Design Research for Change (DR4C) Symposium

Material Design Innovation: Fish leather, a new environmental-friendly material

Abstract
This paper explores the material design innovation process during a cross-disciplinary project working with fish leather. The *Fishskinlab* project aims to generate a deeper understanding of fish leather as an alternative to conventional leather to encourage more sustainable fashion practices. The objective is to create aesthetically relevant fish leather products that illuminate sustainability thinking as a driver for innovation. The project looks at the strategies implemented by practice in the field of material design innovation fed by new technologies, addressing changes in interactions between humans and with our environments.
The research draws on findings gathered through a partnership between the researcher, the Icelandic tannery Atlantic Leather and the Italian analytical laboratory Ars Tinctoria connecting fashion designers, scientists and leather technicians from the UK, Italy, and Iceland to advance material innovation by using new technology (water-based ink digital printing methods) on fish leather. This led to the development of a collection of digitally printed fish leather bags.
The skins were sourced at Atlantic leather, the researcher developed the prints and followed the technical process while the digital printing was produced and tested at the Italian analytical laboratory Ars Tinctoria.
This paper presents the journey of the mapping process, illustrating the key stages of the research, which led to the discovery of new material properties and finishes applying digital printing processes to a food industry by-product material such fish leather.
The methods and practices of the project included dynamic interaction between the researchers facilitated through the cooperative framework of the project. The feedback of the work presented during Brussels Industry days and Milano Design week offered the researcher an information flow that influenced the development of the final prototypes and the ultimate presentation of process and outcomes.
The findings identify that new materials, processes, and techniques are often the result of the successful union of fashion and technology to help drive the industry towards a more sustainable future.

Keywords: Material Innovation, Sustainable Fashion, Fish Leather, Food Industry By-Product, Waste, Digital Printing, Leather Industry.

Introduction
The project explores existing traditional knowledge of fish skin processes and applies the analysis of this learning using state-of-the-art practices and developing new technologies while addressing specific challenges of the use of fish leather for the fashion industry. The research maps best practice and knowledge transfer of water-based ink digital printing technologies for fish leather.
The research has brought together sustainable methods from fashion design, material science, and analytical chemistry to foster international knowledge exchange that will develop the capacity for research and practice in these fields.
This design research is about innovation, design, and sustainability paving the way for the future of fashion by using unique leftover materials such as fish skins while illustrating shifts in material values and resources.
The paper is divided into seven parts. The first part covers an introduction to the project and main objectives. The second part examines the historical context of fish leather. The thrid part covers the environmental context. The fourth part describes the methodology used. The fifth part develops the design research through practice: the Fishskinlab research case study. The sixth part explores the

digital printing methods used and chemical tests done. The final part describes the findings and conclusions.

Figure 1. Atlantic leather fish skin tannery. Picture by Nathalie Malric (2018)

Historical Context

The use of fish skin for clothing is an ancient tradition in Arctic societies along rivers and coasts and there is evidence of fish skin leather production in Scandinavia, Alaska, Japan, northeast China and Siberia.

Before synthetic fibres were invented, people clothed themselves with natural materials available in the surroundings where they lived, including fish skin (Jiao, 2012).

People in the Arctic coastal regions sourced their materials from animals that were necessary for their survival, such as salmon and they used their skins for clothing and accessories (Hatt, 1969).

The shortage of raw materials and omnipresence of modernity have challenged the preservation of the fish skin craft (Lin, 2007). Better access to the modern world meant that Arctic people were able to access textiles like cotton and silk to create their clothing, leaving fewer people to develop the traditional fish skin craft. Overfishing and water pollution have caused fish stocks to drop and many Arctic aboriginals have turned to farming to make a living, abandoning their fish skin skills (Lin, 2007). The use of fish skin by aboriginal Arctic people has recently been assimilated as an innovative sustainable material for fashion due to their low environmental impact.

