MASTERS IN PRODUCT AND INDUSTRIAL DESIGN . 2020

Fish scales

Manufacturing jewellery from food waste

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Abstract

This thesis focuses on discarded fish scales and ways to add value to this waste material, demonstrating its potential for application in products.

Its research aims to pave the way for the creation of alternatives regarding the processing of these food leftovers that are daily generated in the process of fish scraping in markets and fishmongers, therefore minimizing the deposition of fish scales in landfills.

The reflection on the influence of the natural world on products created by human beings came to be allied to the idea of preservation of that same natural world, based on the reduction of the environmental impact generated in the creation of products. In this study, the reduction of the disposal of fish scales as a result of the food industry is put at the spotlight.

An experimental phase was driven by the understanding of this disposed material: firstly, discarded fish scales were transformed according to Material Driven Design Method (MDD), an exploratory process that was considered in a previous research on fish scales as a by-product of the fishing industry - this method considers material properties, exploring and transforming different waste materials into new raw materials. This experimental study was supported by literature throughout all the process and was based on the exploration of different forms of tinkering with fish scales. In this document, the application of the method of hot pressing applied to fish scales was further explored and described in detail. This technique results in fish scales clusters that have a pleasant and natural appearance without resorting to the addition of any binders - thus being 100% organic.

To demonstrate the feasibility of applying this technique, a practical case was conceptualized and produced: a pair of earrings was produced in Alquimia Lab school. These hoop earrings are both circular in their shape and intention to extend a waste product's life span. Stone setting technique was used to attach the fish scales clusters to the silver structure of the jewels. The silver claws frame the organic, delicate, pearly matter - the previously disposed fish scales are now looked at as sea gems.

Keywords

Fish Scales, Uniaxial hot pressing, Food waste, Circular design, Jewellery

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1.

1.1 Context

This document foresees an investigation on the use of discarded fish scales, that are collected as food waste from the fishing industry. It is governed by the premise of promoting knowledge in the handling of this material, while sharing experiments' assumptions with the scientific community.

Its aim is to expose a research regarding the potential of fish scales application through their transformation into alternative materials to those existing abundantly in the market. In addition, the research attempted to do so through the recovery of a discarded material, recovering its value.

It consists of an extensive bibliographical investigation that most of all seeks to understand the limits of this discarded material trough the research based on the technique of thermal pressing fish scales. This research, along with the research project development, enabled the creation of a practical case oriented towards sustainable production - to which the developed concepts will be applied.

This practical case comes from the intention to create an artefact which has a specific meaning to it, that is built while enhancing the properties of the fish scales.

1.2. Relevance

The use of food industry waste is herein addressed. The development of this investigation is, as stated before, based in fish scales processing techniques: the wasted material is collected and transformed into a new raw material.

According to Manzini, *"(…) society can be seen as a huge future-building laboratory —a laboratory that, amidst numerous contradictions, is already emitting signs of a new culture (…)"* (Alexandre Apsan Frediani 2002).

Although information on fish scales application in areas such as medicine was found, little information has been found regarding the reuse and processing of this matter for other relevant purposes.

The performance in this research area is also deeply associated with the development of skills for the creation of alternative technologies to those existing on the market, as a means to seek new alternatives that help extend the lifecycle of wasted materials.

Throughout project development, thermally pressed fish scales' aesthetics took part in the decision to produce jewellery.

1.3. Research question

An initial exploratory research has provided guidance for the application of the previously explored techniques, which were expected to be further explored while opening new paths for the development of products that are more focused on people and on their usability, as in the communication of an underlying ethical message on circular economy.

In fact, the motivation for the research project was questioning the fishing industry given the large number of discarded fish scales in the fishing industry. Residue should be transformed - through material experimentation and application of specific production processes - into the techniques that constitutes a set of creative artefacts.

It was expected for these artefacts to be commercialized.

1.4. Objectives

This investigation aims to produce theoretical knowledge on the use of fish scales. It starts from techniques that involve the processing of this material, focusing on its physical features and its exposure to different temperatures. It also aims to complement the existing information regarding fish scales' features, providing aspects on their transformation when submitted to a certain degree of heat and pressure, along with displaying and providing guidelines to run alternative technologies to those existing in the market.

It was sought to help pave the way of process alternatives in waste utilisation.

1.5. Methodology

Speculation on the applicability of a new technology is expected to take place after testing with fish scales thermal pressing. This work may also inspire other kinds of biological materials' mechanical testing.

Accessing, analysing and comparing scientific peer research has been a crucial factor for acquiring knowledge and overcoming difficulties throughout the process of this research. This phase was followed by producing and disseminating scientific knowledge.

2.

2.1. Bibliometric study

This systematic review protocol section aims to provide guidelines for the research on the use of fish scales and the techniques that have been developed from it. It presents the data resulting from the selected studies on fish scales, meaning getting to understand and compare their mechanical features and components according to diverse data, while researching on the range of existing products and composites that were created with this daily discarded material. This systematic review was expected to provide knowledge on the properties of fish scales, also understanding their behaviour when subjected to different types of treatments; it finally foresaw understanding the range of applicability of this material, based on documented products and/or techniques, while enabling the creation of alternatives ones. Naturally, this theoretical research allowed the opportunity to explore the circular economy as a concept that underlies the research project, through the upcycling of discarded fish scales.

Most found results were written in english, although a few documents written in portuguese and spanish were also analysed. This research was made through web search engines such as Science Direct. Most considered documents are research articles. Online magazines, review articles, book chapters among other types of documents were also considered.

Data was processed and selected through a set of keywords, including synonyms, were searched and selected for their relevance and applied as study methodology.

228882 results were found (see Figure 1) considering the fish scales keywords. First documents were published in 1996 (2895). In 2006 the amount of published studies (5982) demonstrated a significant growth, which also happens later in 2015 (11646). Data has been increasing along the years, as can be seen for 2019, the year with the biggest number of published documents on fish scales (16754).

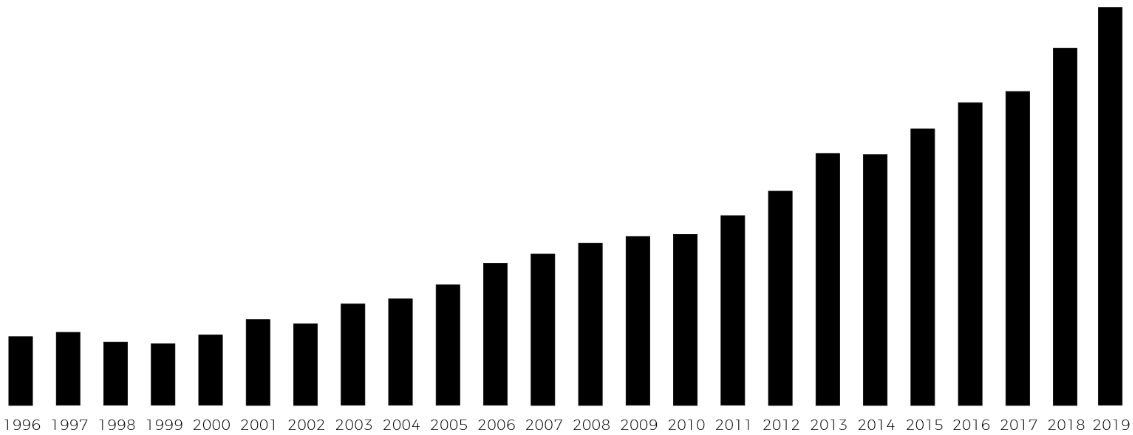

Figure 1. Fish scales: number of published results.

16931 documents (Figure 2) were found for the jewellery subject. Again, first found documented researches have been produced in 1996 (224). Similarly to found documents related to fish scales, a growth is visible in 2006 (509). 2019 was the year with more publications on this matter - 1064 documents were found.

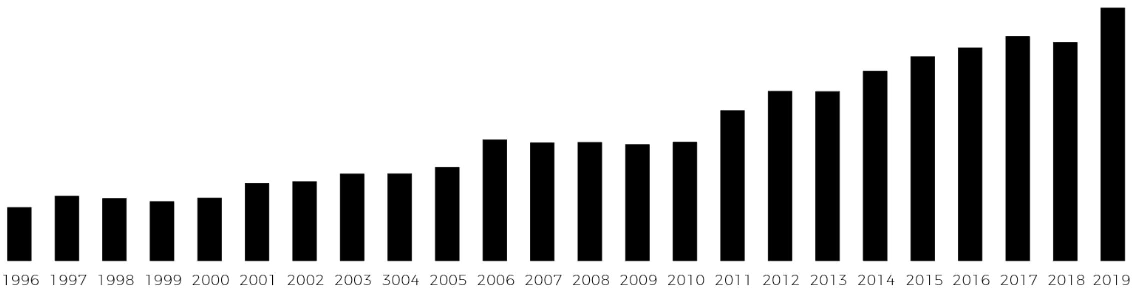

Figure 2. Jewellery: number of published results.

Found publications were subdivided into thematic clusters that helped both organizing and discarding unnecessary information by setting inclusion and exclusion criteria: only documents referring to cycloid, ctenoid and non-specified fish scales were considered (see Figure 3).

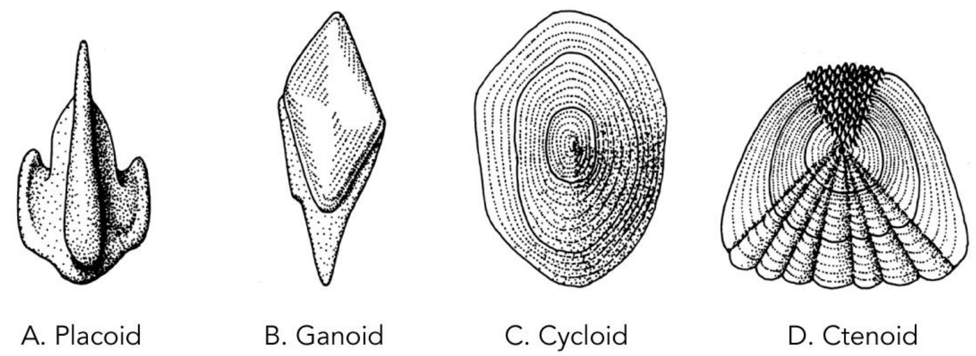

Figure 3. Four types of fish scales A) Placoid, B) Ganoid, C) Cycloid, and D) Ctenoid. Image from Living Ocean, CRDG, University of Hawaii at Manoa (Group n.d.).

The information on fish scales was accessed regarding the physical and mechanical characteristics of this material; among its components, collagen and hydroxyapatite were focused as these are widely explored fish scale components; the scientific community often highlights these components as a key elements for innovative composite materials and for their extraction and application in other product types. In addition to this, special emphasis was placed on the existence of fish scale composite materials: it was sought to explore their production processes and their applicability. Just a few documents were found on the use of fish scales for manufactured ornaments. Fish industry waste and fish waste processing was also briefly approached. Information on fish scales was considered between 2000 and 2020, although most analysed documents were published in the later years (between 2017 and 2020).

The consulted documents foresee distinct approaches. One example is the mention of fish products, their manufacture and application - with a generic overview on recurrent practices of certain cultures. Also, some documents refer to handicrafts made from fish scales by fishing communities, helping augmenting their incomes while simultaneously decreasing residues from fish preparation for the food industry, that are often deposited in inappropriate environments. Fish scales are herein recognized for their quality and durability; they are reused and adapted for the trade of decorative products. Other documents were found on fish scale processing and association with other components to obtain new raw materials. Fish scales are used for medicinal purposes, namely for bone tissue engineering, given their ability to improve mechanical characteristics (such as tensile strength and elongation at break), also preventing degradation. Fish scales were also used to reinforce composites of synthetic organic compounds such as bisphenol-A composites, in this case performing functions of increasing flexibility and as a stimulus for accelerating the degradation of this composite material. Another example refers to food or pharmaceutical applications; in this case the process is based on thermo-compression moulding applied to fish gelatine and epigallocatechin gallate to produce active films, allowing for a reduction in the production time (and energy) of the latter. One of the advantages of the obtained material is its translucency and integrity after water immersion. It was also possible to verify several documents on the use of guanine (contained in fish scales) for the production of false pearls; these elements, which are part of an oily silvery compound, are added to fish glue and mixed with beeswax, filling the inside of hollow glass beads. In this case, these fish residues perform the function of giving manufactured parts a natural shine.

After executing the search, obtained studies were listed for further evaluation and selection.

2.2. Nature's influence on artefacts

In *'Unusual Excrescences of Nature': Collected Coral and the Study of Petrified Luxury in Early Modern Antwerp* Marlise Rijks refers coral as an important cultural mark that is looked at through the lens of early seventeenth-century Antwerp as the centre of the trade and craft of gemstones such as coral. It makes it a case study to understand the culture of collecting and understanding the natural world (Rijks 2017).

Collections would enclose coral as a treasured aquatic world natural specimen that could be found as a collectible in its natural shape, as it could be crafted into jewellery pieces and *objets d'art* (Rijks 2017).

"Also, coral was a pictorial motif depicted by Antwerp artists on mythological scenes, still lifes, gallery pictures, and allegories." (Rijks 2017).

Examples are, for instance, Petrus Christus' *A goldsmith in his shop* and Joos van Cleve's *Virgin and Child*. These paintings would exhibit coral branches and jewellery such as necklaces and rosaries being worn or held inside of jewel cases on see-through display shelves, or even worn coral jewellery (Rijks 2017).

Corals, as 'unusual excrescences of nature' (as designated by Anselmus de Boodt) would suggest meditation on matter and its transformation: questions were raised given its allocation and source and also due to its transformation processes: *"(...)petrifaction as one of the most imaginative natural metamorphoses."* (Rijks 2017).

"As in the debate about fossils, the central issue was how it was possible that something of a stony hardness and quality could have the features of a living organism." (Rijks 2017).

Bloedkoraal (blood-coral) had expansive cultural connotations that exceeded its appreciation as *naturalium*. It was ever since antiquity seen as a means of protection, much like a talisman, and believed to possess antidote qualities. It resembles blood-filled arteries and is related to the myth of Medusa, whose blood is said to have petrified into red coral then spread by sea nymphs. This material was also deeply associated to religion, representing the Blood of Christ, and was materialized by coral rosaries. Petrification itself would be an allegory to both death and immortality (Rijks 2017).

Alongside with amber, red coral was considered *"(...) an essential commodity in the European-Indian network (...)"* (Rijks 2017).

It was likewise combined with other natural materials such as shells (and mother of pearl) and pearls which are epistemologically connected to it, sharing the sea as genesis (Rijks 2017).

Seventeenth-century painters once again succeed in depicting the interest of showcasing coral among other materials in cabinets (pearls, rare shells, rare fish, crystals, exotic bird feathers, moss), as well as combining them in diverse art objects.

Interior of an art cabinet with 'ânes iconoclastes', by Frans II Francken, stands as a distinct kind of still life named *Preziosenwand* (wall of precious things). Jan Breughel's *The element of fire* (Figure 4) portrays a setting that is profusely studded with small details which, if understood as a whole, make up the typical landscape of a goldsmith's - or alchimist's - workshop. It outlines distillation bottles, *"(...) a coral branch on the table (low left) next to all kinds of plates, goblets, jewellery and goldsmithing tools, while people are forging and hammering in the background."* (Rijks 2017).

