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The application of new technologies in fashion and implementation of additive manufacturing in the apparel industry

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Ao meu namorado por estar lá em todos os momentos,

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Resumo

Os setores mais diversos foram influenciados pela democratização das impressoras 3D. Por essa razão os designers de moda tentam aplicar a impressão 3D às suas criações e procuram uma maneira viável de implementar a técnica. A adoção da impressão 3D no vestuário não apenas traz novas vantagens, mas também altera todo o fabrico do produto e o método de design, bem como o relacionamento com o consumidor. A aplicação da impressão na moda ainda é muito focada em acessórios e calçado, contudo para trazer inovação, é necessário lançar novos materiais e introduzir mais tecnologias, representando o que muitos consideram parte da quarta revolução industrial no contexto da moda, onde têxteis inteligentes ou vestíveis ganham cada vez mais espaço no mercado e os "prosumidores" aumentam a cada dia.

Embora a introdução desta técnica na indústria da moda seja recente em comparação com os métodos tradicionais de fabricação de vestuário, houve um progresso significativo e um número crescente de designers entusiastas que tentam desenvolver este tipo de produto. No entanto, embora existam muitos materiais desenvolvidos para impressão e designers para desenvolver suas peças, há um problema recorrente que se traduz na rigidez das peças obtidas e, consequentemente, na falta de conforto e usabilidade. É por isso que a impressão 3D se desenvolveu mais rapidamente na indústria de acessórios. Após uma extensa pesquisa sobre tecnologias de manufatura aditiva e sua aplicação na indústria da moda, foi possível verificar que calçados, joias e outros acessórios foram os que tiveram melhor aderência. Observou-se também que no setor de vestuário a tecnologia ainda está muito ligada à moda conceitual e que existem vários obstáculos para a implementação da técnica. No entanto há ainda um longo caminho a percorrer em relação à viabilidade de soluções para a confeção e a necessidade de encontrar meios que permitam partes mais flexíveis e confortáveis de boa qualidade e com amplo movimento.

É necessário ter uma inovação material que permita a criação de peças nas quais o conforto, o movimento e a flexibilidade sejam priorizados, uma vez que os designers não priorizam somente o apelo estético, mas também a função e usabilidade do objeto. Este projeto visa abordar precisamente a aplicação de manufatura aditiva na moda e obter uma nova abordagem sobre os materiais utilizados, as formas e as máquinas para criação de têxteis e posteriormente vestuário, de forma a tornar mais viável o quotidiano destas peças.

Palavras-chave

Têxteis, impressão 3D, manufatura aditiva, moda, design.

Abstract

The most diverse sectors were influenced by the democratisation of 3D printers. This is why fashion designers try to apply 3D printing to their creations and look for a viable way to implement the technique. The adoption of 3D printing on apparel not only brings new advantages but also changes the entire manufacture of the product and the design development, as well as the relationship with the consumer. The application of fashionable printing is still very much focused on accessories and footwear, yet to bring innovation. There is still a need to launch new materials and introduce more technologies, representing what many see as part of the fourth industrial revolution in the context of fashion, where smart or wearable textiles win more and more space in the market, and prosumers increase every day. While the introduction of this technique in the fashion industry is recent compared to the traditional methods of garment manufacturing, there has been significant progress and a growing number of enthusiastic designers who try to develop this type of product.

However, while there are many materials designed for printing and designers to develop their parts, there is a recurring problem that translates into the rigidity of the components obtained and, consequently, the lack of comfort and usability. That is why 3D printing has developed more rapidly in the accessory industry (jewellery, bags ...). After extensive research on additive manufacturing technologies and its application in the fashion industry, it was possible to verify that footwear, jewellery, and other accessories were the ones that had better adherence. It was also observed that in the clothing sector the technology is still very much linked to conceptual fashion and that there are several obstacles to the implementation of the technique. It is also clear that there is a long way to go about the feasibility of solutions for the manufacture and the need to find means that allow more flexible and comfortable parts of good quality and with ample movement.

It is necessary to have a material innovation that enables the creation of pieces in which comfort, mobility, and flexibility are prioritised since designers do not prioritise only the aesthetic appeal, but also the function and usability of the object. My project aims to address precisely the application of fashionable additive manufacturing and get a new approach on the materials used, the forms and machines for creating textiles and then clothing, to make the daily life of these pieces more viable.