The Atlantic Leather tannery, located on the north coast of Iceland, has been one of the main agents in the renaissance of the fish skin craft. Processing fish leather since 1994, based on the ancient Icelandic tradition of making shoes from the skins of wolfish (Figure 2). The tannery has brought this historic eco-luxury material back into fashion, simultaneously reviving ancestral tanning techniques and providing jobs for the local community (Figure 1). Their fish leather is a by-product of the fishing industry, exploiting fish not bred specifically for their skin, that would otherwise be discarded. All the fish skin used by Atlantic Leather is sourced from sustainably-managed farms in the Nordic countries (Figure 3). Special attention is given to the new technologies used on their fish skin production and

to address challenges such as energy, environment and climate change. The entire process of producing fish skin at Atlantic Leather relies on the power of nature using geothermal water and is non-impactful on the environment. The manufacturing of fish skin leather works with three aspects of sustainability: the economic benefit of creating value from waste; the social benefit of reconciling sustainability with fashionably exotic fish skin; and the environmental benefit of producing skins without damaging endangering animals. Atlantic leather is the winner of the "Tannery of the Year Europe Territory 2016" award, taking in consideration how the tanning process was executed, how the staff was treated, the factory's surroundings and how the small community around the factory is benefiting from it.

Figure 2. Icelandic traditional shoes made of wolffish skin (right). Picture by Nathalie Malric (2018)

Environmental Context

The fashion industry is currently going through a significant change in its approach towards sustainability and luxury brands need to think about the natural resources they rely on and come up with innovation on alternative sustainable materials and processes. Fashion needs to invest in technologies able to reduce environmental impact to enhance the materials and create products that respect the environment (Pavione, E. et al.2016)

FishSkinLab research concentrates on promoting a new category of raw material for fashion: fish leather. Fish skins are sourced from the food industry, using what is now considered waste, applying the principle of circular economy, combining research and innovation to enhance the well-being of the earth and its people through the entire life cycle of the product.

Global production of fish has steadily increased over the last decade and more than 50% of the total fish capture remaining material results in 32 million tonnes of waste. (Arvanito, Kassaveti, 2008). While to date, the European Environment Protection agency allows seafood processors to dispose of fish skins in marine waters, this is expected to change as the decomposing organic waste can suck up available oxygen from marine species and introduces disease to the local ecosystem. (EPA, 2012). The processing of fish leather avoids throwing the fish skins into the ocean and can significantly reduce marine pollution and sustainably protect marine ecosystems in order to achieve healthy and

productive oceans. Consequently, the promotion of fish leather could be of great environmental benefit as well as profit for the coastal economy.

Figure 3. Salmon fish skins through the tanning process. Picture by Nathalie Malric (2018)

The use of alternative materials such fish leather has the potential not only to serve to our material needs but also reduce resource consumption of other over exploited materials such conventional leather and it could lead to more locally sensitive production, more regional sourced materials and more local jobs (Fletcher, 2014).

By growing, sourcing and processing raw materials close to home shortens transport routes, lowers carbon footprint and increases transparency across the supply chain. By using local industry waste such as fish skin, nearshoring material production can provide exciting opportunities for the community whilst minimising environmental impact, both locally and globally (Banathy, 1996).

Fish leather being recoverd as waste, requires limited resources from the sourcing of the raw material leaving a lower carbon footprint than the one associated with raising cattle. Fish leather requires no extra land, water, fertilisers or pesticides to be produced and it has a lower environmental impact than conventional leather (Jacobs, 2018).

In luxury fashion, innovation, new materials and traceability are critical. Many luxury brands are actively researching into new materials to make sure the next product is better than the previous one. Luxury fashion brands in the future will be forced to view sustainability as a business imperative; sustainability, in fact, represents innovation and generates competitiveness in the global luxury marketplace (Pavione, E. et al.2016). Any luxury brand which understand these issues and uses fish leather will be regarded at the forefront of the developing innovative market.

According to Williams, new conversations about the materials that we choose, the products that we make, and the ways in which we work as designers can be responsive and make a positive contribution to the world around us as the premise of all good design. (Williams, 2013)

This research draws on the field of Design for Sustainability with scholars such as Stuart Walker drawing attention to design as a process of re-consideration of the present as part of the creation of shared futures (Walker,2016). Walker has suggested that when people begin to appreciate the level of skill and the massive investment of time involved in making a piece, it is valued more highly. High

fashion conundrum valuing handmade products versus low end disposable fashion are also part of the fish leather discussion. The highly qualified skills necessary to produce fish leather makes it a unique luxury material for fashion.