Figure 4. Jan I Breughel, The element of fire, 1608. Oil on copper, 46 × 66 cm, Pinacoteca Ambrosiana, Milan (Vecchio 1608).

The feast of Acheloüs, a banquet of the gods painted by Rubens and Brueghel, and Simon de Vos' *Bacchanal in a grotto* of exhibit caves with natural elements panelling and growing on the ceiling, respectively. These settings resemble the fashionable artificial *grottos* combining rare natural materials.

Furthermore, coral would mediate the exchange of knowledge between collectors and visitors. *"Not all conversations were in-depth discussions. But the point is that the collection opened up possibilities for conversation, and circumstantial evidence shows that such conversations did indeed occur."* (Rijks 2017).

It was especially admired when combining hand crafted and natural shapes.

"The beauty of such collectors' arrangements lay in the combination of the man-made and the God-made, the artificialia and naturalia, and the objects in-between art and nature." (Rijks 2017).

Manufacturing and process appreciation were associated with natural transformation processes and looked at respectfully: *"(…) artists and artisans themselves were self-conscious about their processes of making."* (Rijks 2017).

Even counterfeiting natural materials was cherished as a broader material metamorphosis undertaken by goldsmiths, who would learn how to produce artificial materials that mimicked natural coral or pearls. False coral and stones and glass pearls would be common examples of 'Material mimesis' (Rijks 2017).

"Art, which is always busy to mimic nature, has not been idle to bring counterfeit pearls to the greatest perfection they are imitated so near, that the naked eye cannot distinguish them from pearls of the first class, or the real ones." (Smith 1799).

This process is thus known to have been applied to precious materials, as is shown by the usage of faux pearls that were used not only in jewellery but also in attire adornments (Figure 5 a) and b)) from the seventeenth to the nineteenth century (Eng and Fusco 2012).

Figure 5. a). (left) Joseph Robins, Fashion Plate, 'Paris, Ball Dress', c. 1830. Hand-colored engraving on paper, 15.24 x 8.89 cm, London. Gift of Dr. and Mrs. Gerald Labiner. Photograph: Steve Oliver © LACMA (Robins n.d.).

Figure 5. b). (right) Pink silk dress, c. 1830. 121.92 cm × 72.5 cm. Los Angeles County Museum of Art M.2007. Photograph: Steve Oliver © LACMA ("Pink Silk Dress" 2012).

Natural materials are seen to act as elements to be incorporated in everyday artefacts, and they can also represent a source of inspiration for biomimetic strategies. They unravel natural transformations and stimulate knowledge exchange and may carry a strong symbolic meaning. Considerations about biomimicry and its relevance today prompted a reflection on identity and on sustainability in design, as can be seen below.

Additive manufacturing techniques, alongside with laser cutting, among others are often used these days because they enable mimicking biological structures from a modelling and manufacturing perspective and seem to capture geometries found in Nature, simulating the behaviour of complex biological structures from micro to macro scale in a considerable afficient way (Le et al. 2019).

However, looking at mimicry might not be as plain it appears at first glance. Boaventura de Sousa Santos (1997) would look at the increasing exchange of material goods as the factor that triggered commercial and aesthetic devaluation. This last concept, he believed, might pave the way for counterfeiting, exacerbation and mimicry with a negative impact on product value. This attempt to copy visual identity seems threatening.

Although this may look like a pessimistic perspective, it should be thought of given that it presents a coherent constructive prospect on mass production and imitation between brands and companies, which is linked with lack of identity.

Niemeyer (2010) would later refer that, although this is not a new subject, identity is an increasingly debated issue with regard to Design creation that is still lacking speculation and understanding.

Thus, the relevance to address Identity in the production of artefacts seems to be unavoidable. It also seems imperative to look at product design through sustainable lens.

Nowadays, this notorious relationship between artefacts and the natural world is substantially reinforced by sustainability, given the urgency to preserve the place where we and future generations will live. The often irreversible problems caused by resource depletion and environment pollution have changed mentalities all over the world and reveal that if on the one hand Nature shows itself as an inexhaustible source of inspiration for object creation, its resources are, on the other hand, limited. However, it comes as no surprise that these barriers which had to be considered in product development made room for new materials (for instance, bioplastics), techniques and processes of production that reflected ethical concerns, especially related to ecology. Thus, Nature seems to be at the very epicentre of every big change in humankind, shaping the way humans relate to each other and to things around them, thence the everchanging, kaleidoscopic reality of product Design.

2.3. Fish scales

"Scales are bony or keratin structures formed on the skin of many animals as a protective organ." (Souza et al. 2013).

Biological materials science was important to enable the study of fish scales, helping in understanding their structure and properties that are linked with functionality that governs fish performance facing protective structures.

Fish scales are lamellar natural constructs exhibiting exceptional armour systems. Generally, they are essentially made of type I collagen fibers and hydroxyapatite - components that are also found in bone and teeth. The relation between apatite crystals and collagen fibers is considered preeminent for the scale's mechanical performance (Le et al. 2019).

Scales come from the fish skin and are known to cover it - standing out and overlapping along its body (Figure 6). These elements are simultaneously lightweight, flexible and tough, and those features stand as key elements to provide protection from predators without severely compromising fish mobility (Yang et al. 2019).

Figure 6. Prussian carp ("Carassius gibelio"). (Chernilevsky 2013).

For instance, arapaima scales are penetration-resistant due to a highly mineralized outer layer *"(...) and a tougher lower layer with a twisted arrangement of mineralized collagen fibrils to absorb deformation (...)"* (Yang et al. 2019).

"Many fish scales are efficient natural dermal armors that protect fish from predators without impeding their flexibility." (Yang et al. 2019).

Ctenoid scales (Figure 7) combine two conflicting properties - hardness and flexibility - enabling body protection against predators and environmental impacts, while allowing body bendability for locomotion, respectively (Spinner et al. 2019).

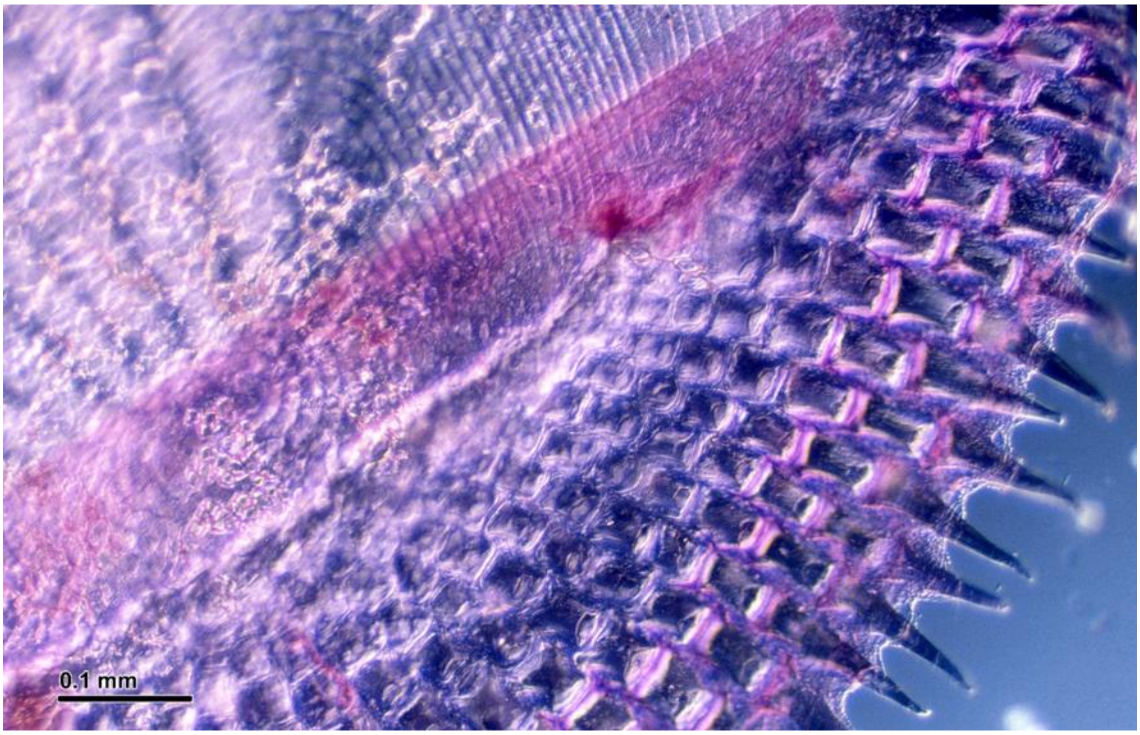

Figure 7. Fish scale: ctenoid scale. Differential interference contrast microscopy (Josef Reischig 2014).

Fish scales resistance and weight determine the balance between protection and movement. These hydrodynamic armour systems are both lightweight and flexible, optimizing locomotion (Le et al. 2019).

Spinner et al. (2019) investigated the flatfish Solea solea's mechanical behaviour to understand ctenoid scales' material properties: posterior field structures of stacked mineralized ctenial spines - a part of the scales that is exposed to the environment - were examined in detail.

"Bending tests showed that the ctenoid scales have two functional zones: a stiff supporting main body and an anisotropically deformable posterior field." (Spinner et al. 2019).

Joint-like structures within scales (Figure 8) were identified: soft material between those structures optimize flexibility of scales' posterior field. These structures boost scale deformability during downward bending, however, interlocking - preventing scale deformation during upward bending (Spinner et al. 2019).

"Fish scales are often well recognized as plywood-like, cross-laminated structures." (Le et al. 2019).

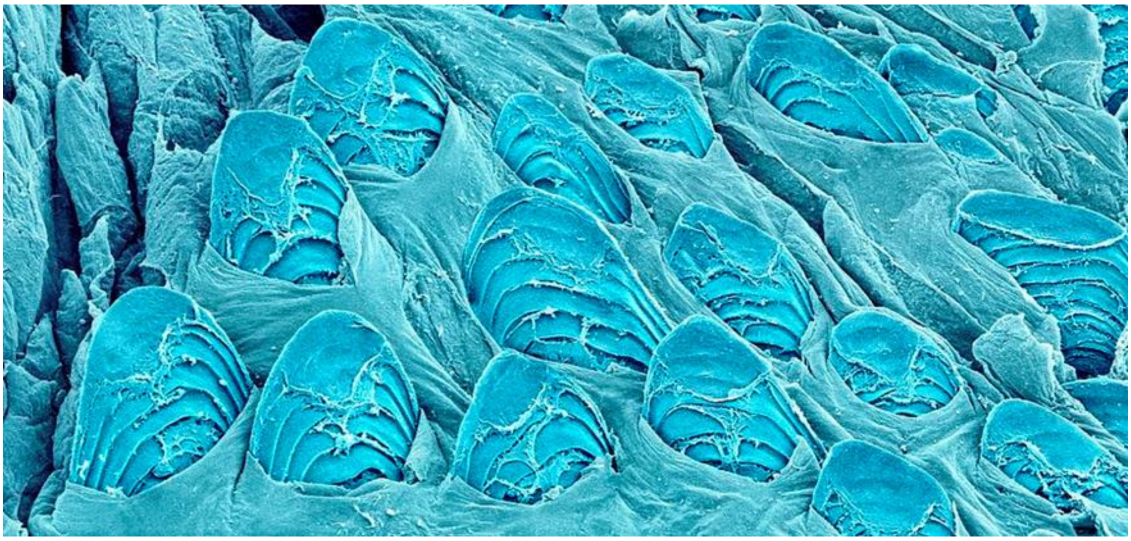

Figure 8. Fish scales, coloured scanning electron micrograph (SEM) (Library 2014).

A mineralized outer layer covers elasmoid scales, granting penetration resistance through its hardness. A more ductile inner collagenous lamellae layer follows a Bouligand-type pattern, generating deformability to accommodate excessive deformation – providing higher strength and involving *"(...) the breakage of more interfaces during the plastic deformation, which is vital for toughening the material."* (Yang et al. 2019).

"The thicker lamellae can not only provide higher strength due to the larger number of collagen fibrils but also involve the breakage of more interfaces during the plastic deformation, which is vital for toughening the material." (Yang et al. 2019).

A fundamental parameter bridging hardness and strength is fracture toughness, which is to say, the capacity a material has to forgo the generation of cracks when burdened (Yang et al. 2019).

As was stated before, fish scales' collagen fibers are often densely stuffed lamellae arranged in different directions, building a plywood-like structure. Crack deflection and bridging across different lamellae are governed by toughening mechanisms, as can be seen not only in fish scales but also in nacre and conch. This means natural arrangements can have concurrent features as high stiffness and toughness through deflecting cracks, alongside with considerable strength depending on lamellae orientation (Le et al. 2019).

Collagen fibrils (~100 nm diameter) are organized similarly to a hexagon-shaped arrangement, comprising the lamellae (~50 mm thick.) (Yang et al. 2019).

Thus, it can be concluded that fish scales toughness *"(...) results from multiple deformation mechanisms acting in concert in the twisted plywood structure of the scale, involving the collagenous lamellae at varying orientations retarding crack advance through stretching, reorientation, delamination and shear, and fracture."* (Yang et al. 2019).

Arapaima scales seem to undoubtedly exhibit a higher toughness when compared to other fish scales, which might linked with the scale thickness and a higher degree of mineralization, that are both indispensable for protection from piranha attacks (Yang et al. 2019).

Arapaima gigas fish scales were also tested in both dry and hydrated conditions. Results have shown *"(…) an elastic modulus of 1.2 GPa and 0.1 GPa, and a tensile strength of 47 MPa and 25 MPa under dry and hydrated conditions, respectively. The hydrated scales showed much higher deformation prior to failure, whereby the failure strain was less than 10% under dry and 30–40% under hydrated conditions. This indicates that the scales required high flexibility to flex with the body of the fish during swimming."* (Le et al. 2019).

2.4. Analysed methods

It was necessary to divide the different types of processing of fish scales-made materials to organize the collected information. These were divided between noncompound and composite materials, which were ordered chronologically in the following tables.

Table 1. Analysed documents referring to non-composite materials.

NONCOMPOUND MATERIALS	
(Simmonds 1879).	Other fish products and their uses.
(Ramachandran 1989).	Processing of fish scales for ornamental Use.
(Souza et al. 2013).	Avaliação espectroscópica e quimiométrica de escamas de tilápias submetidas a diferentes tipos de lavagem para aplicação no artesanato.
(Costa et al. 2016).	Aproveitamento de resíduos de pescado: o artesanato com escamas de peixe.
(Carter 2017).	Icelandic designers turn dried fish into uggi lights.
(Andrade et al. 2018).	Zooartesanatos de pescados e seus subprodutos comercializados em Santarém (PA)
(Morris 2019).	Cast bronze furniture by Campana Brothers channels the story of Noah's Ark

Table 2. Analysed documents referring to composite materials.