Keywords

Textiles, 3D printing, additive manufacturing, fashion, design

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List of acronyms

ABS - Acrylonitrile butadiene styrene

AM – Additive Manufacturing

BPM – Ballistic Particles Manufacturing

CAD – Computer Aided Design

CEO - Chief Executive Officer

CLIP - Continuous Liquid Interface Production

DfAM – Design for Additive Manufacturing

DLP - Digital Light Processing

DMLS - Direct Metal Laser Sintering

DTM - Desktop Manufacturing Corporation

DWG – Design Web Format

DXF - Drawing Exchange Format

EOS – Electro Optical Systems

FDM – Fused Deposition Modelling

FIT - Fashion Institute of Technology

IoT – Internet of Things

JK Design GmbH

KES - Kawabata Evaluation System

LOM - Laminated Object Manufacturing

MAK - Museum of Applied Arts in Vienna

MET - Metropolitan Museum of Art

MIT - Massachusetts Institute of Technology

MOMA - Museum of Modern Art

PLA - Polylactic acid

RC – Rapid Casting

RM – Rapid Manufacturing

RP – Rapid Prototyping

RT – Rapid Tooling

SGC - Solid Ground Curing

SLA – Stereolithography

SLM - Selective Laser Melting

SLS – Selective Laser Sintering

STL - Standard Tessellation Language

TPE – Thermoplastic Elastomer

TPU - Thermoplastic Polyurethane

UCLA - University of California, Los Angeles

USA – United States of America

UV – Ultra-Violet

Part I

Theoretical approach

Introduction

3D printing is now seen as part of a new industrial revolution and may be the future for the fashion market. In general, 3D printing is most often used with hard materials and geometric shapes, which makes its application easier on jewelry, glasses, watches, and accessories in general. However, throughout this dissertation, we intend to overcome these barriers, to create flexible and wearable clothes that simulate fabrics and laces, with a zero-waste production.

In weaving and knitting, the use of 3D printing can include rigid adornment pieces, and there are already machines that work as a clothes printer. To produce more malleable objects, it can be created through TPU (thermoplastic polyurethane) as well as polyamide. Every day, new technologies are emerging that make the future more promising as this reality is adopted, making it possible to print seamless garments or mix materials.

Overview

- This document is organised and divided in six chapters.
- The first chapter describes the evolution and development of 3D printing, from time to time, from its discovery through to its introduction in fashion to the present day, also, is presented the point of view of two relevant professionals in the area of relating 3D printing and fashion.
- In second chapter deals with the relationship between design processes and traditional methodologies and for 3D printing, as well as the advantages and disadvantages and sustainability involved in the development process.
- The third chapter gives an overview of the main additive manufacturing technologies that can be introduced in the textile process as well as some of the materials used by the same ones that allow for fashionable applications.
- In the fourth chapter presented all the practical steps of the research from the recycling process to the production of various textiles through different filaments as well as some manipulations carried out under the material.
- The fifth chapter presents some of the determining components in Fused Deposition Modelling 3D printers for the textile production and some of the possible applications for them.
- In the sixth chapter, we approach the sensory analysis of a restricted sample of people and their reaction to new fabrics.

Objectives

- To understand the course of 3D applications in fashion, especially in clothing;

- Detect and analyse the advantages and disadvantages of 3D printing;

- Identify the most suitable manufacturing methods for the possibility of developing printed textiles;

- Test the hardness of printed textiles and pull the boundaries of the industry and the printing of 3D textiles;

- Find out if there is room in the market for 3D printing as well as a real possibility of implementation.

Methodological design

In this investigation, we have chosen to combine different techniques of data collection, in a mixed-type methodological strategy. In terms of research design, we used quantitative methods, such as a survey, but also qualitative methods, such as interviews, as well as the experimental method. The option of this triangulation of data allowed us, through the combination of collected data, to comprehend the research problem and respond to the objectives of the work.

In the first phase of the research we proceeded to a literature review, focusing on the evolution of the use of 3D printing in the field of clothing, making for this purpose an exhaustive research on projects already developed in this area.

Secondly, we collected information on existing 3D printing technologies, but also on the materials that can be used and the ones that can be adapted to the fashion industry. Later, we created different textile structures for printing, considering not only the principles of 3D printing, but also knowledge on weaving and knitting. In the following moment, we carried out tests with different materials, in order to understand the possibility of using existing printing techniques in the textile industry. It should be noted that in the course of collecting data and during the experimentation process, we have always sought ways to make the process as sustainable as possible.

We consider that the studies already carried out on the printing of 3D clothing were decisive in this work since they allowed us to understand the different steps that need to be taken when developing printed textiles.

On the other hand, the work analysed on the different methods and the existing materials for printing, helped us to look for new solutions and, in this sense, to try to overcome some of the limitations in terms of technologies for printing. Material testing has also helped to identify new challenges in the area of printed textiles, especially when considering the use of 3D printing. We believe that this work is an important contribution to the area of study of Fashion Design and Creative Textiles, but it is mainly assumed as an innovative research and opens new ways for future research.

Chapter 1. A brief history of 3D printing.

The whole world is talking about 3D printing (Alabi, 2018; Campbell, Thomas Williams, Christopher Ivanova, Olga Garrett, 2012; Laplume, Petersen, & Pearce, 2016; McCue, 2018). But in fact, it is only the most widely used name to refer to the additive manufacturing industry, which consists of the method which develops a physical object from a three-dimensional digital model (Deckard, 1992), generally through the successive deposition of layers of the object's constituent material. This manipulation of objects in digital form and the production of new ways based on the addition of material, brought a new era of truly disruptive technology, rapidly evolving. However, these new methods can not only profoundly affect traditional manufacturing but also revolutionise design and bring geopolitical, economic, social, demographic, environmental, and security implications for our daily lives (Berman, 2012; Deckard, 1992).

Before 3D printing, traditional manufacturing, based mainly on human and handmade work faces several limitations (Bernard Marr, 2018) while in the manufacturing world the shift to automated processes such as machining, casting, and moulding are processes requiring machines, computers, and robot technology (Kietzmann, Pitt, & Berthon, 2015). However, the introduction of these subtractive technologies based on the removal of material from a more massive block, to reach the final product itself or to produce a tool for casting or moulding processes, came to change the industry (Tofail et al., 2018). The traditional design together with the production processes impose restrictions such as the need for complex assembly parts. In addition to the subtractive manufacturing processes such as machining, can result in up to 90% of the original material being wasted (Sun & Zhao, 2017).