Figure 4. Fishskinlab project: Wisteria digital printed fish skin clutch by Elisa Palomino. Photo by Giacomo Iezzi (2019)

Methodology

A preliminary round of research was conducted to understand the status of the field in terms of research coverage and gaps, and towards a better definition of the research objectives and their scope. The analysis covered studies on historical and contemporary use of fish skin, sustainability aspects and alternative digital printing methods.

The research looked into demonstrating the contemporary relevance of fish leather as a new sustainable material identifying fish skin's positive ecological impact and its potential for application in fashion. The methods included prefiguring avenues and sketching strategies for developing new printing techniques for fish leather within the fashion luxury industry.

The methodology of this research identifies risk-taking and co-experimentation of materials as essential strategies as the key stages of the research process: Mapping new terrain of sustainable materials, fish leather material investigation, public feedback and critical evaluation.

This paper presents a journey of the process, illustrating the key stages of the research. Observational and participatory methods were utilised to obtain data. This involved talking to the general public during the presentation of the project at Brussels Industry days and Milano Design week. Feedback from the general public during the design fairs supported the progression of the project applying design thinking to the journey.

The key findings from the general feedback verified that the public would be likely to buy fish leather items as an alternative material for fashion.The information influenced the development of the final fish leather prototypes and the ultimate presentation of process and outcomes.

Design Research through Practice: Fishskinlab research case study

Leather remains a vital material for most luxury fashion houses, even more so when it is an exotic skin. Thanks to the use of new technologies, the luxury industry offers a vast array of appearances and finishes among conventional leather, while both the use and creative development of fish leather has been largely neglected. The aim of this design research is to pilot and develop non-polluting technologies for fish leather finishes to advance the development of future manufactured fish leather products. The results can bring a fresh look at how fish leather development with new technologies can underpin and reshape luxury fashion accessories.

This research draws on the researcher Elisa Palomino's experience working in the fashion luxury industry back in 2002, designing for John Galliano fish leather garments and accessories sourced at Atlantic leather. The researcher has experience running network projects linked with fish skin (e.g. EU Horizon 2020-MSCA-RISE Marie Sklodowska Curie: Fish Skin a Sustainable Raw Material; and she is the recipient of the UK-US Fulbright Scholar Award: 'Arctic Fishskin clothing traditions' at the Smithsonian Institute)

In 2018, the author collaborated with Atlantic Leather in the development of 'Fishskinlab', a Worth Partnership Project, funded by the European Commission, EASME, under (COSME 2014-2020) with access to financial funding, market exposure and mentoring to produce a collection of bags made of fish leather developing new embellishments and eco-friendly digital printing which has informed this practice-based research.

Phase 1

With her knowledge on textile and leather printing the main aim for the researcher was to see how fish leather would be transformed under digital printing, compared with the relatively well-known process of textile and leather digital printing. The first round of tests, as seen in Figure 7, resulted in findings that the water-based inks did not adhere easily to the fish leather when the designs had full coverage.

Phase 2

The first review of the digital printed tests identified the need to expand the selection of designs to include designs with less coverage (Figure 8) that could withstand the even coverage and produce new results. As the author became more specific in her design choices and experiment with a number of design combinations the final results were very successful.

Phase 3

Prototypes of small bags were created with the print samples to exemplify the materiality of fish leather for luxury fashion accessories.

Phase 4

The author decided that, in order to gain feedback on the project, it would be advantageous to build in a participatory knowledge exchange. In 2019 the Fishskinlab project took part in Milano Design week and EU Industry Days in Brussels (Figure 6) under the theme of industry and sustainability. Both exhibitions provided an excellent opportunity to engage with a diverse audience representing a variety of industrial sectors from all over Europe. A key element of the participation on the Brussels Industry days was to facilitate a venue that could inspire consumers and EU policy makers to engage with materials through closed-loop thinking, to share their ideas with the designer and to obtain additional professional feedback. The aim of the participation was to push the boundaries of material design practice to identify how it can be used as a tool for citizen engagement, for both: the designer, and the public who wished to engage with the product to identify opportunities to improve both its environmental and social impacts.