COMPOSITE MATERIALS	
(Reaumur 1716).	Observations Sur La Matière Qui Colore Les Pierres Fausses, et Sur Quelques Autres Matières Animales d'une Semblable Couleur à l'occasion de Quoi on Essaie d'expliquer La Formation Des Écailles Des Poissons.
(Smith 1799).	Of Artificial Pearls
(Shaw 1804).	Bleak.
(Percy and Percy 1826).	Anecdotes of Ingenuity.
(Ure 1868).	Pearls, Artificial.
(Balfour 1885).	Pearl
(Hanano, Wildman, and Yurkiewicz 1990).	Majorica Imitation Pearls.
(Eng and Fusco 2012).	Fish scales and faux pearls: A brief exploration into the history of manufacturing faux pearls
(Etherington 2011).	The Fish Feast by Erik de Laurens.
(Aouf 2019).	Fish Scale Bioplastic Wins UK James Dyson Award for Student Design.
(Kara et al. 2019).	Bioactive Fish Scale Incorporated Chitosan Biocomposite Scaffolds for Bone Tissue Engineering.
(Razi, Islam, and Parimalam 2019).	Mechanical, Structural, Thermal and Morphological Properties of a Protein (Fish Scale)-Based Bisphenol-A Composites.
(Nilsuwan et al. 2019).	Properties of Fish Gelatin Films Containing Epigallocatechin Gallate Fabricated by Thermo-Compression Molding.

This step was followed by the characterization of the used material/technique; of the type of resources that are needed to manufacture it; of its production process; of prospects/potential for product application; of its scale and perspective regarding sustainability; and of the context that motivates its production/creation.

Non-compound materials were analysed. Two of those examples refer to the use of fish skin (one of which refers specifically to the use of Amazonian fish skin) to produce leather.

These documents do not contemplate the process or equipment implicit in the production of this fish leather. Technical skills would be needed for producing it. This material (Simmonds 1879) was once commercialized as decorative or small household objects, attires, bags, shoes; and adornments as an abrasive material. The second example (Morris 2019) refers to Campana Brothers' Piracuru armchair (Noah series), exhibited Hybridism, that took place at the Carpenters Workshop Gallery in London. Its production process involves upholstering, a technique that requires specific technical skills.

Dried cod skin is also addressed (Carter 2017). Its process involves hand skinning the fish and remodelling it according to its original shapes (which both require technical knowledge) and finally hanging it up and leaving it to dry. The fish processing is manual and the material is biodegradable. It was used to design Lamps (Fanney Antondsdóttir and Dögg Guðmundsdóttir), exhibited during DesignMarch 2017.

These are followed by other examples of noncompounds, which were assembled to other materials.

These cases (Ramachandran 1989; Souza et al. 2013; Costa et al. 2016; Andrade et al. 2018) refer to fish scales handicraft, combined with the use of standard metal parts, threads and beads (the last mentioned elements are of optional use). This is a meticulous work of small dimension. The fish scales are washed under running water (some processes involve the use of acids), submitted to using natural and artificial dyes and cut (the latter two are also optional). The fish scales are pierced and in some cases attached to metallic elements; threads and beads are added for aesthetic purposes only. This technique is used to produce personal ornaments and decorative household objects. Metal parts (recyclable) and other components are separated from the fish scales (biodegradable). Its production takes place in workshops related to the fishing community, and the pieces are mostly sold to tourists.

Another market niche was found in documents that provide information on the production of fake pearls through the use of fish scales, among other materials. These documents seek to explain and add contributions to the production of these artificial pearls that were and still are are used for personal and attire adornments.

The first examples (Reaumur 1716; Smith 1799; Shaw 1804; Percy and Percy 1826; Ure 1868; Balfour 1885; Eng and Fusco 2012) describe a technique using fish remains, ammonia, isinglass derived from sturgeon, hollow glass blown beads and wax. It involves a meticulous work of removing scales and producing Essence d'Orient. Expertise is decisive to perform glass blowing. The process depends on long lasting manual labour. It first foresees removing, washing and rubbing fish scales on a horsehair sieve. Several affusions of water are needed to finally obtain the Essence d'Orient. Ammonia and a solution of isinglass derived from sturgeon are added. Glass blowing is necessary to produce thin hollow glass beads. The mixture is dropped inside the hollow glass bead, while hot. The bead is agitated and finally it is filled with wax, after which it is bored with a needle. Monsieur Jaquin, a French rosary maker, is known for having established an artificial pearl manufactory in which these false pearls were produced and supplying all Europe.

Another document (Hanano, Wildman, and Yurkiewicz 1990) describes a similar process involving the use of fish remains, ammonia, Isinglass derived from sturgeon with colouring and binding agents, hollow glass nucleus and acid. In this case, manual labour is combined with machinery that used for fish scales removal, leaving the fish in marketable conditions, and to produce glass nucleus. First, the glass nucleus is produced and put in an acid bath. It is exposed to Essence d'Orient successive coatings, mixed with colouring and binding agents. The pearl is gradually polished and submitted to a final coating. Majorica pearls are known since 1951, after the Heusch family moved their factory to Majorca.

Composite materials can be looked at as an innovative path to create sustainable products including them in the market, while following circular economy principles *"(…) as a convenient solution to meet the goals of sustainable development."* (Saidani et al. 2019).

Thus, composite materials have been playing a fundamental role in the transformation of product design as we know it. Other found documents, which fit into the category of composites, imply knowledge in the handling of specific machinery; their production processes are vaguely specified.

Two of them involve a thermo-compression moulding process. In the first case (Etherington 2011), a fish-scale-plastic with no exterior binding agents is produced. It foresees the use of simple industrial equipment to simultaneously press and heat the fish scales; colouring is optional. This material is biodegradable. Erik de Laurens was asked to design objects for the canteen of a primary school (Macassar, Cape Town): therein he created The Fish Feast, displaying googles, beakers, spectacles and an inlayings. Another example is given (Nilsuwan et al. 2019) considering fish gelatin and epigallocatechin gallate (EGCG) fabricated films, created to produce food packaging. This material has can potentially be used for pharmaceutical applications.

Another example (Aouf 2019) shows a bioplastic made of fish waste: fish scales, fish skin leftovers and organic agar, considering a low-energy production process. It is Biodegradable (breaking down in four to six weeks in home composts or food-waste bins) and can be used for single-use packaging. Developed by Lucy Hughes, this bioplastic won UK James Dyson Award for Student Design.

Next (Kara et al. 2019a), a bioactive fish scale incorporated chitosan biocomposite scaffold is described. It combines the use of decellularized fish scales (biological macromolecules), physically fragmented into microparticles to be incorporated into a chitosan matrix. It can also be used for producing plastic bags and for potential bioactive reinforcement in polymeric scaffolds for bone tissue engineering applications.

The final example from this section refers to a Bio-composite made of fish scale (bio-filler) blended with epoxy resin (Razi, Islam, and Parimalam 2019). In this case fish scales were previously heated and submitted to acetic acid.

2.5. Market Research

The natural universe that surrounds us has long been undeniably inspiring for object creation. Here we discuss how its presence has been and still is a fundamental for the creative process that underlies behind every artefact.

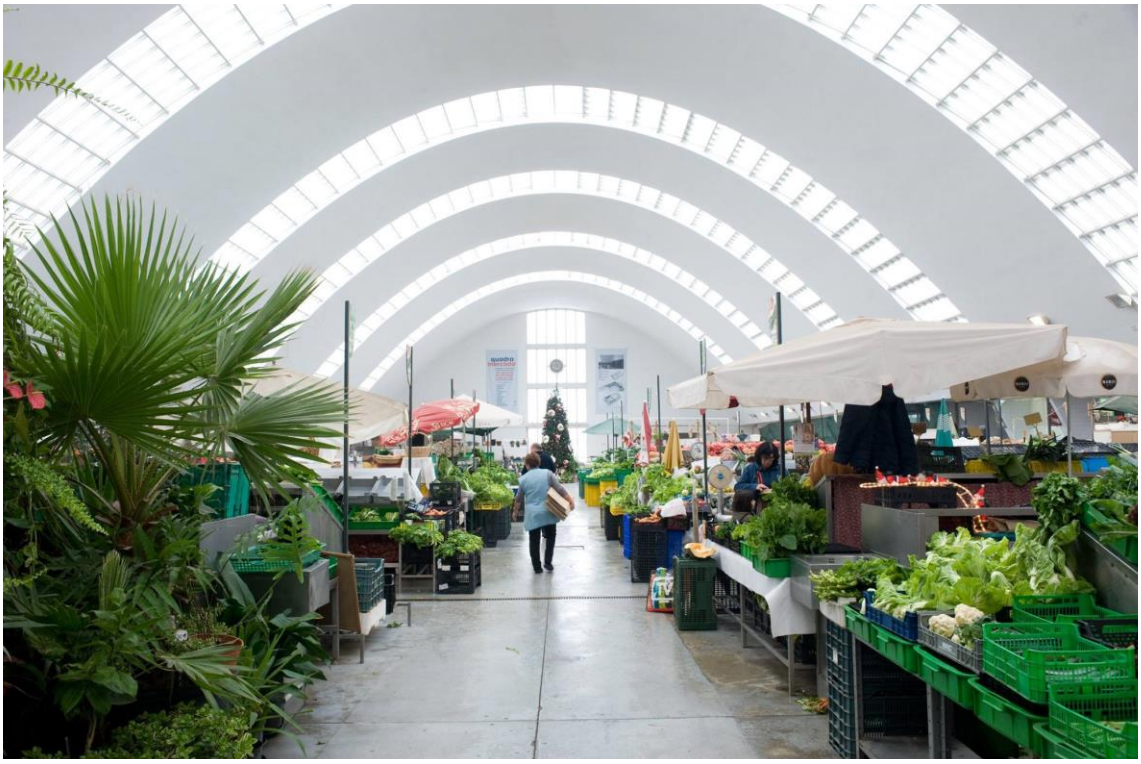

Figure 9. Municipal Market of Matosinhos, Portugal. ("Mercado Municipal de Matosinhos" n.d.).

Figure 10. Fish scales for Marinatex, developed by Lucy Hughes in 2019. (Hughes 2019a).

Knowing what has already been done with fish scales has opened new paths for this research project investigation and provided useful insights for the practical case project development and its creativity process.

The importance of knowing references from distinct backgrounds is shown in the work of several authors who work in different areas of artistic expression. The metaphorical, ironic, humoristic construction of Oswald de Andrade in Manifesto Antropofágico (Madeira Filho 2006), in which anthropophagy is socially elevated and defended as a necessary element of cultural reciprocation. Furthermore, a similar catharsis can be seen in the exhibition Panorama by Konstantin Grcic, which shows a world of idiosyncratic full of visual references; Grcic withdraws preconceived ideas and references the most diverse spheres of creation in unison. Cultural memory enables him to expand his vocabulary and apply it throughout his work *"He finds forms of expression for risk or fear, for the inversion of dystopia and utopia (...)"* (Kries and Lipsky 2014).

Likewise, Hybridism by the Campana Brothers, exposes a dystopic world of references that will be discussed later. The artists' work is presented as a result of a process of acknowledging the mixture and coexistence (as the exhibit's name suggests) of different cultures, languages, materials, forms, textures, sources, techniques and craftsmanship. This aspect will follow (Morris 2019).

Market research came as an approach that manifests the importance of object examination as a catalyst to explore the history of fish scales manufacturing technology, while exploring its historical context. Products made from fish leftovers are prompted by the fact that tons of fish derivatives are daily wasted in the fishing industry.

"The UK Sea Fish Industry Authority calculates that the country produces nearly 500,000 tonnes of waste annually through fish processing," (Aouf 2019).

The main terms composing the research question are the following: *fish scales, cycloid scales, ctenoid scales, fish integument, fish integumentary system; jewellery, jewelry, jewel, adornment, personal ornament.*

Jewellery was studied through information on different jewellery techniques and application of natural materials, also referring biomimicry as an important way to communicate the relation between body worn elements and the natural world. Ancient and contemporary jewellery were addressed to provide examples on what is being produced and compare that with what was before created for the human body. Documents were analysed since 1888 to 2020. A bigger time span was considered for this subject since it was an objective to compare ancient artefacts with contemporary ones.

The most common procedures to produce fish scales handicraft imply washing the scales with running water, which may be followed by *"(...) clarifying and degreasing chemicals such as detergents, bleach, soap, among others."* (Souza et al. 2013).

These chemical treatments will transform the fish scales' colour, which is believed to be caused by the changes of chemical properties occurring in the material. Different shades may be induced, depending on variables such as the type of chemical that is used, in what proportion it is applied, the number of washing cycles, the time of immersion, among others. (Souza et al. 2013).

"Fishermen, particularly the rural ones, can augment incomes by establishing their own production lines on a cottage industry level without much capital investment." (Ramachandran 1989).

Products that were made of fish scales, but also fish skin, among other leftovers, were investigated: both artefacts and techniques were considered and analysed. The present section catalogues the following examples: fish scales handicraft, depicting one handmade piece that represents cut fish scales handicraft in Azores (Portugal); the production of fish-glue, of jewellery and decoration artefacts, through techniques that involve crushing and rubbing the scales; the manufacturing of faux pearls made of glass beads and fish scales and other fish residues, for which three different techniques are described; two kinds of fish scale biocomposites; fish gelatin films fabricated by thermo-compression moulding and a material exclusively made of thermally pressed fish scales; a fish scale bioplastic; the use of fish skin as an abrasive material, and the production of Shagreen leather to produce decorative or small household objects, attires, bags, shoes and adornments; two examples are shown for the usage of fish skin to produce lamps and furniture.

Fish processing for the food industry generates a large volume of residues, such as the fish's head, fins, skin, scales, and viscera. Fish scales are considered an abundant material which is still to be further explored by the scientific community (Souza et al. 2013).

The sum of fish scales leftovers seems to have inspired coastal regions around the world to manually make house decoration pieces, personal ornaments and adornments, among others. Azores archipelago is no exception, as can be seen in Figure 11, which shows a decorative set of fish scales that are cut and arranged to resemble flowers and leaves. This kind of art may be called *zooartesanato*, as it is a craft that takes animal leftovers as its raw material (Andrade et al. 2018).

Figure 11. Fish scales handicraft, Azores (*"Artesanato: Escamas de Peixe."* n.d.).

Several attempts have been made *"(...) to process and dye scales for ornamental purposes, such as making decorative wall fixtures, artificial flowers and greeting cards."* (Ramachandran 1989).

These delicate pieces reveal not only entrepreneurial but also ecological perspectives through the decision of reusing discarded materials.

"The fish waste processing technique is an alternative to reduce the negative impact caused by the disposal of such material in garbage dumps, landfills, ponds, margins and unsuitable environments." (Costa et al. 2016).

Fish scales are often collected among the fishing community to hold training workshops on production of handicrafts (Costa et al. 2016). Pierced fish scales can be cut or used in their original shape, and are most often attached to metallic elements, connected to each other though very fine silvery threads with beads, or even both. Creation is herein triggered by the fact that fish scales are understood as attractive elements per se, and fish diversity (different shapes, textures, colours and sizes) certainly plays an exhilarating role in artisans' virtuous work.

Ornaments and jewellery made of fish scales are commercialized as artefacts that come to value the traditional practices of coastal regions, bringing equity to small-scale fisheries through the hands of local artisans (Andrade et al. 2018).

These are interesting examples of Nature's influence on the creation of artefacts: a natural material is chosen to operate the mentioned handicraft technique, yet their motif is found elsewhere, which is to say seeking inspiration in terrestrial ecosystem, instead of an aquatic one, and alluding to flora through portrayed flower sets.