In the 1980s, when the first patent application was made (Su & Al'Aref, 2018), the whole world was about to experience another change that would change everyday life from the 2000s, when 3D printing patents expired, and companies adhered to large-scale this new technology. After that, also, to be a process of industrial prototyping and manufacturing, 3D printing has become affordable for small businesses and even individuals (Printing, 2011). The liberalisation of access to this technology has exponentially increased its adoption in the most diverse areas, allowing the creation of more and more systems, materials, applications, services, and auxiliaries. This new manufacturing process can be seen as a technology that stimulates and drives innovation without precedent design freedom, a process without tools that reduces prohibitive costs and deadlines. Components can be explicitly designed to avoid complex geometry assembly requirements and sophisticated features created at no additional cost (Mellor, Hao, & Zhang, 2014). 3D printing is besides emerging as an energy-efficient technology that can provide environmental efficiencies in terms of the manufacturing process, using up to 90% of standard materials and over the useful life of products through a more lightweight and durable design (Jiang, Kleer, & Piller, 2017).

1.1. 3D Printing History.

Additive manufacturing, commonly referred to as 3D printing, consists of the process of creating a physical object from a three-dimensional digital model (Alabi, 2018), usually through the successive deposition of layers of the object's constituent material (Bogue, 2013). This manipulation of objects in digital form and the production of new ways based on the addition of material, brought a new era of truly disruptive technology, rapidly evolving. However, these new methods can, not only profoundly affect traditional manufacturing, but also revolutionise design and bring geopolitical, economic, social, demographic, environmental, and security implications for our daily lives (Attaran, 2017; Rayna & Striukova, 2016).

Before 3D printing, traditional manufacturing, primarily based on human and handmade work faces several limitations while in the manufacturing world the shift to automated processes such as machining, casting, and moulding are processes requiring machines, computers, and robot technology (Ford, Mortara, & Minshall, 2016). However, the introduction of these subtractive technologies based on the removal of material from a more massive block, to reach the final product itself or to produce a tool for casting or moulding processes, came to change the industry (Lu, Li, & Tian, 2015). The traditional design together with the production processes impose restrictions such as the need for complex assembly parts. In addition to the subtractive manufacturing processes such as machining, can result in up to 90% of the original material being wasted (Tofail et al., 2018).

At the end of the 1980s, some processes were designed with a faster and more economical method to prototype objects for the industry; these technologies were denominated “rapid prototyping”. The first patent application was submitted in May of 1980 by a Japanese lawyer, Dr Hideo Kodama of the Municipal Industrial Research Institute of Nagoya (Kholiya, 2016). He reported the creation of a functional rapid prototyping system considered the ancestor of the SLA. The process he described consisted of the polymerisation of a photosensitive resin by UV light which enabled the formation of a solid and printed model built in layers, each corresponding to a transverse slice in the model (Su & Al’Aref, 2018). Four years later, a French team of engineers was interested in the stereolithography but abandoned due to a lack of business perspective (Printing, 2011).

However, the first patent was not awarded to Dr Kodama due to problems with patent documentation. Years later, the American inventor Charles (Chuck) Hull made history with the first device to print a physical part from a digital (computer generated) file. Although Hull invented stereolithography in 1984 (Deckard, 1992), it was only in 1986 that the technology was patented. He later founded 3D Systems, a company that produced and sold stereolithography machines, particularly the SLA-1 that was released for sale in 1988 (Bensoussan, 2016). Almost simultaneously, Carl Deckard, still a student at the University of

Texas, developed the concept of the selective sintering process (SLS) and founded the Desktop Manufacturing Corporation (DTM Corp.), which was eventually acquired by 3D Systems, producing the first SLS printers in 1992 (Gornet, 2017).

The first technologies of additive manufacturing are the three principals until now; the most commonly known is the fused deposition modelling (FDM) patented in 1989 by S Scott and Lisa Crump, the founders of Stratasys (Su & Al'Aref, 2018), one of the biggest companies of 3D printing in the world. Another notable company is the Electro-Optical Systems (EOS) founded in Germany by Hans Langer focused particularly in printing metal (Luís, n.d.), because of that, in 2004 he acquired the right to all DTM patents. At the 90's, were launched several others 3D printing methods such as ballistic particle manufacturing (BPM) by William Masters (Relvas, n.d.), LOM (Laminated Object Manufacturing) initially patented by Michael Feygin (Deckard, 1992), SGC originally patented by Itzchak Pomerantz (Bogue, 2013) and 'three-dimensional printing' (3DP) originally patented by Emanuel Sachs (Library, Hom, & Kong, n.d.), are some of the many patents and founders of companies that have emerged in the rapid prototyping market by creating a vast competition. Although only three of the original endure today and are those who have higher turnover annually - 3D Systems, EOS, and Stratasys. When its talked about 3D printing, it is imperative to mention the leading companies in the area because they are the ones that mostly develop new machines, programs and the main advances, which has been increasing exponentially (Su & Al'Aref, 2018).

