2021.

Smart material exploration and embedding of force pressure sensors in vegetable tanned saddle hide. Seat surface registers weight distribution which is processed through Arduino micro controller and a force distribution map.

Summary

Display of project during RCA Work-In-Progress Show 2018 18 January to 21 January. On display in Stevens Building in Hockney Gallery, Design research student exhibition, desk mounted and titled "Smart Leather: Perceived Quality and User Acceptance of Sensors and Structural Biomaterials". The functional prototype includes a swivelling stool, Arduino and sensors embedded in embossed leather plus a screen that displays a force distribution map. The seat surface registers weight distribution which are visualised by yellow, amber and red circles which are corresponding with the 6 force sensors (purchased from Rapid, Colchester), controlled by an Arduino Uno and connected via USB cable to a mains powered iMac. Interactive interface is written in Processing 3 format.

Functional prototype was designed and exhibited to assess participant engagement with the surface and interface, by:

1. Eliciting cognitive and sensory response to haptic stimuli;
2. Engagement of participants to vary pressure on seat
3. Use of the functional prototype as a probe within social settings to elicit public reaction and response

Location: RCA London. Participants: 21 RCA Design Research Student exhibitors, RCA community and general public.

Assembly Details

8 Force Sensors purchased from Rapid, Colchester, i.e.

4 x Interlink Electronics FSR400 0.2" Diameter Force Sensing Resistor

4 x Taiwan-Alpha-18mm-Circular-Membrane-Force-Sensor

https://www.ebay.co.uk/itm/Taiwan-Alpha-18mm-Circular-Membrane-Force-Sensor-/132076484507?_trksid=p2349526.m2548.l4275

Arduino is an open-source physical computing platform based on a simple i/o board and a development environment that implements Processing.

Sensing and Interactivity with Arduino (Smart Zone Kensington, Training Room) devised and conducted by Paul May on 9 March 2017.

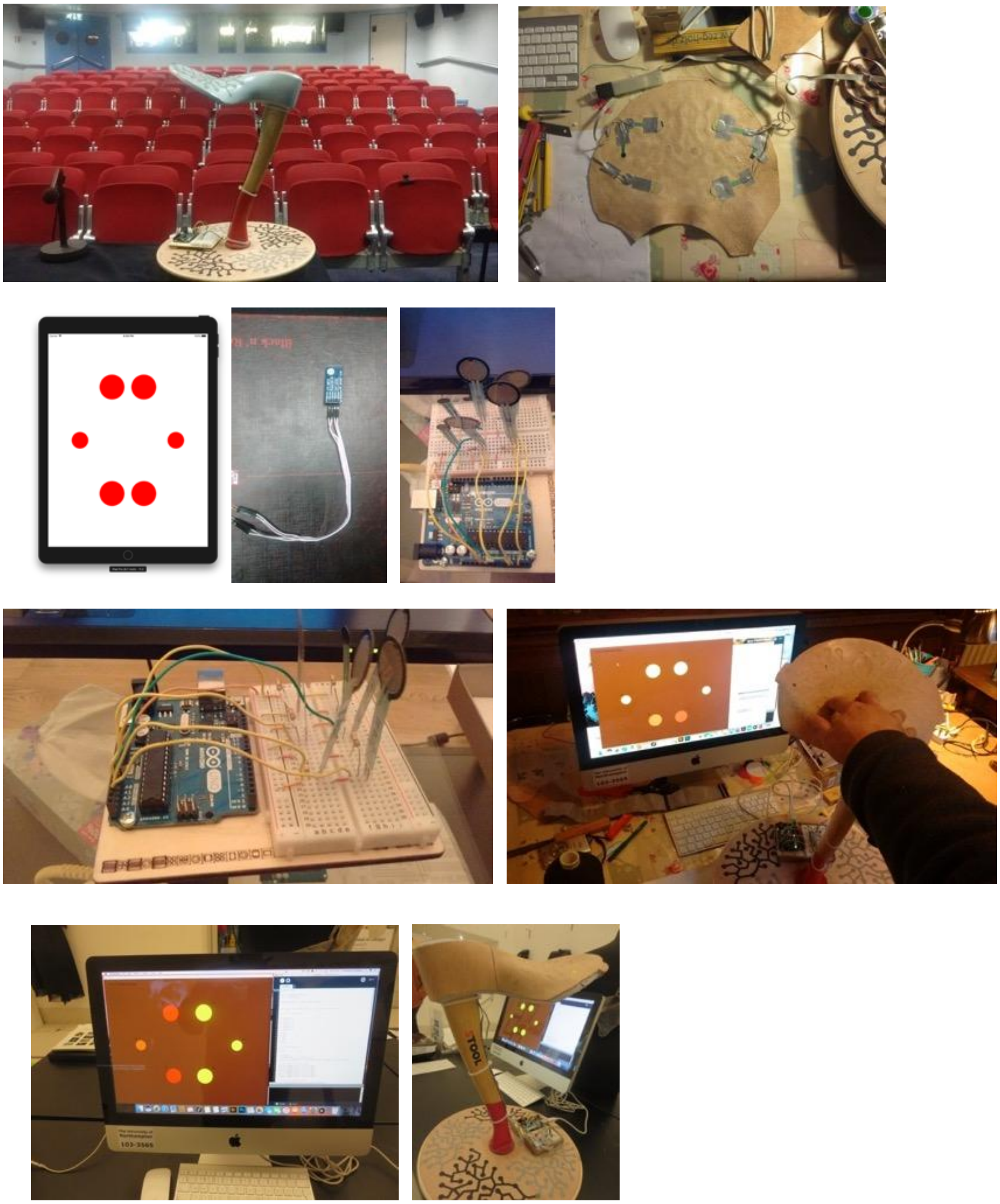
Code for Work in Progress Exhibition January 2018:

Sources: Arduino Sketch, Processing 3

Code written by Sara Zarakani

Research Findings

Functional prototype partially succeeded as a probe in providing a discussion for participants and the researcher to engage at least on a conceptual level, some questions about usage, design viability and market desirability.



Images: Setting-up Arduino and Processing 3 Code Display Prior to WIP Work in Progress Exhibition and Display, 2018.