As Peter Simmonds would refer in *"Other Fish Products and Their Uses"* (1879), several uses have been given to this material other than the decorative ornamental flowers made of cut fish scales: fish scales have also been used to produce fish-glue to reinforce and coat ribands; to produce other kinds of parures and ornaments that wore once broadly sold at the Crystal Palace, London. The author speaks of a diadem made from fish scales and eyes that was sent as a gift from the Royal University of Norway to the Smithsonian Institution, in Washington (Simmonds 1879).

The author also refers a technique used at Newark, in United States, in which fish scales are first imbued in a solution of marine salt for one day. *"They then undergo five or six washings in distilled water, which is renewed every two or three hours. Each scale is then separately dried with a clean cloth, and lightly pressed and left to dry. Finally, they are macerated for an hour in alcohol, and rubbed dry. They then appear like mother-of-pearl, and for a firm and elastic consistence."* (Simmonds 1879).

The scales can be plain or coloured, and are used to produce artificial flowers and marquetry articles, among others. The Chinese are said to have a unique way of crushing fish scales *"(…) to give a brilliancy to parts of pictures."* (Simmonds 1879).

Although cultural values differ a lot depending on their context, it is known that pearls were (and still are) desirable and sought for throughout the ages, as can be illustrated by several portraits of important figures such as Queen Elizabeth I (Eng and Fusco 2012).

The Art of making false pearls has long been sought as an affordable alternative to the use of expensive natural pearls, and it could only be achieved through ill-regulated imagination of the curious (Reaumur 1716).

In the mid-nineteenth century, several attempts would successively appear to mimic natural pearls and their shiny nacre surface, as can be seen in the following figure (Eng and Fusco 2012).

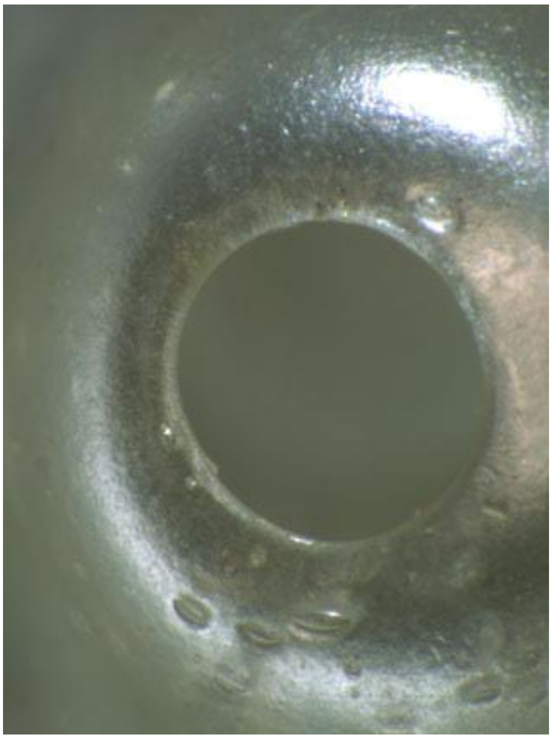

Figure 12. a) (left) Digital micrograph of hollow bead showing even application of coating and bubbles orbiting the beadhole. Los Angeles County Museum of Art M.2007. Photograph: Keyence digital microscope: Maria Fusco © LACMA ("Digital Micrograph of Hollow Bead Showing Even Application of Coating and Bubbles Orbiting the Beadhole." 2012).

Figure 12. b) (right) Faux pearls in a floral motif. c. 1830. Photograph: Yosi Pozeilov © LACMA ("Faux Pearls in a Floral Motif" 2012).

A technique is described (Percy and Percy 1826) in which globules of glass are manufactured and covered with a material that was identical to natural pearls' appearance. Soon it was found that the pearly gloss would disappear when influenced by heat. However, once having removed fish scales, and saving the water with which they are washed, it was found that a certain sediment in that water would settle, and with it it was possible to obtain an alluring powder, This essence, later called *Essence d'Orient*, would be of a great use in a slightly distinct process in which the essence would be applied in the interior hollow glass beads.

It is believed that this essence was discovered in the seventeenth century, having been first used by Monsieur Jaquin – a French rosary maker (Eng and Fusco 2012).

Although this technique can be applied with other types of bright-coloured fishes, it is a small common fish in the Seine called Ablete, french for Able (Albula), shown in Figure 13, that was first used to prepare artificial pearls. The latter are known to have been originally produced in Paris, a city that *"(…) has long been famous for this elegant manufacture (…)"* (Shaw 1804).

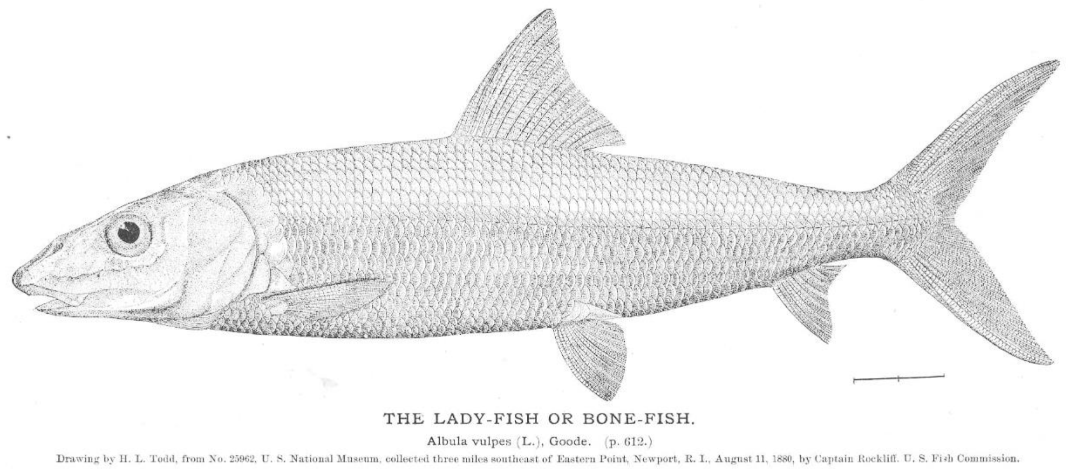

Figure 13. Albula vulpes, also called Lady-Fish or Bone-Fish (Todd 1884).

After delicately scraping off the scales from the fish's belly, one should *"Wash and rub these in fair water, changing the water, and permitting the several liquors to settle: the water being carefully poured off, the pearly matter will be found at the bottom, of an oily consistence, named by the french essence d'Orient."* (Smith 1799).

This solution, that may be received on a horsehair sieve, is known to formerly lubricate the fish scales. *"(…) the mucus or essence (guanine) sinks to the bottom of the tub and appears as a very brilliant blue-white oily mass."* (Simmonds 1879).

Several affusions of water are needed to obtain the thick liquor, which colour resembles that of natural pearls, that is kept in a glass container (Reaumur 1716).

Fishermen were said to *"(…) seal it in tin boxes with ammonia, and in this condition send it to Paris. If a drop of the essence be taken up by a straw and let fall upon water, it floats, giving forth the most brilliant colours."* (Simmonds 1879).

If observed under a microscope, these very small regular bodies can easily be distinguished from the liquid in which they swim (Reaumur 1716).

It was then determined that *"(…) the iridescence is caused by minute crystals embedded in the skin covering the fish scales."* (Hanano, Wildman, and Yurkiewicz 1990).

"The iridescence effect is caused by light interaction with multiple layers of these crystals in the cytoplasm. The shape of the crystals is such that they act like tiny mirrors so that the light reflecting off them is identical to background light which helps the fish hide from predators in open water." (Eng and Fusco 2012).

Regardless of the fish that is used, these crystals have always been found to have the same shape and brilliant silvery tone, which can sometimes approach golden hues. Reaumur (1716) would add that *"Nothing compares to the vividness of the colors of certain fishes which have just been fished; they still owe it to our silver matter."* However, after the fish is pulled from the water, its vessels dry up and lose their transparency, so the silvery matter no longer has the same appealing effect.

Essence d'Orient is not only composed of the shiny blades mentioned before; it also contains parts from the fish's vessels and membranes and associated cells that enfold these silvery elements (Reaumur 1716).

A solution of isinglass is then added to the essence. Glass beads (pale rose, blueish and other colours can be used) are very thinly blown, which a worker carefully blows with a blowtorch once he has put a drop of the previously referred mixture inside. The latter is agitated, creating a movement that spreads the liquor over the interior walls of the bead (Reaumur 1716).

When this mixture - which is similar to a varnish - dries, the glass beads are filled with wax. Wax gives them weight, solidity and security (Balfour 1885).

These small globules exhibiting the iridescent reflections of mother of pearl are bored with a needle, creating two opposite holes. and applied to jewellery pieces (Ure 1868).

Essence d'Orient was disclosed, along with the process of manufacturing these false pearls, thanks to the naturalist René-Antoine Ferchault de Reaumur (Eng and Fusco 2012).

"The use of essence d'orient coating on the inside of glass beads demonstrates the great effort and creativity involved in making an affordable substitute for such a rare natural 'gem'." (Eng and Fusco 2012).

The process of producing these artificial pearls mirrors an exhaustive search and a hard, virtuous work in mimicking the natural gems, to an extent that one can hardly distinguish them of those which are the work of Nature (Reaumur 1716).

Manufacturing these artificial pearls implied the work of men who possessed great dexterity (Ure 1868).

"(...) though one man would blow six thousand of these globules a day, Jaquin gave employment to a great number of hands, and established an artificial pearl manufactory, that supplied all Europe." (Percy and Percy 1826).

The majorica imitation pearls are also known for a different process of producing artificial pearls, in which that same technique is applied.

When Eduardo Hugo Heusch first established a small factory in Barcelona, he started producing imitation pearls which consisted of glass beads coated with man-made resins. Over time, the Heusch family moved their factory to Majorca, where a more elaborate technique was developed. In 1951, the Majorica pearls (Figures 14 and 15) as they are known today were created. They can be round, but they can have other shapes; their size ranges from diameters of 1mm to 22mm. Colours vary between cream rose, white, black, and gray. (Hanano, Wildman, and Yurkiewicz 1990).

Figure 14. Majorica pearl necklace advertisement: 'We're not knocking oysters... we think they're delicious.' 1964 ("Majorica Pearl Necklace Advertisement" 1964).

Figure 15. Majorica Classic pearl necklace ("Majorica Classic Pearl Necklace" n.d.).

Majorica pearls are produced through gradually dipping a glass bead nucleus (grading from translucent to opaque) in a Essence d'Orient coating. First, a glass ball is formed onto a rotating metal wire: larger and pear-shaped nuclei are still manually produced by specially trained technicians; the smaller round ones are produced thanks to special machinery that has replaced what once were the joint efforts of about 240 workers. These pearls are then checked for roundness and placed in an acid bath that dissolves the metal wire. They are separated according to their size. The nucleus is coated with Essence d'Orient, also called Pearl Essence, that is mixed with colouring and binding agents. *"Majorica S.A. has developed special machinery that removes the necessary fish scales while leaving the fish in marketable condition for the food industry."* (Hanano, Wildman, and Yurkiewicz 1990).

This translucent material is consecutively applied to the bead in multiple layers that are always followed by polishing, except for the final coating that hardens it, while protecting it from ultraviolet radiation and giving it a finished look. A surface is created that is appealing for its prismatic colours that resemble saltwater cultured pearls (Hanano, Wildman, and Yurkiewicz 1990).

A Bioactive fish scale incorporated chitosan biocomposite scaffold (Figure 16) has been developed for bone tissue regeneration. Fish scales (biological macromolecules) were found to have cytocompatibility; they were decellularized and physically fragmented into microparticles to incorporate into a chitosan matrix, originating scaffolds of a uniform, high porosity. Its microparticles have structural similarity with bone and *"(…) can be considered as a potential bioactive reinforcement in polymeric scaffolds for bone tissue engineering applications."* (Kara et al. 2019a).

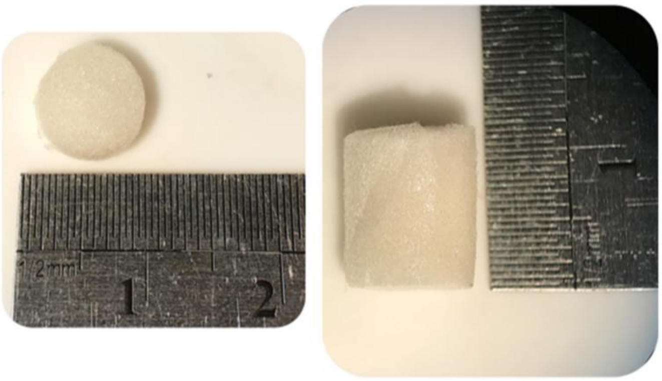

Figure 16. Stereomicroscopy images of Chitosan and Fish scales composite scaffold (Kara et al. 2019b).

Bio-composites made of fish scale blended with epoxy resin were prepared and tested according to different percentage of fish scales. Fish scales act as a bio-filler and provide flexibility. Additionally, they perform as a stimulator for composites degradation. Fish scales were previously heated and submitted to acetic acid (Razi, Islam, and Parimalam 2019).

An alternative composed of fish gelatin and epigallocatechin gallate (EGCG) fabricated films, through thermo-compression moulding process, is also presented, The last reffered process enables the reduction of production times. These gelatin films could be applied in food packaging or pharmaceutical applications, as they combine characteristics such transparency, *"(...) rendered compact structure, mechanical resistance, high UV-light barrier, thermal stability, and integrity after water immersion, as well as a controlled bioactive release and antioxidant activity."* (Nilsuwan et al. 2019).

Similarly, De Laurens has created a fish-scale-plastic with no exterior binding agents that was produced under heat and pressure. This material can be found in a range of colourful objects such as googles (Figure 17), beakers, spectacles and an inlaid table that are all part of The Fish Feast; a fish leather water dispenser could also be found. This project inherits the artist's childhood lively memories and takes inspiration from the by the large amount of discarded scales in the fishing industry. Through it, De Laurens sought to evince the potential use of leftovers arising from industrial flaws (Etherington 2011).

Figure 17. Erik de Laurens, The Fish Feast, 2011. Thermally pressed pigmented fish scales (Laurens 2011a).

MarinaTex (Figure 18) is a fish waste bioplastic developed by Lucy Hughes. The material is composed of fish scales and skin leftovers and an organic agar (culled from some species of red algae) binder. It combines several appealing features such as being compostable (breaking down in four to six weeks in home composts or food-waste bins), strong (featuring a higher tensile strength than low-density polyethylene), flexible, translucent, and implies a low-energy production process. It is an interesting material for single-use packaging (Aouf 2019).

Figure 18. Lucy Hughes, MarinaTex bioplastic bag (Hughes 2019b).

Fish skin is known to be used for the manufacture of different kinds of objects (Figure 19).

The latter referred material (Figures 20 - 22) ranges between smooth and rough, uniform and regular, with and without spots depending on the fish, Scale or spine marks provide unique patterns to fish skin. Colours vary between shades of black, green, white, and red (Simmonds 1879).

"The skin of fishes is chiefly gelatinous, and is easily soluble in water; but some is of a firmer, stronger, and more useful character." (Simmonds 1879).