During the 1990s and early 2000s, more and more technologies were introduced to facilitate prototyping and with other industrial applications that sought more advanced methods for more specific functions and looking for direct manufacturing in some areas. At that time, 3D printing started to have new terminologies and serve unique purposes like Rapid Tooling (RT), Rapid Casting and Rapid Manufacturing (RM) (Yap & Yeong, 2014). This period of time had a marked and fundamental growth for the beginning of the new era of manufacture, where several companies were launched, like Sanders Prototype (Relvas, n.d.) in 1996 (later rebranded as Solidscape), ZCorporation (1996), Arcam (1997), Objet Geometries (1998), MCP Technologies introducing SLM (2000) technology, EnvisionTec (2002), ExOne (2005) created as a subsidiary of Extrude Hone Corporation and Sciaky Inc (Deckard, 1992), a pioneer in the additive process based on an exclusive beam welding technology electrons (Ngo, Kashani, Imbalzano, Nguyen, & Hui, 2018). Until that time, a monopoly of western companies operating in the global market was created (Deckard, 1992), which gave a new nomenclature to these technologies due to the proliferation of applications, the term surrounding all these new processes changed to Additive Manufacturing (AM). At the same time the eastern hemisphere was developing (Deckard, 1992), but the emerging technologies, although significant and even achieving some local success, did not reach the global market at that time.

By the mid-2000s, signs of diversification began to appear in two distinct areas of emphasis, on the one hand, it was possible to observe high-quality 3D printing and expensive systems to produce high-value , highly-designed and intricate pieces (Wimpenny, Pandey, & Jyothish Kumar, 2016). The development of these areas is now more notable, visible in production applications in the aerospace, automotive, medical and jewellery sectors, although much of what is done and has already been discovered remains behind closed doors and under agreements of non-disclosure (Deckard, 1992). At the other side of the spectrum, the “concept model” was developed by some of the manufacturers of 3D printing systems, which consists of 3D printers with the focus on improving the development of functional concepts and prototypes (Campbell, 2012) developed explicitly as economic and friendly systems for the office and for the user. Although these systems were still for industrial applications, here are the first steps for the current desktop printers, which we can perceive today as the beginning of a storm.

It was not long before a price dispute began along with incremental improvements in accuracy, speed, and print materials, and in 2007, 3D Systems launched a system under $ 10000, although the repercussion was not what was wanted in part due to the system itself, but also to other market influences. The big goal of the time was to design a 3D printer under $ 5000 - considered by a whole range of enthusiasts on the subject, the opening 3D printing technology to a broader audience. The highly-anticipated Desktop Factory caused a bustle when many predicted that a low-cost printer would finally be released but the organisation failed in the lead-up to the production (Bogue et al., 2018) and Desktop Factory and its leader, Cathy Lewis, were eventually purchased, along with IP, by 3D Systems in 2008 and disappeared. Although many did not realise at the time what was happening, it was in 2007 that 3D printing technology took a turnaround and became a more reachable step with the rooting of the RepRap phenomenon (Tymrak, Kreiger, & Pearce, 2014). The RepRap concept of an open source auto-replicating 3D printer as early as 2004 designed by Dr. Bowyer left a seed that would germinate in the ensuing years with the team's hard work in Bath, when Vik Oliver and Rhys Jones through prototypes developed a 3D printer using the deposition process creating the beginning of an embryonic and open source 3D printing movement that gained worldwide visibility (Tymrak et al., 2014).

Finally, in January 2009, the first 3D printer based on the RepRap concept in kit form, the 3D BFB RapMan printer, was made commercially available. As early as April of the same year, the MakerBot Industries launched its version of the kit, since it had been heavily involved in the development of RepRap to the departure from the philosophy of Open Source (Nussey, 2013) following a considerable investment. Since that year we have seen the appearance of a series of similar deposition printers with exclusive selling points (USPs) (Wu et al., 2018). As the 3D printing industry site explains "The interesting dichotomy here is that, while the RepRap phenomenon has given rise to a whole new sector of commercial, entry-level 3D printers, the ethos of the RepRap community is all about Open Source developments for 3D printing and keeping commercialisation at bay." (Deckard, 1992).

In 2012, alternative 3D printing processes such as B9Creator (Fisher, 2013)(with DLP technology) were introduced in June, followed by Form1 (using stereolithography) in December. Both were launched through the Kickstarter funding website and achieved tremendous success. Market differences and the significant advances in technical level with capabilities and applications produced a dramatic increase in awareness and acceptance of a growing movement of creators. With significant growth and consolidation, one of the most important moves on the market was the acquisition of MakerBot by Stratasys (Deckard, 1992). The impact 3D printing has on the industrial sector, and the enormous potential it has shown for the future of consumers is undeniable and has created a revolution before our eyes (Mitchell, Lafont, Hołyńska, & Semprimoschnig, 2018).

1.2. 3D printing as part of the 4.0 Industry.

The fourth industrial revolution, also nicknamed Industry 4.0 (Dilberoglu, Gharehpapagh, Yaman, & Dolen, 2017), characterised by movement in a new way in the intelligent automation technology. The modification from mass production to the possibility of complete customization of centralised output to distributed production allows 3D printing to be one of the possible factors that can in due course disrupt the manufacturing value chain entirely (Hannibal & Knight, 2018). The possibility of an alternative to the "conventional" manufacturing technologies allowed through 3D printing profoundly affects the manufacture of the products (Berman, 2012).