The feedback outlined the successful elements of the project, the value of sustainability and use of waste materials and highlighted the qualities that a waste approach can bring to accessories design. The element that emerged was the close link created between the sustainable approach and innovation. The public was surprised of how something that is considered waste in many countries is given a much higher value through the action of design. Seduced by its beauty, the public was aware

of the material being the skin of a fish and inspired about the value of everyday materials. The high visual standards of the final product fits with luxury fashion and becomes a benchmark for redefining the beauty of sustainability. (Figure 5) The project is a fine example of an innovative way of linking the preservation of traditional knowledge and culture and the development of relevant fashion items taking in consideration the sustainable limits of the planet's natural resources.

Figure 6. Fishskinlab project: Pagoda digital printed fish skin clutch by Elisa Palomino. Banner for the Brussels EU Industry days. Photo by Giacomo Iezzi (2019)

Fish leather digital printing

The researcher is an expert in the field of textile design, familiar with digital and analogue printing methods but there are no previous attempts known to the researcher to print fish leather. There are different methods that could be used: silk screen printing and digital print.

Textile digital printing emerged in the 1990s as a prototyping tool and a vehicle for printing small batches of fabric for niche-market products (Provost, 1994). Inkjet printing involves the propelling of tiny droplets of dye or pigment onto a fabric electrostatically. The selected dyes or pigments are dosed on demand and avoid print paste residues at the end of each run and if pigmented inks are used (rather than those based on dyes) no solvent which associated volatile organic compound emissions is required to dissolve the colourant. (Fletcher, 2013) Recent decades have seen the growing popularity of preparing water-based ink-jet inks for textile printing.

Water-based ink-jet inks for digital textile printing were used on fish leather for this project. Fish leather printing can be difficult since ink generally does not bond well to a non-uniform, organic, complex substrate. The non-uniformity and surface roughness of the fish scales was one of the main obstacles during the process. (See Figure 7). The significant variation on a single fish skin as well as between skins of a batch was also a challenge. Techniques for printing on fish leather may suppress at least one usual property of fish leather, e.g. appearance, feel and/or absorption. Printing onto the surface of fish leather could be disadvantageous if the ink is weakly bonded and it could be easily removed during normal wear and tear, or if the print cracks when flexed. (Pantelis, 2013)

During the test phase, the printing of fish leather included the application of an ink base coat directly onto the surface of the fish leather. The experiments show that a selected combination of pressure

and temperature is required. Success was achieved when the transfer of ink into the fish leather occurred across the leather sample with good penetration (See Figure 8). In unsuccessful tests, the transfer of ink into the leather had a non-uniform penetration (See Figure 7).
The digital printing was produced and tested at the Italian analytical laboratory Ars Tinctoria.

They are specialised in colour, light and organic analytical research. Based in Santa Croce sull'Arno, heart of the Italian Leather production cluster, the laboratory is equipped with the latest generation instruments and is active in several fields, including synthesis, analytical research and the study of molecular structures of dyes, the search for hazardous substances, and measurement and standardization of colour and light. Gustavo Adrián Defeo, its CEO is an industrial chemist, active in the leather field since 1985 with multinational chemistry groups with expertise in dyes kinetics, psychophysics, colour perception, light and colour measurement, industrial waste recycling, ecology and analytical methods for the leather sector.

The physical and rheological properties of the inks were measured for the evaluation of ink stability and suitability for ink-jet printing. The tests were found to be suitable. The prints were subjected to light and rub fastness tests and colour measurements. Colour consistency and fastness results, especially after fixation, are comparable with those on conventional leather, which paves the way for the production of environmentally friendly water-based ink-jet inks for the digital printing of fish leather.