Fish skin is known to be used like emery paper to soften different materials, and is also used for polishing wood, ivory and metal surfaces. Shagreen leather (also known as galuchat) would be used to cover boxes and cases, and to produce gloves, purses, bags, garments, shoes, watch cases, penholders, *"(...) large office-table inkstands, candlesticks, boxes and caskets, paper knives, reticules, card-cases, frames for photographs, bracelets, scent-bottles, etc."* (Simmonds 1879).

Figure 19. The Fish Feast, Erik de Laurens (Laurens 2011).

Figure 20. Workers processing fish leather for the Blue Fashion show, Nairobi. (Show n.d.).

Figure 21. Soaking salmon skins and scraping the scales as part of their tanning process (Hinkel n.d.).

Figure 22. Fish leather, NYVIDD (NYVIDD n.d.).

Fanney Antondsdóttir and Dögg Guðmundsdóttir's long-lasting Uggi lights (Figure 23) are also a great example depicting the use of fish skin. These pieces were exhibited during DesignMarch 2017. They are made from dried cod skin, exhibiting the Icelandic tradition of preserving fish. This series of lamps mirror the duo's cultural identity. The fish are first caught and hand skinned, after which they are remodelled to acquire the original shapes, and finally they are hung up and left to dry (Carter 2017).

Figure 23. Fanney Antondsdóttir and Dögg Guðmundsdóttir. Uggi lights. Dried cod skin. Limited edition. Length between 80-90cm (Antondsdóttir and Guðmundsdóttir 2017).

Hybridism, a Campana Brothers' exhibition, took place at the Carpenters Workshop Gallery in London. This show depicted sculptural, surrealistic, animal-like and mythology-inspired furniture called the Noah series. The set of 13 artefacts in cast bronze and aluminium, woven strips of fabric and fish leather came as a result of an extensive research into integrative materials and production processes. The Sereia Pirarucu lounge chair is made of Amazonian fish skin. Its name, alongside with the flaking anthropomorphic aesthetic, make reverence to mermaid mythology. Pirarucu armchair (Figure 24) is made of a cast bronze structure and upholstered with discarded fish skin (Morris 2019).

Figure 24. Campana Brothers, Pink Piracuru Armchair (detail). Piracuru leather, bamboo. Limited edition. 95x37.4x120cm (Brothers 2019).

2.5.1. Hot pressing technique

After analysing the existing methods for handling and processing fish scales, there was a need to focus on hot pressing as a technique.

In this case, only hot pressing was considered for this research, since it was known that this kind of equipment (Figure 25) would be available to perform the processing of fish scales in the future. The following Figure showcases the kind of equipment that would be necessary to carry out this technique.

Figure 25. a) (left) BLAZE 120: Hydraulic hot press for pressing laminates, veneer onto mdf, plywood and chipboard. Biesse (Biesse n.d.).

Figure 25. b) (right) Manual hydraulic hot press ("25T Hydraulic Lamination Hot Press with Dual Temp. Controller & Water Cooling Jacket up to 250°C n.d.).

It was understood that the simultaneous application of temperature and pressure (which is applied uniaxially) allows to increase the plastic flow and the densification process of the used material. The latter will reach a higher density at the end of the process, according to the time of exposure to heating and pressing.

The scheme in Figure 26 helps showcasing how the referred technique works. (Torralba 2014).

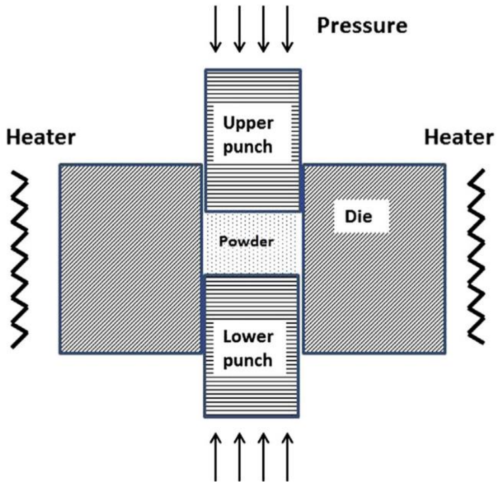

Figure 26. Hot pressing scheme. (Torralba 2014).

This technique is known to help both producing biocomposites and optimizing of materials properties.

"A new generation of organic / inorganic composites is offering a promising approach for creating biocompatible and biodegradable materials with mechanical properties that match that of human bone better than traditional metallic implants." (Russias et al. 2006).

Hot uniaxial pressing is widely used for biomedical applications such as prosthetics. Hydroxyapatite often used to enhance osteointegration and a list of its possible applications follows - densifying hydroxyapatite (HAP) (Halouani et al. 1994; Kim, Seo, and Lee 2008), creating ceramic-polymer biocomposites that combine HAP with materials such as poly-L-lactide (PLLA) (Nenad Ignjatović et al. 1999; N. Ignjatović et al. 2001; Russias et al. 2006; Gay, Arostegui, and Lemaitre 2009), poly-L-lactic acid (PLA) (Kasuga et al. 2000; 2003) or polypropylene (PP) (Younesi and Bahrololoom 2009; 2010); combining HA with tricalcium phosphate (TCP) or biphasic calcium phosphate (BCP) (Raynaud et al. 2002; Tang et al. 2004); creating HA-collagen composites (Uskoković, Ignjatović, and Petranović 2002); creating HA/alumina/diopside ceramic composites (Xihua et al. 2009); producing HA-polymethylmethacrylate (Pattanayak, Rao, and Mohan 2011); polyetheretherketone (PEEK)-hydroxyapatite (Ma et al. 2014).

Hot pressing technique is also known to aid panel formation of wood composites; articles were found on hot pressing MDF (Carvalho and Costa 1998; Nigro and Storti 2001; Madhoushi and Shahrebabak 2017), kenaf core binderless boards (Okuda, Hori, and Sato 2006).

This technique is also known to be applied on flax fibre reinforced polyamide biocomposites (Amenini et al. 2019), on zinc powders (Schuh and Dunand 2002; Gorokhova et al. 2008), aluminium composites (Nofar, Madaah Hosseini, and Kolagar-Daroonkolaie 2009; Montes et al. 2012), nanocomposites (Jiang et al. 2009), silver-functionalized silica aerogel (Ag0-aerogel) (Matyáš et al. 2016), This process will change materials features depending on their miscrostructure. Some of those features may be density, flexural strength and fracture toughness, elasticity modulus, compressive strength, tensile strength, porosity, humidity, crystallinity, luminescence depending on the materials and their microstructure. (Halouani et al. 1994; Nenad Ignjatović et al. 1999; N. Ignjatović et al. 2001; Tang et al. 2004; N. Ignjatović et al. 2005; Younesi and Bahrololoom 2010; Carvalho and Costa 1998; Gorokhova et al. 2008).

2.6. Brief

It is clear that the use of fish leather has been known for a long time, and it still is nowadays, which may mean that this kind of material has great potential for the production of artefacts since it is strong and can portray different appearances depending on the fish and its scales' natural patterns and textures. Of all the analysed processes, the fish scales handicraft is the simplest to produce as it does not imply the use of specific machinery or tools to perform it. It is also the best example for a sustainable perspective. Unfortunately, these ornaments appear to be fragile when compared to the other analysed materials. The composites group is in some cases characterized by an industrial production process: although in some cases only a small type of machining is necessary. The energy spent in machining this kind of materials may be balanced by the fact that some of those are biodegradable. The production of false pearls from fish scales implies the slowest production process in comparison to all the others.

3.

3.1. Previous research

It is important to mention that this thesis comes after a project that was previously carried out during the Master in Product and Industrial Design.

According to the proposed briefing, in the first year of this course students had to make products from discarded materials to create innovative products for a sustainable, socially inclusive project named We Won't Waste You (WWWY),

The goal was not only to design regarding social and environmental aspects, but also to focus on the identity of Matosinhos, a Portuguese fishing town. Discarded fish scales were thought of, since they symbolically allude to the Portuguese fishing tradition.

The conceived project consists of the development of two jewellery lines – each one depicting a distinct technique – produced from fish scales that were collected among local fishmongers.

The first to be explored consists of fish scales that were included in layers of glass, and finally fused together along with brass. Maré collection (Maré means *tide* in Portuguese) arose from this technique (Figures 27 and 28).

Figure 27. Maré pendant. Fused glass with fish scales; brass. 2018.

Figure 28. Maré pendant and earrings. Fused glass with fish scales; brass. 2018.

A second jewellery line called Escama (portuguese for scale) was created from the thermal pressing of fish scales (without any added binders); these elements were later attached to brass pieces as can be seen in the following figures.

Figure 29. Escama earrings. Thermal pressed fish scales; brass. 2018.

Figure 30. Escama earrings. Thermal pressed fish scales; brass. 2018.

3.2. Methodology

The adopted methodology firstly implied the development of a concept for the practical project, based on the scientific and exploratory research that had been carried out before. This acquired knowledge was then linked to the field of jewellery: a previous research of the techniques that could be involved and adapted to such a practical project, based on the usage of pressed fish scales as an innovative material, was taken into account. The choices that were performed throughout the process, at the conceptual level and regarding technical solutions, led to a research on the techniques that were carried: this meant having a closer look at the uniaxial hot pressing technique, for a better understanding of fish scales processing.

The idealization of jewellery pieces was supported by quick drawings or more detailed ones; it was also inspired by found marine ropes, fishing nets parts and small chains, as well as different types of self-adornment in the form of earrings, necklaces, bracelets, pendants, pins, cufflinks, among others.

This phase was followed by analysing and testing the ideas that were considered most relevant. Some of them were immediately discarded due to their production complexity, which at the outset would dramatically increase the price of the jewels to be created. In the workshop, various jewellery techniques were considered and tested to lead to an understanding of the production processes to be chosen regarding their feasibility or the advantages they present in relation to other processes. The material to be used alongside with the fish scales was also directly related to the type of manufacture that was chosen. The relation to the human body (e.g. weight of each jewel), a sustainable, ethical approach, materials costs, production costs, time of production and complexity of production, aesthetic analysis, among other factors, were always considered through this process and would change significantly according to the materials and techniques to be considered in each case scenario.

The precious metal that was chosen to complete the pieces as jewels - given all the production techniques that this implies - complemented the thermally pressed fish scales through a symbiotic relationship.

A general reflection was made on the developed practical project, encompassing its pros and cons, in order to understand what aspects there are to complete and improve in future developments.

3.3. Exploratory research

First experiences were made at home: fish scales were put inside vegetal paper, and later heated with an iron over a rigid, plain surface (Figures 31 a) and b)).

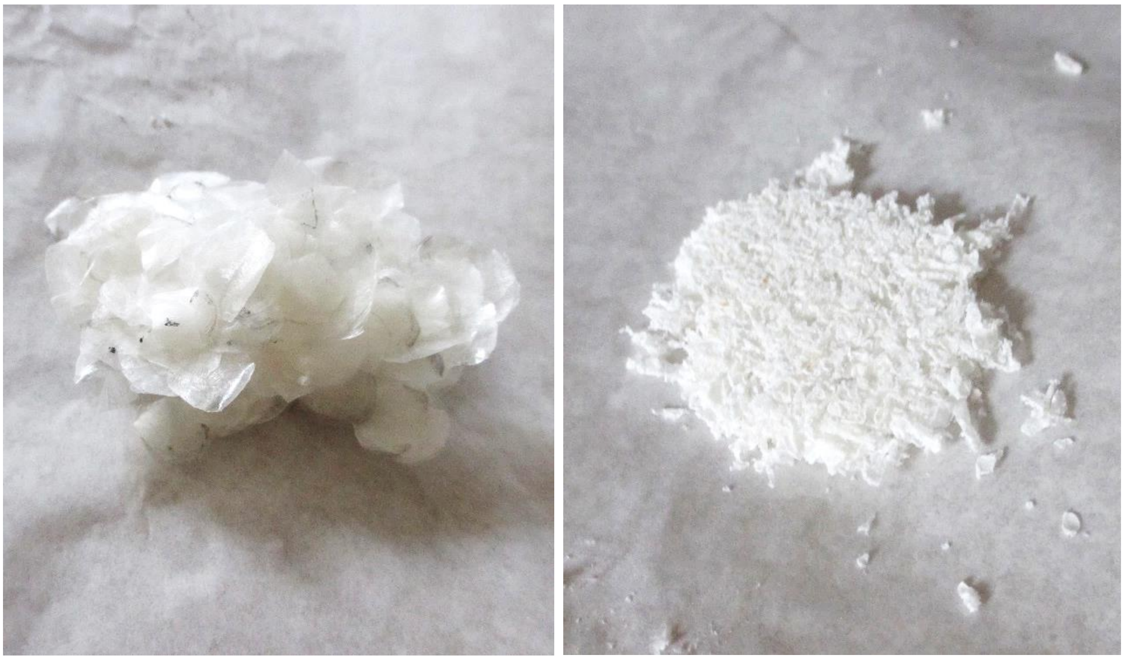

Figure 31. a) (left) Fish scales after ironing on even surface.

Figure 31. b) (right) Crushed fish scales after ironing on even surface.

However, regardless of the temperature used (from 135 to 230ºC) or the time of exposure (from 1 to 30 minutes) to iron - used interchangeably in order to explore all possible variations in the relationship between temperature and time of exposure to heat - the result was always a set of very fragile scales.

When it was finally possible to use a hydraulic press again, other samples were produced in the workshop. A large SATIM hydraulic press (Figure 23) was used, given the lack of an alternative equipment with lower energy expenditure and that presented an efficient regulation for unequivocal treatment of the obtained results - thus guaranteeing an interpretation of the samples obtained, to be as reliable as possible.

Figure 32. SATIM Hydraulic press, INEGI.

Test making was, as previously mentioned, proceeded along with the successive analysis of results, in order to obtain a set of conditions that approached the desired features.

Eventually, with the process of experimenting and pressing the fish scales, it was decided to give up using the crushed fish scales (Figure 24), as the obtained results did not show equal resistance as the ones with the whole fish scales, also losing their reference as such.