Cyber and physical systems cooperate profitably to build smart factories redefining the role of human beings. While the virtual environment is based on the Internet of Things (IoT) (Verhoef, Budde, Chockalingam, García Nodar, & van Wijk, 2018) where it becomes possible to collect vital information from physical objects through computer networks or accelerated wireless connections that will be analysed; Big data; Cloud Computing ...(Alabi, 2018). The physical area includes Autonomous Robots and Additive Manufacturing (AM) (Dilberoglu et al., 2017). The aforementioned cyber technologies enable the use of existing information for the intelligent manufacturing of the future. On the other hand, the physical part of the factories is limited by the capacity of the existing production systems, which makes AM as one of the vital components of industry 4.0 by necessity for customization to correspond the demand in mass, become crucial to create sophisticated objects with advanced features (new materials, shapes) (Bogue, 2013).

Although additive manufacturing is more than three decades old, it is a relatively new tool in which engineers and designers have little experience and insufficient knowledge about capabilities and limitations (Pei, Shen, & Watling, 2015). For this reason, Design for Additive Manufacturing (DfAM) has been developed as one of the additional tools to facilitate process parameters (such as cost, time, quality, reliability and CAD constraints). In spite of the advancement of information, technology has accelerated the transition to the next industrial age, the existence of the fourth industrial revolution depends substantially on the capabilities of AM in four of its components: knowledge, materials, processes, and design issues (Alabi, 2018).

In the future, more cross-disciplinary research efforts are likely to be expended (Pailes-Friedman, 2016), and the role of designers, factories and customers will be remarkably redefined, as the manufacturing business is very diverse and ranges from large enterprises to small self-educators. Because of the opportunities offered by the new AM technologies and the entire 4.0 industry landscape with large information networks and custom software, design and production challenges are restricted only by the imagination (Laplume et al., 2016).

1.3. 3D printing and Fashion Design.

Fashion is continually evolving (History, n.d.), but in the last few decades, we began to see fashion repeatedly reinvented past trends (Kellogg, Peterson, Bay, & Swindell, n.d.). Due to the voracious launch of new collections (Patsy Perry; Neil Towers, 2012), there has been no time between each season to gain novelty, as research needs time. To bring innovation, new materials are launched, and more technology is introduced, representing what many consider part of the fourth industrial revolution in the context of fashion, where smart textiles or wearables gain more and more space in the market and prosumers[1] increase every day (Rayna, Striukova, & Darlington, 2015).

The use of 3D printing is seen as an evolution of the industry for a faster and cheaper method of printing more complicated things and qualifies individuals, small businesses and companies with creativity and reduced supply chains (Gebler, Schoot Uiterkamp, & Visser, 2014). However, most sectors outside of manufacturing, medicine and some craft and DIY[2] sectors have been slow to adopt 3D printing (Schniederjans, 2017). It's beginning to change, and fashion is an industry that leads the charge (Walker & Corral, 2017).

Today's technologies already allow for the more dynamic visualisation, and prototyping of new fashion designs and potentially can entirely replace physical samples (Burdon et al., n.d.). The use of these new technologies related to the 3D provides a competitive advantage to the companies (Ernst & Young Gmbh (EY), 2016), the established relationship with the consumer that can customise their product in place and visualise the result before the purchase.

[1] Prosumer is a customer who helps a company design and produce its products. The word is formed from the words "producer" and "consumer"
[2] DIY: Do It Yourself

With the cost of these customisations to decline, coupled with proven returns, increases the likelihood of possible change (Ford et al., 2016).

Not long ago an emerging designer would hardly have the money for the investment needed in acquiring a high-quality 3D printer for prototyping. Nowadays, the democratisation of technology makes it possible for small designers to access tools that will release a wave of creativity in design and business models (Guo, Cheng, & Liu, 2018). 3D technologies can be easily converted into time and money, as well as the creation of samples is one of the phases that generates more "costs" that may be amortised in the design process (LaMonica, 2013). As the fashion industry speeds up the production and sales cycle, 3D modelling and printing can shorten traditional development lead times.

The fashion industry joined the additive manufacturing with Janne Kyttanen's Black Dress, the first functional dress in 3D printing (R Kuhn & Minuzzi, 2015). Although the introduction of this technique in the fashion industry is recent compared to traditional garment manufacturing methods (Chiu, Yip, & Tang, 2018), it has made significant progress and a growing number of enthusiastic designers trying to develop this type of products (R Kuhn & Minuzzi, 2015). However, while there are many materials developed for printing and designers to develop their pieces, there is a recurring problem that translates into the rigidity of the parts obtained and consequently the lack of comfort and usability (Yonson, 2012).

Since pieces of clothing, accessories, glasses, watches, and more can be created from CAD, which enables 3D modelling. From this, a design is printed on the most suitable material for its use. 3D technology has evolved at great strides in recent years, enabling a wide range of options for the final product. Thus, its use in the creation of fashion pieces accompanied the evolution of the technological processes of systems and materials.