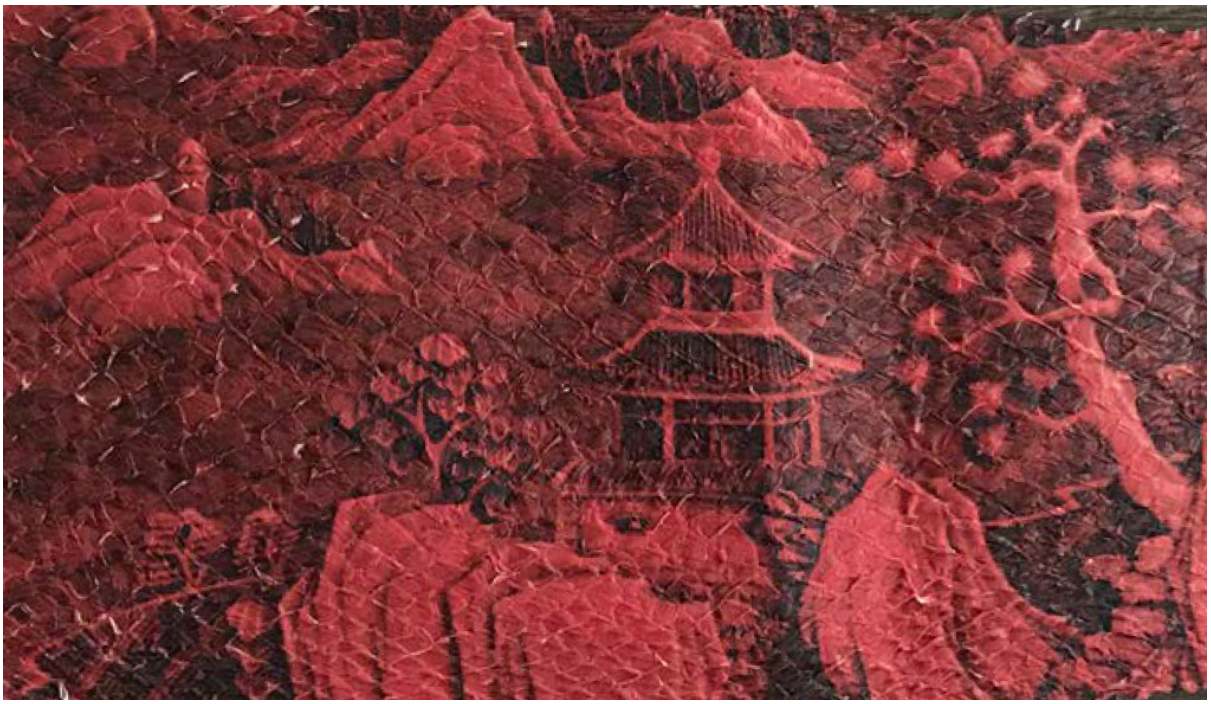

Figure 7. Non uniform penetration of ink on the Pagoda digital print sample. Picture by Elisa Palomino (2019)

Figure 8 . Good penetration of ink on the Wisteria digital print sample. Picture by Elisa Palomino (2019)

Fastness properties of Wisteria digital printing

Fastness properties were analysed following updated ISO standards.

ISO 15701:2015 (IULTCS/IUF 442) Leather - Colour fastness to migration into polymeric material (for this test migration was tested on standard PVC layers: This test helps to understand if there will be potential colour migration into plastic materials, and eventual stain of polymeric finishings applied, by contact with neighbouring materials.

Results obtained which can be observed on Figure 9 were excellent (rate 4,5 /5 on grey scale, where the value 5 represents the highest standard). Such a result allows combining the print obtained with any other neighbouring material without risk of stains.

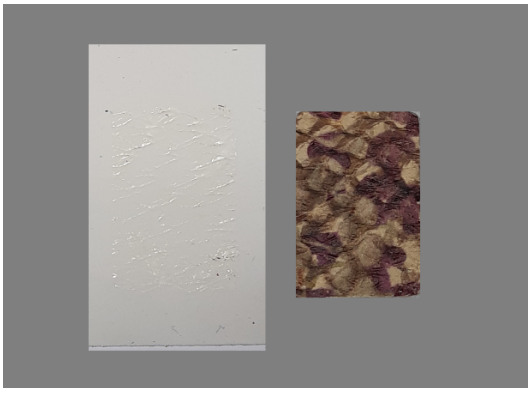

Figure 9 – Migration into polymeric materials

ISO 11641:2012 (IULTCS/IUF 426) Leather - Colour fastness to perspiration (on multifibre): This test was developed to understand eventual colour fading or migration into different textile fibres with artificial acidic perspiration (Figure 10). A multifibre fabric composed, from the top, of Acetate, Cotton, Polyester, Acrylic and Wool was used in this test.

Apart of a Light stain on Acetate (rated 4/5), all fibre types showed excellent performance. Also in this case staining was rated against grey scale where perfect values are represented by rate 5.