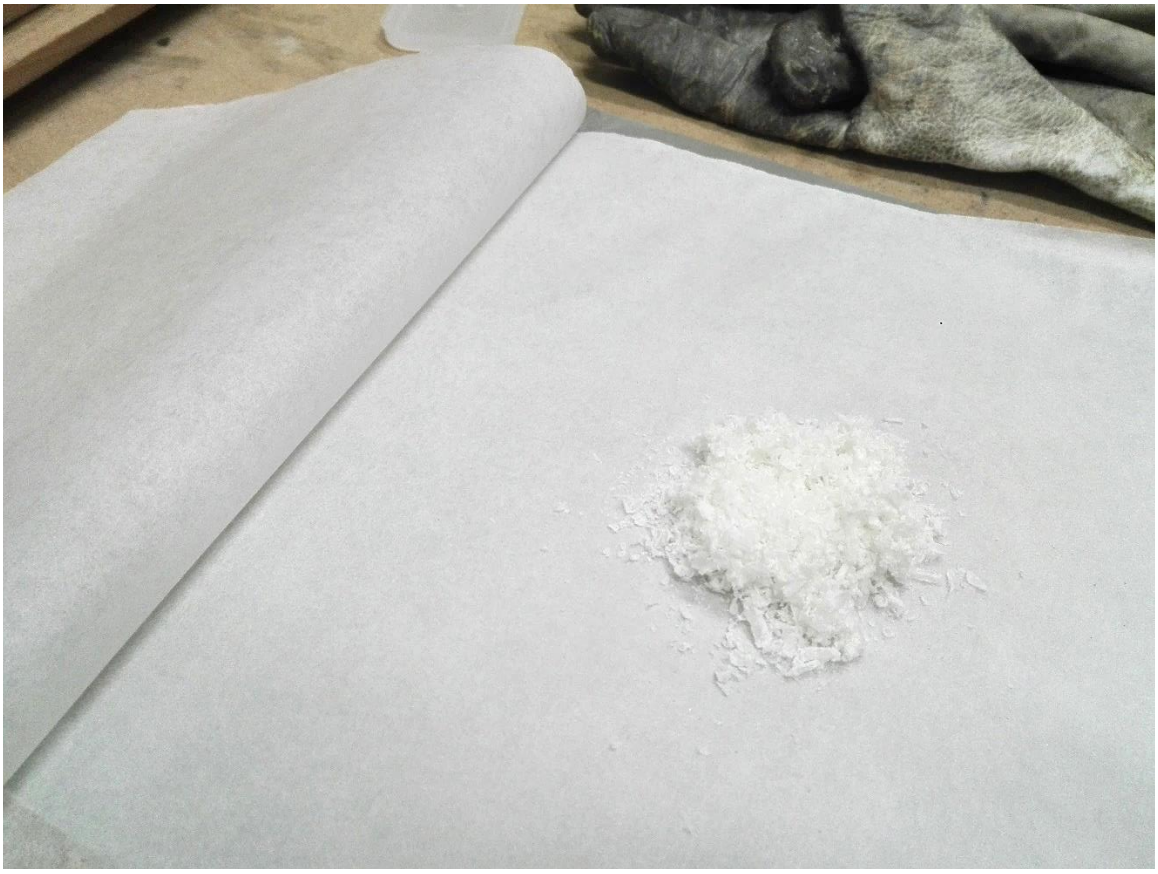

Figure 33. Crushed fish scales about to be thermally pressed.

Given the intention of applying these fish scales to pieces of jewellery, the following variables were privileged, above all: 1) the agglomeration of fish scales, making the agglomerates more resistant; 2) the whitish appearance of the fish scales (in accordance with their natural hue after washing in water and drying). Given the nature of the project, it is considered that the aesthetics of the obtained samples were privileged; this was balanced with the concern with the usability of the pieces.

It was necessary to register which factors were necessary for the samples to be sufficiently resistant - instead of remaining fragile and brittle - which implies some release of collagen for the agglomeration of the same to take place. It was found that in situations where more pressure was applied and when the temperature of the platens was increased, the final result had a polymer-like appearance and hardness. However, in these cases, the appearance of the scales was no longer recognizable, translating into a kind of uniform, translucent and yellowish mass.

Preferably, the thermal press is programmed to reach 120º. It should take about 10 minutes to reach this temperature. However, some samples were recorded with the previously idealized characteristics in which the heating interval varied between 5 to 20 minutes.

When the platens reach 120º, a pressure of 50BAR is exerted on them for 10 minutes, keeping the temperature of 120º as constant during that period of time.

The platens are separated when the temperature reaches the minimum cooling temperature. The samples in which the best results were obtained, taking into account the objectives of the practical project to be developed, were subjected to a cooling period of approximately 5 minutes, with the temperature falling to values between 60 and 70°C.

3.4. Creative process and idealization

In an initial phase, a research was made around the lexical field of "fish scales", in an attempt to find and trigger other ideas related to that material. Among the various words that were found, three seemed to stand out as maritime icons: these elements are the rope, the chain and the net (Figure 34).

Figure 34. Moodboard displaying representations of ropes, chains and nets.

All of them seemed to portray shapes that could be easily incorporated into jewellery. These were also part of the idea of reinforcing this marine heritage in the jewellery pieces to be create - already suggested by the presence of the fish scales. Several sketches were made (Figure 35) in which each of these concepts was drawn, always thinking from a three-dimensional perspective and a close relationship with the human body. This procedural phase was essential to propose different ideas of potential jewellery to be created.

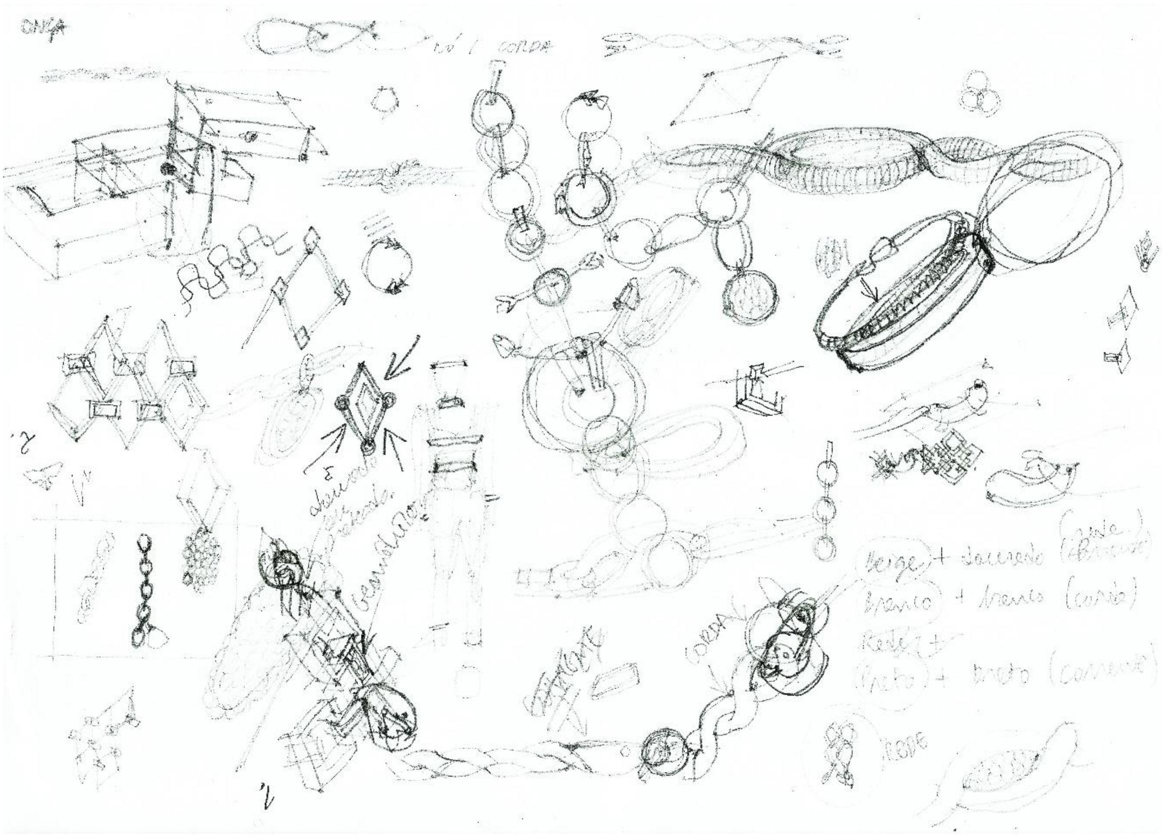

Figure 35. First drawings depicting ropes, chains and nets.

Drawings helped to think about what would be the shape depicted by the pressed fish scales (Figures 36 and 37). Among several simple forms, such as drop-like shapes or lozenges, as they relate to sea water and jewellery or the idea of value, respectively, the idea of resorting to *navete* as a shape arose.

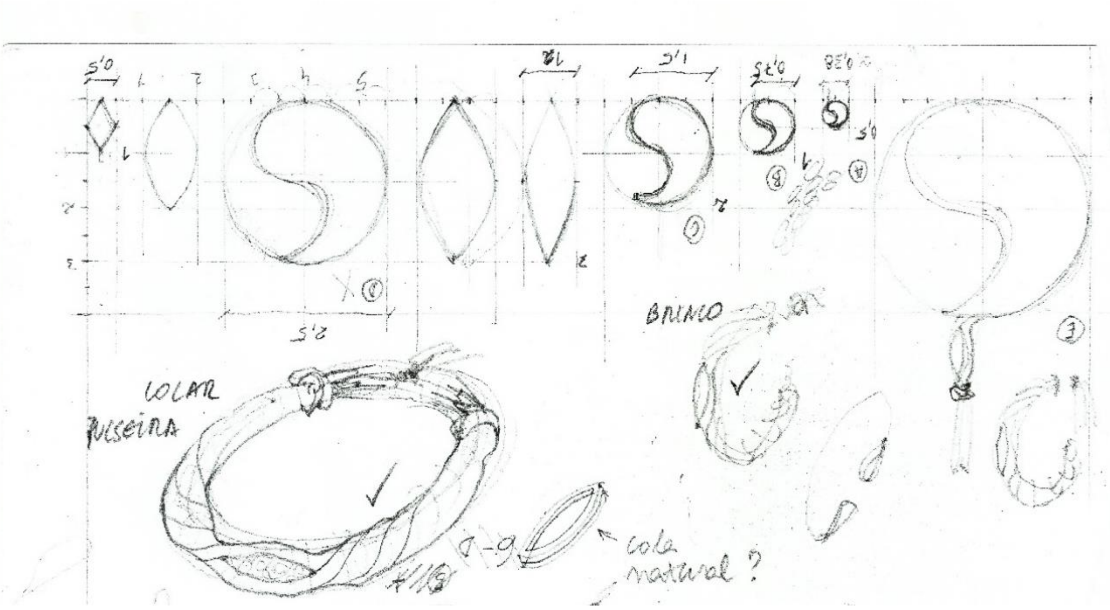

Figure 36. Study of the shape to be depicted by the pressed fish scales.

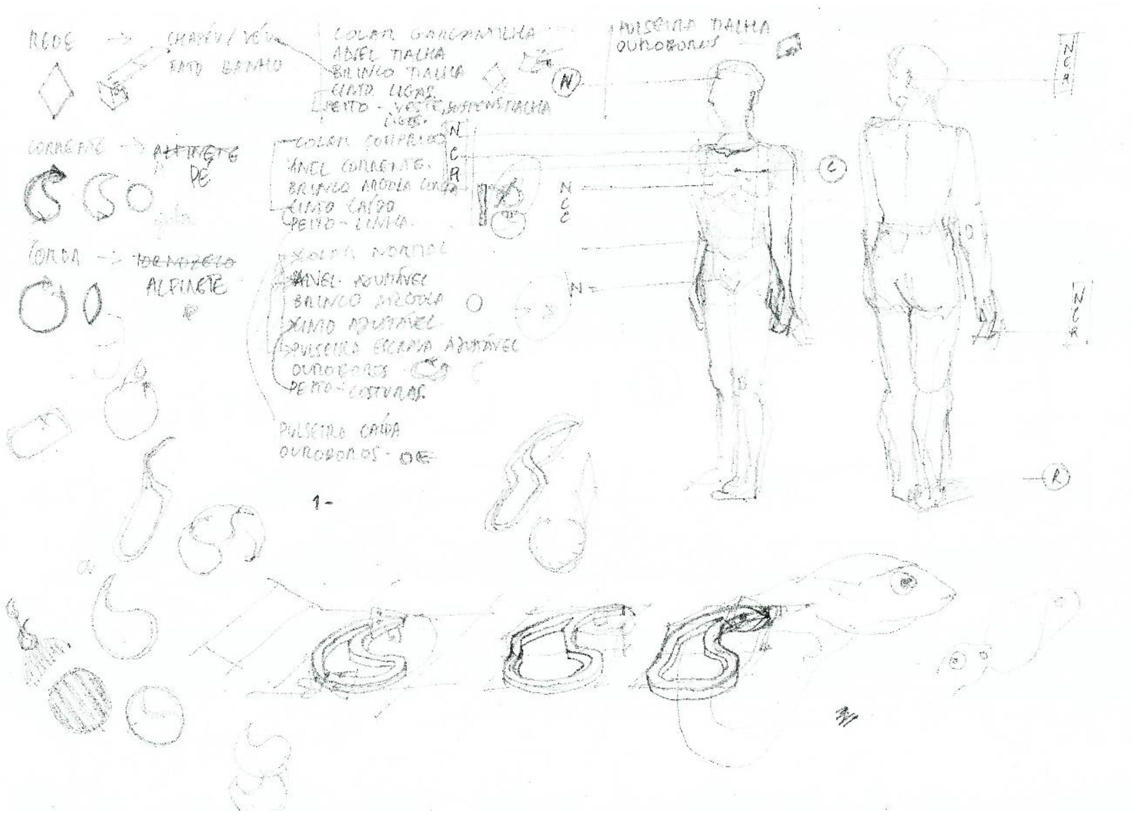

Figure 37. Study of the shape to be depicted by the pressed fish scales.

The word 'naveta' refers to a small ship, and this shape is reminiscent of the top view of an old vessel, as is the case with the Rabelo boats, with an elongated shape and sharp corners. Tatting shuttle designates a type of needle used to produce and mend fishing nets. Simultaneously, this silhouette is used extensively in the jewellery universe, as a source of inspiration, even designating a type of cut that can be applied to the most diverse precious stones. A metallic frame was also designed, in which the fish scales would be inscribed.

An aluminium mould (6000 Series Aluminium Alloy - Alu 6061) was produced to assist the process of pressing the scales taking into account the final shape intended to be added to the earrings. This mould consists of a base, walls and a last element, whose internal structure fills the inside of the walls, putting pressure on the fish scales in the vertical direction, and performing a function similar to that of a punch. The edge of this punch rests on the walls of the mould, like a lid,

Then, the idea of designing earrings in the shape of a hoop was thought of, simulating the work of of marine ropes' twisted thread (Figures 38 and 39). They would show the fish scales in the *navete* shape, which would be framed between two sections of the marine ropes.

Figure 38. Jewellery sketches inspired by marine ropes.