1.3.1. Relevant Designers and apparel enterprises in the use of 3D printing in fashion and textiles.

Despite the immensity of areas where designers are already acting with 3D printing and get high acceptance, namely jewellery and footwear, this study will focus mostly on their development in clothing. 3D printing, in the context of technological innovations, besides providing new aesthetic perspectives in garment design, has been used for creating 'intelligent' pieces. “Interactive clothing incorporates intelligent materials that respond to changes in the environment or the human body” (Kuhn & Minuzzi, 2015).

a) Janne Kyttanen

Janne Kyttänen is a pioneering digital sculptor who creates a multidisciplinary work that results in the intersection of 3D printing, virtual and augmented reality ("Janne Kyttanen - Janne Kyttanen," n.d.). The Finn discovered 3D printing during his studies and speculated on the possibility of creating digital products, making their distribution as simple as a download. Kyttanen believed so much in this possibility that he dedicated to the creation of products only with digital technologies, which led him to the foundation of Freedom of Creation in the year 2000 , a pioneer company, specialised in design for 3D printing with a team of specialists in design and innovation (Pei et al., 2015). It was also in 2000 that in partnership with a Dutch industrial engineer, Jiri Evenhuis, that the industrial designer created a piece known as Drape Dress, printed by selective laser sintering (SLS) with powdered nylon (Yap & Yeong, 2014). Later, the Freedom of Creation, also created the White dress, a newer version of Drape Dress but with polyamide, in 2005 (Mikkonen, Myllymäki, & Kivioja, 2013).

At the time they conceived the dress, the concept was about travelling with items that could live in the "cloud" and were printed in 3D when they reached the destination. This idea was totally disruptive to the reality of travel at that time as now, and with the technology and materials available, considering that 5 MB was a large amount of data and the dress consisted of thousands of individual particles, far exceeding the boundaries of the slicing software, which controlled the EOS laser sintering machines used at the time (Galleryall, n.d.). These types of structures (see appendix I) that have become ordinary in 3D printing are part of numerous permanent collections of museums such as MOMA and the Museum at FIT in New York (Systems, 3D.), but it is essential to understand the vast importance and difficulty at the time they were designed and conceived, in which these pieces were unthinkable in hardware and software. The 3D Systems acquired the Freedom of Creation in May 2011, providing the Kyttänen access to software, most innovative materials and technology in the world. After five years of experience with rigid structures (appendix 1) in the company (Pei et al., 2015), their collaboration ended when Janne left the company in May 2016. Kyttanen's work is widely acclaimed making his projects influential around the world. His revolutionary work with 3D printing has consecrated him as one of the most influential designers of his generation.

b) Iris Van Herpen

Several designers began incorporating 3D printing into their work. However, Iris van Herpen was the leader of the pioneers of fashion in 3D printing. His work with 3D printing has grown significantly and has become more improved with each collection. The designer graduated from the Institute of Arts in Artez Arnhem in 2006, the year it began an internship with Alexander McQueen, and in 2007 launched the brand with his name ("Iris van Herpen | BoF 500 | As pessoas que moldam a indústria global da moda," n.d.). In 2010, she renewed the first designer to present a 3D printed piece on the catwalks, the result of collaboration with the London architect Daniel Widrig, the piece was printed by MGX at Materialise, a top reminiscent of how limestone deposits form shells, printed on polyamide presented at Amsterdam Fashion Week in the Crystallization collection (Renato Kuhn, 2000).

In January 2011, it was the turn to debut the 3D printing at the Haute Couture Week in Paris, where Iris van Herpen presented four printed looks (see appendix II) from the 12 presented. This collection entitled "escapism" featured a greater variety of materials than the previous one, with a focus on surfaces filled with fine yarns, creating the illusion and lightness of the coordinates. In partnership with the architect Daniel Widrig, the designer again used rapid prototyping to create wearable sculptures that were not sewn together, the white pieces were printed in polyamide and made with the selective process of laser sintering, the black part is also printed in 3D in polyamide and finished in black lacquer (Hanusiak, 2015). In July of the same year, it was the turn to present the dress Skeleton with polyamide (see appendix III), leather and acrylic bones hover around the body like an X-ray, in the week of Fashion in Paris, where the highlight of the dress in 3D printing refers more to the details and structural forms of the skeleton than to the chosen materials (Kim, Lee, Kim, & Jun 2015). The dress was purchased by the Metropolitan Museum of Art and is seen by herself as a reflection of her way of seeing beauty.

In January 2012 the Micro collection for microorganisms was presented in Paris, where the "Cathedral" dress, printed with SLS technology in polyamide and with sculptural details, was performed (R Kuhn & Minuzzi, 2015). In July of that same year, the designer introduced the Hybrid Holism collection, where she launched parts produced using Mammoth Stereolithography technology, a 3D printing method built from a slice upwards in a polymer container that hardens when hit by a laser beam. The combination of Mammoth technology and the material used allowed the creation of the 3D piece exhibited this week in Haute Couture in Paris, which had a transparent, liquid appearance with a certain similarity to honey. In its 2013 Voltage collection, Iris Van Herpen presents the first in collaboration with the MIT Media Lab, developed a differentiated texture, incorporating a hard material and a soft material, able to impart more exceptional softness and elasticity (Emilie Chalcraft, 2013).

Although the dress in the Biopiracy collection has already been printed with TPU 92A-1 and the silicone coating, in this collection the designer transmits other textures, working with Neri Oxman, creating a sculptural dress printed in 3D where flexible materials were moulded during MIT's printing, a product of Stratasys's multi-material 3D "Object Connex" print technology, which, according to the company, allows a variety of material properties is produced in a single construction. Another dress featured in this collection was created with computer architect Julia Koerner, who flows through the body like a braided web and where flexibility was the aspect that most stood out (Palsenbarg, 2014). Also, for the "Lucid" collection of 2016, the architect Niccolo Casas and Iris Van Herpen have merged technology with craftsmanship with two Magma dresses printed in 3D that combines flexible TPU printing, creating a thin web together with rigid polyamide print. The dress is not just a dynamic combination of rigid components printed in 3D, but also stitched from 6,052 elements printed in 3D. Another dress is characterised by a light and delicate, flexible lace printed in 3D that gently moulds itself to the curvatures of the body (Palsenbarg, 2016).