The final test was ISO 105-B02:2013 Textiles - Tests for colour fastness - Part B02: Colour fastness to artificial light: Xenon arc fading lamp test: This test emulates weathering of a colour sample by exposition to natural solar light. In this case samples' colour fading is rated against a blue scale on

fabrics representing the values 1 to 8, where rate 8 is the highest standard. The light fastness obtained (Figure 11) is > 6, which is an excellent result considering the naturality of the finishing.

Figure 10 - Colour fastness to perspiration

Figure 11 - Xenon arc fading lamp test

Chemical Tests:
Wisteria printing on Salmon leather was analysed to verify the eventual presence of Substances of Very High Concern (SVHC) after European REACh protocols.
Results shown the absence of any substance of concern, such as Aromatic amines derived from Azo dyestuffs, Hexavalent Chrome (Cr VI), Reach Annex XIV and Annex XVII listed Phthalates, Alkyl phenol and Alkyl phenol ethoxylates, Free formaldehyde and Chlorophenols.

Conclusions

This paper portrays the journey of a collaborative research project between the authors Elisa Palomino, designer, educator and researcher at BA Fashion Print at Central Saint Martins and Gustavo Adrian Defeo, industrial chemist CEO at Ars Tinctoria. The project started as an open-ended research investigation combining design with science and technology exploring fish leather material testing in the hope to develop new finishes and techniques.
Material research has rapidly expanded into a more interdisciplinary practice and designers need to broaden the disciplines in which the methods and concepts of sustainable materials are taken as a vehicle for new collaborative ways of making. This paper suggests methods and processes to invite more sustainable material research and investigates how knowledge about materials can be integrated and communicated within the framework of research.
Current research is now looking into the development of low environmental impact processes to offer new sustainable production methods for the fashion industry. More than ever before the task of design is to articulate the right directions in material development to move towards more sustainable choices.
Understanding materials, production processes, viability, and desirability are key to the fashion industry. New materials and techniques are often the result of the successful union of fashion and technology to help drive the industry real change in terms of sustainability.

The Fishskinlab project was designed to experiment with new techniques, generate a deeper understanding of the fish leather processes and open up further opportunities for research with other disciplines.
This project wants to bring more attention to urgent international matters such as sustainability in the leather industry by using nature-given resources and upcycling leftovers from the food industry.
The paper reflects ethical values linked to research on sustainability and renewable sources, destined to become the driving force for the future of high-quality fashion.
The paper outlines an investigation between design and chemistry and the space in between them.
The potential use of water-based ink jet printing for the production of environmentally friendly fish leather prints was investigated. The results were excellent, and this paves the way to challenge more manufactories to sustainable and innovative visions in existing production processes. We were able to measure challenges and possibilities of a design framework based on sustainability values.
The project has enhanced the creativity and innovation in the UK and Italy's leather sector, building stronger connections between the researchers and creating opportunities for future exchange. The fashion creative industries are critical to industrial and commercial success in the UK and Italy. This Anglo-Italo-Icelandic network has blended the skills of Italian leather technology and their passion to create high-quality products with Icelandic sustainable technology and British cutting-edge sustainable design.
The project will have an economic impact by putting fish skin leather on a new level of excellence capable of conquering new markets globally.
By bringing the field of fashion design from Arts and Humanities in contact with Science and Technology, this project has the potential to bring benefits to a wide range of subject areas. It will encourage the joint development of scholarship and collaboration across these disciplines, and it will support the cross-referencing of methods to advance scientific and artistic knowledge of fish leather as a more sustainable alternative to conventional leather.
The outcomes of this project will enable an informed discourse on sustainable thinking for creative practitioners, fashion designers, fashion students, leather manufacturers of luxury goods and retailers across a broad contemporary landscape.
The research developed in this project will benefit scientists coming from a polymer and chemical backgrounds from the research know-how in transforming fish skin, a biological residue, into fish leather – a workable raw material. Chemical scientist at the tanneries will benefit from the transferring of the bio-digital printing results and technology. Practice-based academics from fashion higher education and fashion designers will benefit from the new possibilities for visual and physical attributes for fish leather for the purpose of creating a rich library of effects relevant for the fashion industry.
From a research perspective, this project has enabled the work of the researcher as Fashion Print pathway leader at UAL, to inform future design for sustainability practices in industry and education.

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