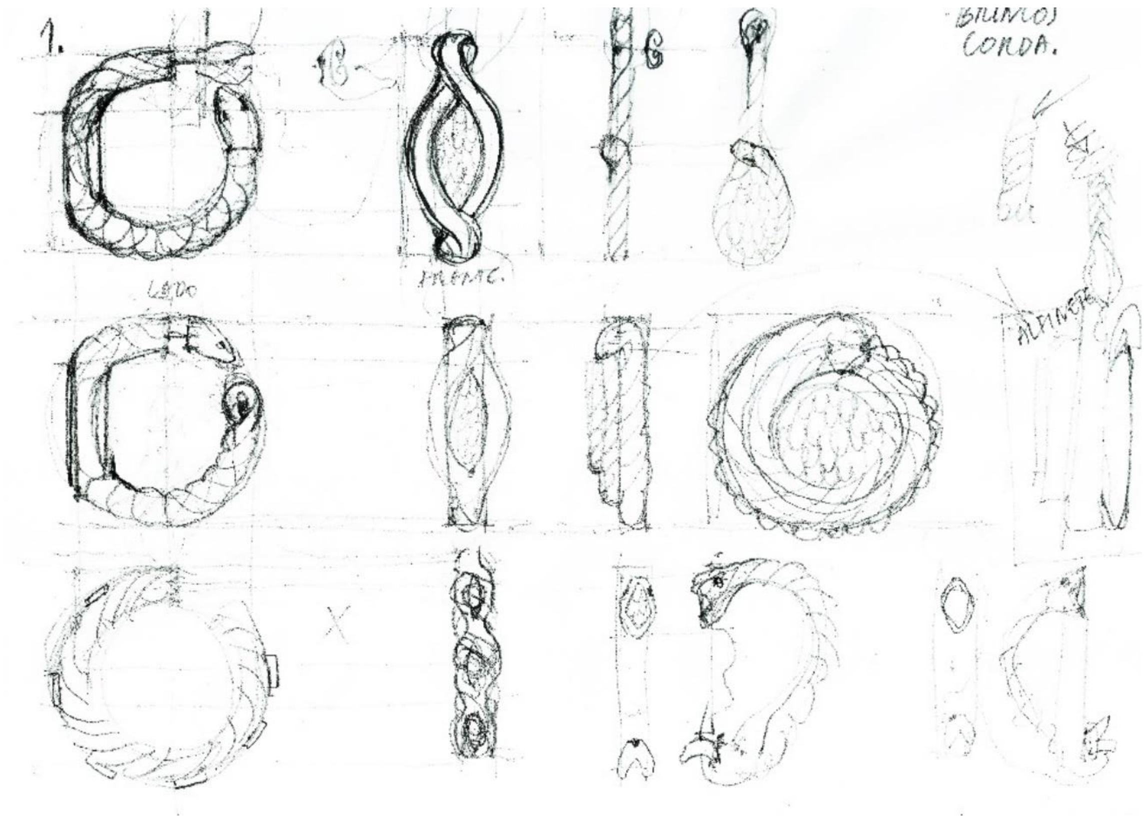

Figure 39. Jewellery sketches inspired by marine ropes.

From this moment on, the drawings (Figures 40 and 41) and small models were produced on a real scale, to assist the production process and to anticipate issues that hinder the usability of the earrings, as well as to visually balance the various elements that compose the piece.

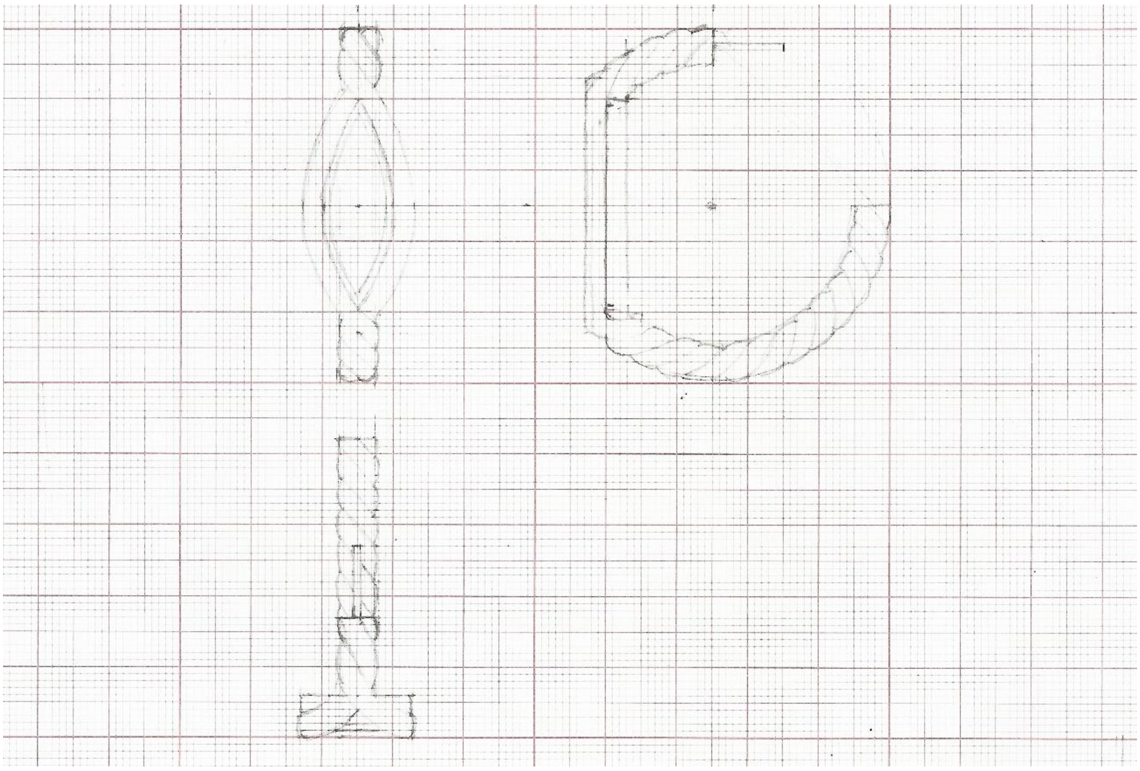

Figure 40. Real scale rope-inspired earrings.

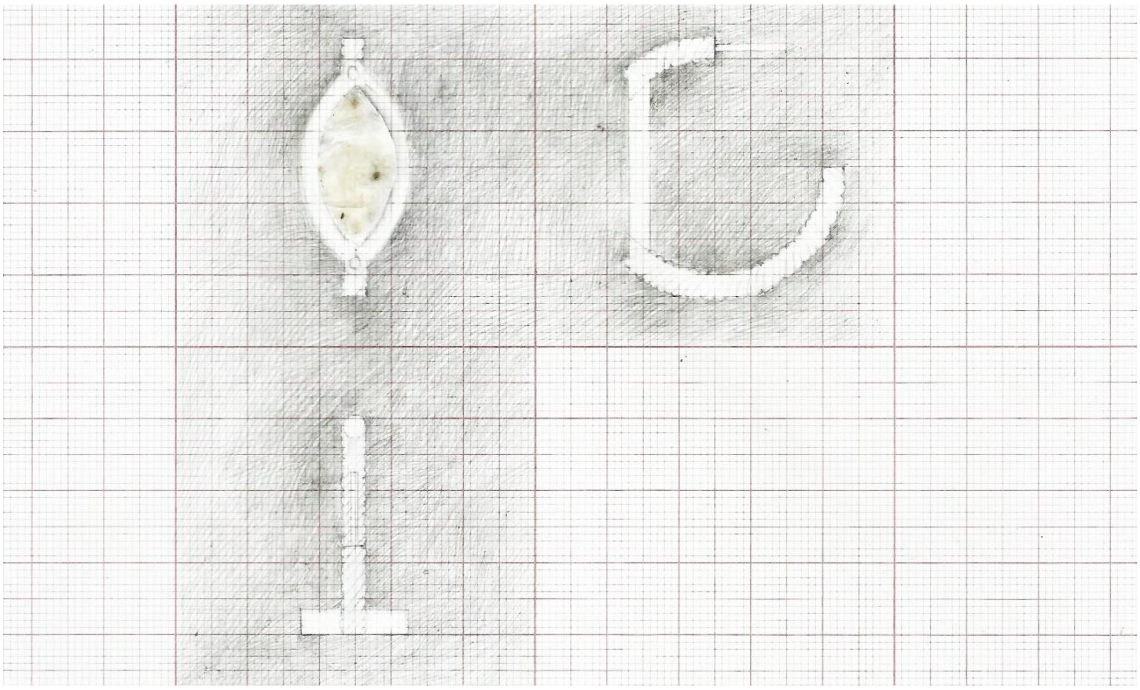

Figure 41. Real scale rope-inspired earrings.

It was later understood that this option brought constraints at the level of production, namely regarding the excessive weight of the piece, the very high cost of gold, the raw material that made it easier to produce this braid, and finally the technical complexity implicit in produce this structure using cannons, necessary to guarantee a significant reduction in the weight of the jewel.

For this reason, the idea of simulating a rope was abandoned and a clean tubular structure was favored. The latter gave more importance to the pressed fish scales - displayed in the form of a *navete*, protagonists of the earrings to be produced. The structure of the piece is reinforced by the fact that it is tubular: this simple tubular structure creates a solution of greater durability – it has been verified through the experiments that were carried out that a metallic tubular structure presents a greater resistance when compared to a metallic wire of the same dimensions. Simultaneously, this solution means that less material will be used in the production of the jewel, and its simplification (the decision to produce a regular tubular structure instead of simulating of a rope by intertwining two metal wires) meets a more sustainable solution. The idea of producing hoops remained: resorting to regular silhouettes seemed to be a simple metaphor for the idea of circularity in rethinking the life cycle of materials, very characteristic of this research project.

Handling fish scales, a daily discarded material, in the manner of a gemstone seemed as unusual as it was pertinent. The solution of fitting the fish scales to a metal frame was then discarded: instead, it was thought to place the fish scales on a metallic structure with the same shape, attaching it to the scales using claws, often used in jewellery for carving of several gems. This last idea can be seen in the next figure:

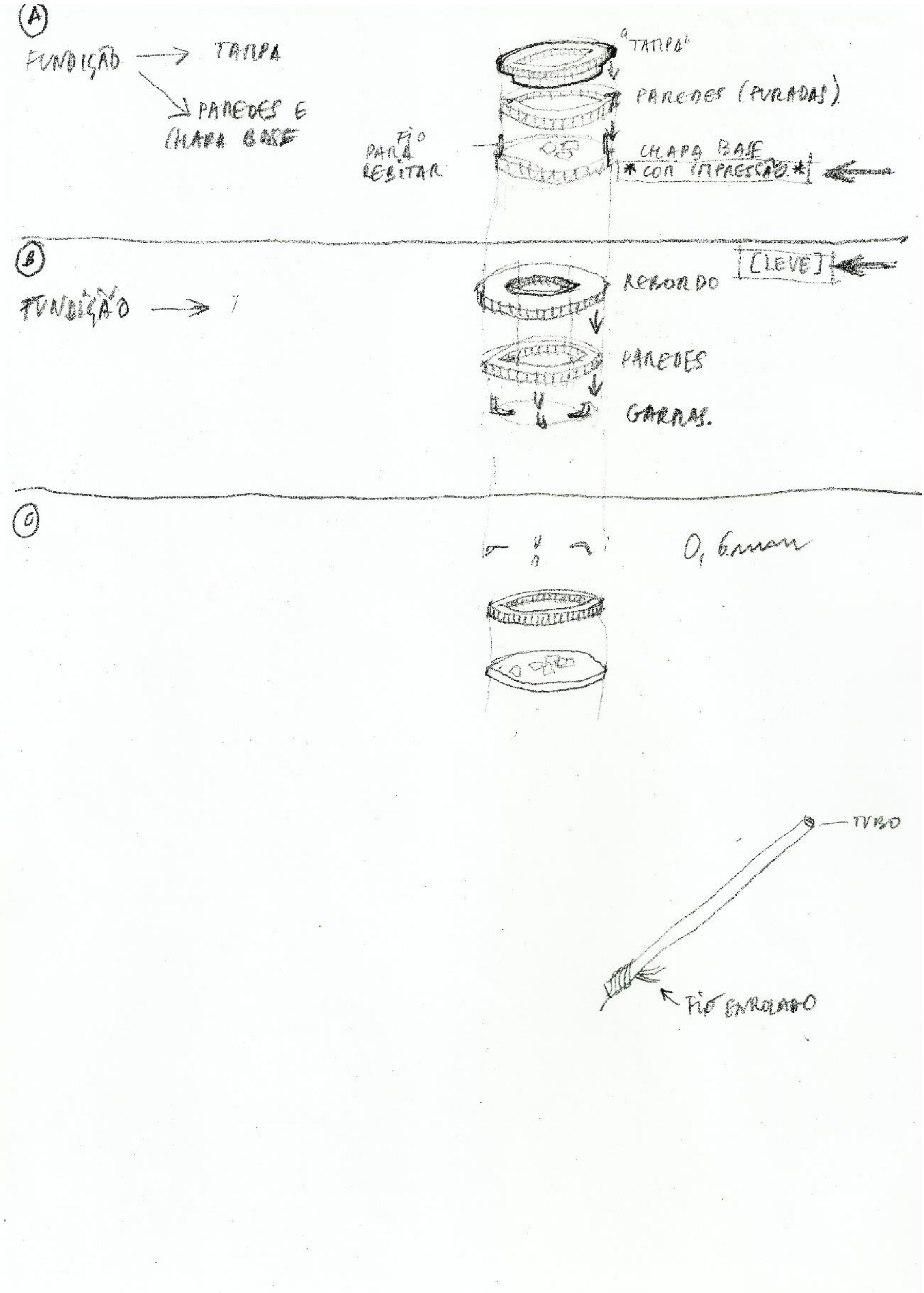

Figure 42. Drawings depicting the comparison between three possible production processes.

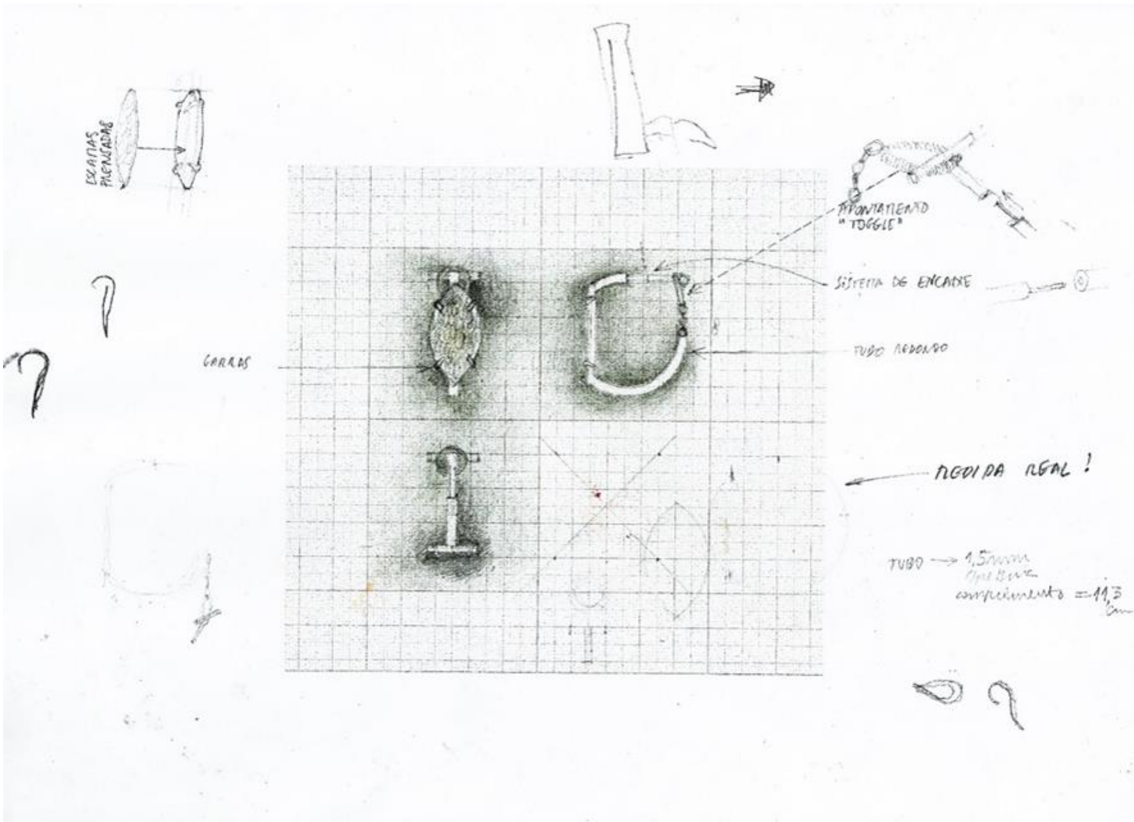

Figure 43. Scheme of the jewels to be produced.