The way that Iris van Herpen in collaboration with engineers, artists, designers, scientists, and various companies is extensive and allowed an evolution that would make several designers look at 3D printing as a possible way to fashion and her work is the result of constant research, creativity and the connection between science and fashion.

c) Julia Koerner

Julia Koerner is recognised and awarded internationally for her work in 3D printing and the convergence of these technologies with architecture, fashion, and engineering. His work has already been published in magazines such as National Geographic, VICE, WIRED and the New York Times, and there are several museums and institutions such as the Metropolitan Museum of Art in New York (MET), the Palais des Beau Arts in Brussels, the MAK Museum of Applied Arts in Vienna, Ars Electronica, the Art Institute of Chicago and the High Museum of Art, already exhibited their work (Julia Koerner, n.d.).

After founding JK Design GmbH in 2015, she launched a 3D ready-to-wear collection entitled "Sporophyte" in partnership with Stratasys, the company with which it often works, is made up of three high-end fashion pieces, including the Hymenium Jacket, the Kelp Jacket, and the Kelp Necklace (Julia Koerner, n.d.). Inspired by the intricate structures of fungi and algae, some species were scanned in 3D and subsequently worked on to obtain a digital combination for multi-colour and Object 500 Connex3 multi-material where the combination of TangoPlus, a rubber-like photopolymer, and VeroBlack, which produces highly detailed and great-looking prints. Already in 2016, a survey gave rise to the Venus dress based on the analysis of the sponge of the bottom of the sea. The fabric-net structure of the living organism grows on environmental influences and adapts to the environment, influenced by currents of light and water, so the dress printed in 3D is a woven and mosaic matrix, generated from a cloud of points, mapped based on the characteristics and dimensions of the user allowing reactions in the dress through the mapping of heat. To enhance your emotions, some parts of the dress are printed in 3D using biodegradable polylactic acid filaments (PLA), adapting to temperature and touch, changing according to the environment. This dress also served as a basis for the work of the later "Iceland" collection (“About | Salzburg | Julia Koerner - JK,” n.d.).

His work also goes through academic research, since 2012, is part of the faculty of the Department of Architecture and Urbanism of the University of California at Los Angeles (UCLA), but previously, she also worked at some academic institutions like the University of Applied Arts and Lund University. It is also quite common to give lectures on 3D printing, the development of your work and your research. As previously mentioned among his collaborations are pieces of clothing that paraded in the couture week in Paris and film productions, the most recent and which has already won several awards was the printed costume for the Queen Ramonda character in Marvel's Black Panther (see appendix IV), in collaboration with Ruth Carter. The outfit was designed to embody the combination of traditional African culture and the most high-tech fashion. The parts were printed by SLS technology, with PA 12, a polyamide that possessed a high level of precision, flexibility, resistance, and also suitable for contact with the skin. More recently, he has collaborated with Swarovski on a continuing quest for innovation by getting the first developments of 3D glass printing technology.

d) Julia Daviy

Julia Daviy began her journey in 3D printing after attending a course in design thinking and innovation at the Darden School of Business at the University of Virginia. It was in 2016 that she began his career in 3D printing after attending specialisation courses in 3D printing at the University of Illinois Urbana Champaign and many other courses on 3D modelling and 3D printing. Initially acquired a 3D scanner, after that, bought the first 3D printer. Subsequently, the domain of these techniques produced two suits printed in 3D and tailored dresses and skirts, combining two different filaments for printing. She believes in 3D printing as a future for sustainability in which she maintains a strong focus and is concerned with reducing waste and environmental footprints across the industry ("Blog - 3D Impresso Roupas e Moda Inovação - Julia Daviy," n.d.).

His first attempt was a top for which she used only a 3D pen and a flexible filament. It took about a week of work to complete the task. Shortly after that, she produced a three-dimensional, ocean-inspired relief, made of a biodegradable flexible filament, printed in 3D manually which took almost 80 hours to complete the work. The primary purpose of this dress was to inducement attention to the problem faced by the oceans, such as overfishing, killing of sharks and other sea predators, the death of coral reefs and massive pollution.

Julia Daviy presented the first fully 3D-printed collection in the USA, where the technology used was large-format printing, but also concerned with the creation of functional, delicate and wearable clothing for women, where the thickness, shape, pattern, and colour already was possible to print. In addition to the goal of creating clothing similar to what we used to custom, the designer also tried to include zero waste in the production of clothing and the life cycle, as well as seeking the resemblance to leather but without cruelty. The collection with more than 2000 hours of printing was produced with 3 re-engineered large-format FDM 3D printers, 2 usual FDA 3D printers, 1 SLA printer, 5 3D pens, the materials used consisted of TPE (with 100% recyclability) and flexible resin, and the lining of the clothes was made with organic cotton blend, recycled econyl fabric, and ahimsa silk organza ("Impressão 3D e Vestuário de Moda | Vestuário / fato impressos 3d," n.d.).