3.5. Production process and conceptualization

To produce the hoop earrings, models were first made to help in drawing the desired shape into the silver plate: the silver sheets are worked on until obtaining a diameter and length that allow to produce the desired shape.

First, a plate is sawn and worked: a regular cylindrical tool is placed on it, and it is hammered with a mallet against the metallic shape in the shape of a half cane on which the piece rests, in order to create a slight curvature (Figure 44).

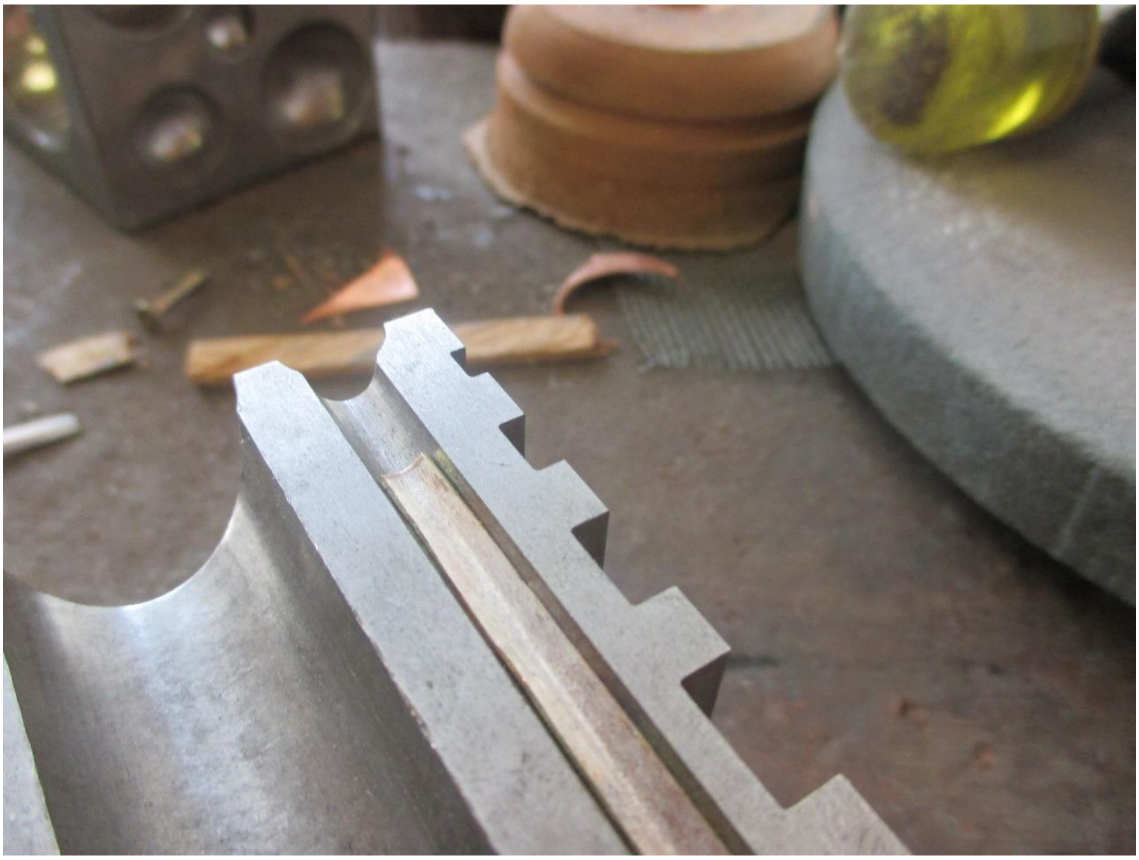

Figure 44. Hammered cut silver plate.

A thinner tip is then produced in the curvy plate to allow pulling it successively (Figure 45), which gradually closes the shape of the plate. When the outer edges of the sheet metal meet, it is ready to be welded.

Figure 45. Pulling the metal plate to make it cylindrical.

After obtaining the desired dimensions, the method of manually wrapping cotton thread around the tubular structures created is used (Figures 46). The latter are carefully curved (Figure 47) with the aid of a mandrel. Cotton has the function of protecting the garment during this process. Tubular sections were produced according to the design developed for the piece.

Figure 46. Wrapping cotton thread around the tube.

Figure 47. A hoop is created after being curved with a mandrel.

Then, the hoops were cut with the help of a small saw according to the drawing and saw-shaped plates were sawn (Figure 48), where the fish scales would land. These were properly sanded and polished, until surfaces were clean and without traces of scratches or unwanted marks.

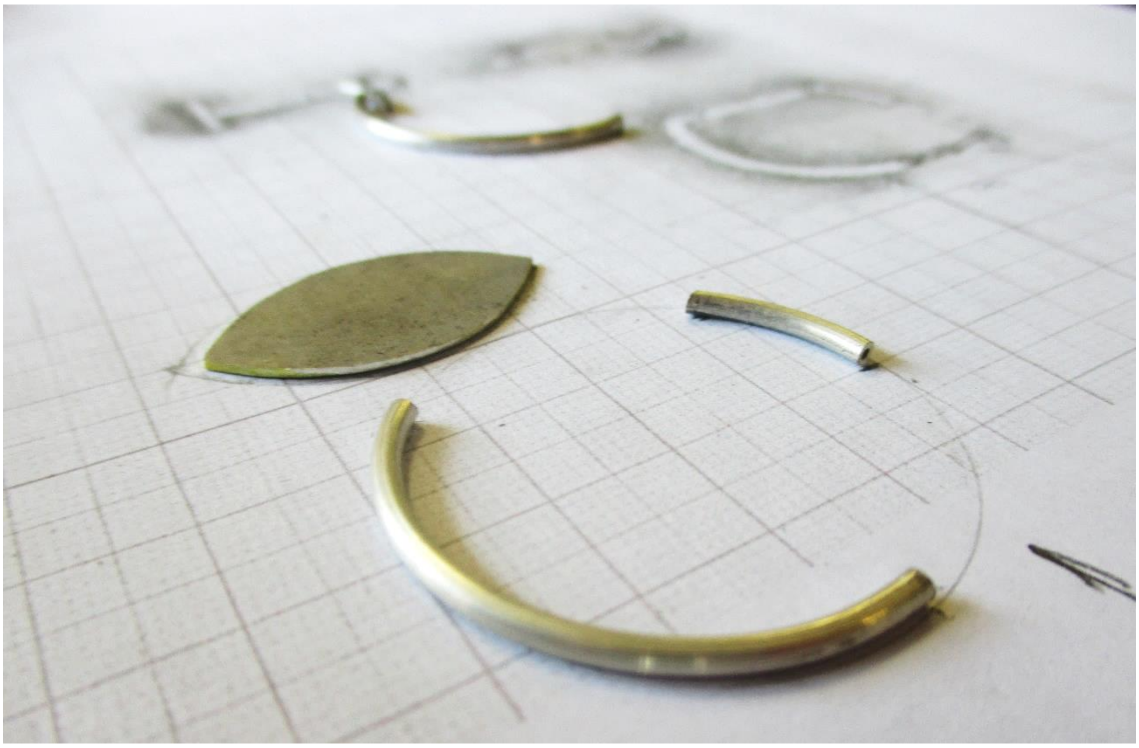

Figure 48. Preparing the assembly of the various components of the earrings.

Contrarily to the nature of silver, of great durability, it is expected that the pressed fish scales will deteriorate in a shorter period of time. Thus, the idea to add a detail to this jewel that would give it value beyond the material it carries arose. It was inspired by the moment when, after pressing the fish scales, it was found that their shape was caught on the metal plate's surface (Figure 49).

This circular movement provided by the hoops is interrupted by the linearity of the hooks, creating an intriguing profile shape.

Figure 49. Fish scales pattern engraved on the metal plate, as a result of the pressure exerted on it.

It was then thought to create a drawing in the metal, to be hidden by the fish scales, and thus only revealed when the jewel starts the process of deterioration of the latter. After polishing the pieces, the engraving process was followed. Initially, the pieces were painted with varnish. Then, with a scratcher, the varnish was removed until the metal was uncovered, in order to unprotect the lines to be etched by the acid. A design was created based on a microscopic image of a fish scale: composed of several lines grouped in different positions and aligned in different directions (Figure 50). The aim was to create a memory of the fish scales, which allows the use of the piece even in the absence of them. The pieces were immersed in the acid solution for 15 minutes. After their removal, they were washed and heated so that all impurities and traces of the varnish disappear (Figure 51).

Figure 50. Engraving on a varnish surface.

Figure 51. The final result of the engraved elements.

After the engraving, the various components of the earrings were assembled (Figures 52 and 53) through the process of welding: the engraved plates in the form of a hook, the sectioned tubular structures and the spikes. Four claws were created to drive the pieces into pressed fish scales.

Figure 52. Welding the navete-shaped piece.

Figure 53. Obtained piece with engraved drawing and claws.

Excess welds have been carefully removed to make the surface of the metal part as smooth as possible. It was removed using a bastard flat file, followed by the same process with a flattened, smooth file until leaving an even surface. After this process, the metal was sanded, starting with a larger size (600) until reaching a finer size (1000). Given the option of giving the metal a matte and whitish appearance, the process of exposing the metal parts to the heat of a flame was used (Figure 54): they are successively cleaned (dipped in a bleaching bath with salt and vinegar solution) and exposed to the same conditions; the process is repeated until they present a very light hue and a dull shine.

Figure 54. Giving the jewel a matte appearance.

After this stage, the pieces constituted by the pressed fish scales are finally put into the metal frame of the shuttle. The metal claws are carefully sanded and curved in order to retain this organic matter.

In order to contrast with the dull shine given to the piece, it was decided to produce a shiny finish on the back of the navete shapes (Figure 55), conferred by slight irregularities made through the use of diamond drills.

Figure 55. Finishing the back of the earring.

3.6. Results description

Ideally, it was known that, in addition to fulfilling a specific functionality, this artefact should express itself through the lines of a sensitive and emotional design, full of meaning, generating interaction and wisdom, enriching the experience of its recipient and that penetrates its symbolic universe. It must innovate while respecting its past. It should be the projection of the trust of its user and provide satisfactory durability; it should also be able to effectively communicate these characteristics through its materiality; its surface, its *skin* provoking visual and tangible stimuli.

Looking at the created jewels, it is possible to verify a compromise between discreet and harmonious tones; between unusual materials and finishes, which arouse curiosity, preventing them from going unnoticed.

Rather modest dimensions and proportions were favoured in terms of the diameter and thickness of the hoops, and in their relationship with the navete-shaped surfaces. This circular movement provided by the hoops is interrupted by the linearity of the hooks, creating an intriguing profile shape.

These earrings are subtle, elegant and light due to its fine, clean lines, from the regular circle-shaped hoops to the simplicity of the claws that hold the natural misaligned pattern of the fish scales which, as an organic raw material, confer a unique aesthetic richness and complexity, highlighting the idea of exclusivity of each piece.

The traditional butterfly back reinforced the connection with traditional jewellery, which is offset by modern and minimalist lines.

There is a clear message that meets sustainable ideals, promoting the cult of these jewels even after the disappearance of their "gem": the fish scale clusters.

When this gem, made of discarded fish scales, disappears or is damaged over time, the opportunity remains to unveil *the other side of the medal*: this hidden design, as a way of remembering the importance of reusing products, giving them a second opportunity, thus prolonging its life and valuing manufacturing processes.

"It is this constant game of hide-and-seek between the meaning and the form which defines myth." (Barthes 1972).

The following images show the final results of the hoop earrings.

Figure 56. Fish scales hoop earrings.

Figure 57. Fish scales hoop earrings.

Figure 58. Fish scales hoop earrings: rear finishes.

Figure 59. Fish scales hoop earrings: detail.

4.

4.1. Summary

Discarded fish scales are herein seen as a material with great potential for application in the design field, and the performed research on this material is motivated by the aim to add value to a waste material, extending its life cycle and proposing alteratives to reduce the fish scales disposal in landfills.

An innovative approach was carried out involving uniaxial hot pressing to transform fish scales leftovers. Not only does this method show a low energy consumption, but it also has no adhesive to process the fish scales and transform them into fish scales clusters. Samples were produced at INEGI (Institute of Science and Innovation in Mechanical and Industrial Engineering).

This sustainable, 100% organic material was then applied to the jewellery field and expressed throughout the production of a pair of earrings. The fish scales clusters were added to the silver structures of the earrings using the stone setting technique, without adding any binders. Jewels were produced in Alquimia Lab school’s workshop.

4.2. Discussion

It is thought that this research project, as well as the developed practical project are not in a final state. There is more to be discovered and tested about this fish scale processing technique. As for the product developed, it still needs validation.

Furthermore, new ways of exploring materials as surpluses in the food industry are multiplying with the need to move towards a more sustainable future, which will certainly bring valuable insights for future research.

Speaking of the practical project specifically, it is still lacking feedback from the public in general: a dialogical conversation applied to a design process requires involved available actors to listen to each other, exchange ideas and converge towards a common vision. Manzini states that in this dialogue, listening and speaking are equally important; he also refers that *"(...) the culture for emerging design will result from discussion in various design arenas and from stimuli encountered in interaction with other cultural worlds."* (Alexandre Apsan Frediani 2002).

It is considered that an alternative way of approaching this organic fish scales material has been found, while simultaneously transmitting an intriguing, captivating message that necessarily falls on the extension of the life cycle of products.

4.3. Future developments

This research project is not yet considered to be finished. Further research will have to be carried to test fish scales hot pressing, in order to better support the conclusions regarding the properties of this material. More tests will be needed to understand and obtain evidence that determines the durability of fish scales.

The same can be said about the practical case study that was produced in the jewellery workshop. Its development should be continued so as to improve the final result. Impressions on the usage process of these jewels should be collected before their insertion in the market.

The creation of a brand and definition of market positioning strategies are also envisaged, as a development. Packaging development will also be carried out according to the brand's concepts. Thus, the next challenge would be creating a strategy which would lead to a better understanding of the best way to both expose and distribute these jewels, considering partnerships and creating an online store.

Ethics, namely sustainability should be considered in the process of exposing and selling the jewels: this means analysing the life cycle of the jewels in detail and making the necessary changes; thinking carefully about the journeys that are strictly necessary to collect the raw material, as well as the journeys necessary for other types of tasks associated with the production and sale of earrings in different locations, and their distribution. Jewellery maintenance will be considered, and its process and inherent costs will be cautiously thought of, thus providing the alternative to further extend the life cycle of the designed jewellery.

Work ethics will also be looked at with special attention to silver suppliers and fishmongers (for fish scales extraction) which will be carefully selected; a percentage of the income from selling jewellery should be given to the suppliers of fish scales, valuing their work.

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