Most recently, as early as 2019, the designer launched a piece that advertised as the "first digitally customizable and widely available 3D printed skirt". The skirt is considered environmentally friendly, ethical manufacturing, and is customizable to fit the size and personality of the customer. "This is a truly sustainable, no-waste skirt that was designed and produced in the USA using innovative technology invented and patented by Julia Daviy. This method allows Daviy to print 3D clothing with less than 1% waste in the garment production process, "the site says. The skirt is produced by combining innovative 3D printing practices with fabric linings and luxury finishes that meet the highest environmental and ethical standards (see appendix V). Customers can choose from a model of the pencil skirt, mini or A-line, determine whether or not to have pockets, select one of three colours for the lining and one of five colours for the exterior that is precisely the printed part. The colour options are black, blue, white, nude and yellow, and the lining can be black, white or bare. It is still possible to choose not to have wrap around the waist, waist down or high waist. After choosing one of the five available sizes, Daviy and his team create a digital model using the information provided and fabricate a large-scale 3D printer using Daviy's patented zero-residue process with recyclable TPE material; the organic and elastic lining is 5% Lycra and 95% silk. The skirt is designed for a slightly loose fit and should be hand washed separately in cold, dry water; should not be ironed. Just like most of the customizable pieces, the price varies with the options and can range from $ 780 - $ 1500.

e) Comme des Machines

Comme Des Machines is a studio founded in 2012 in Bilbao, Spain. Since 2013, we focus on 3D printing for the creative industries with personalised products made quickly, efficiently, flexibly and sustainably. With high relevance in this area, but not so much dissemination, the project initially composed of four members develops works in several areas of 3D printing and uses the most diverse materials. In partnership with several designers, they produce various fashion articles as biodegradable buttons, appliqués, bags, and jewellery (Moisés Nieto, 2018). However, their most prominent project is called Nora, research and development of 3D printed fabrics with diverse textures and a very approximate appearance of traditional textiles (see appendix VI). The quest for creating thin, flexible structures through 3D printers is top secret. Aran Azkarate, CEO of the company, has just revealed that the material used "comes from a completely external sector to the fashion world" and that "can be dyed, sewn and incorporated by Industry." According to Azkarate: "This technique makes it possible to produce fabrics more creatively, less standardised and above all, less aggressive with the environment, because it will be produced on demand, thus avoiding the huge stocks that now exist." Azkarate believes that 3D printing of fabrics will bring an end to the traditional textile industry and welcomes a new era of "endless" possibilities. "This technology will change the way we do things, distribute, sell and consume," she predicts (Estel Vilaseca, 2016).

f) Tamicare

One of the significant advances made to date in the production of 3D printed textiles to apparel industry comes from Tamicare, a private engineering company founded in 2001 by the Israeli couple Tamar and Ehud Giloh. Over the last decade, they have developed a three-dimensional printer that works from layered cellulose fibers and Vytex natural rubber latex under a moving surface it is possible to create finished fabrics and products without cuts, seams, and waste (see appendix VII). The patented material is incredibly durable, flexible and absorbent in addition to having a low production cost. The technology Tamicare can produce a pair of disposable underpants in three seconds or up to 10 million per year. They may be used for various types of liquid polymers, such as natural latex, silicon, Teflon, and polyurethane, as well as a variety of textile fibers, such as cotton, viscose, and polyamide, to make all types of clothing in addition to print numerous variations of fabrics with any pattern, embossed or perforation on the same surface (TamiCare, n.d.).

g) Danit Peleg

Danit Peleg caught the attention of everyone when she presented her final collection of masters fully printed in 3D (see appendix VIII). After printing at PLA, she understood the rigidity of the material and together with TechFactoryPlus and XLN, experimented printers like Makerbot, Prusa and finally Witbox. The final collection was printed on FilaFlex, material from the Spanish company called Recreus which has a TPE with an 82A shore. It combined the structures of Mesostructured Cellular Materials of Andreas Bastian and through the software Blender, designed a collection printed in domestic FDM printer that took more than 2000 hours to be printed (Danit Peleg, 2017).

Interviews

In order to understand the point of view of some big names in the area of 3D printing directly related to the application in fashion, we conducted an interview, which we sent to various designers and companies, to complement our research. We only got a response from Janne Kytanen and Julia Daviy. Still, it was interesting to see the vision of these two designers and what they foresee in the near future, as well as the possibility of a real implementation, considering that both already works in this environment and have been very successful.

Janne Kyttanen.

Q: How did the interest / work in 3D printing come about?

A: It was during my studies when I saw one of the machines working. Middle of the 90's. Everything around turned into wireframe right away and I saw the full potential in a blink of an eye.

Q: What are the main work tools you use in projects (printers, materials and software)?

A: Every machine under the sun and the same for materials too. Depending on the project. I am recently doing a lot of work in VR, which has similar exponential opportunities as 3DP.

Q: What is your PERSPECTIVE about the future of 3D printing?

A: It will increase to imbed itself into everything we create. We are also becoming smarter to really understand what we can use it for and not just doing it for the sake of the machines. AKA…the true added value applications are becoming ever more important and complex

Q: How you did the connection between 3D printing and fashion in your work?

A: It was merely about trying to find those industries which have not changed in millennials. In principle all garments are made from 2D patterns and then sewn back together. Which is crazy, because we are all 3-Dimensional creatures. Time will tell if the 3D technologies will one day catch up with 2D and the manual process

Q: Do you believe in implementing this technology in the area of clothing? Explain.

A: I did 20 years ago. I am less of a believer at the moment. The textile industry is so powerful and has been there literally for thousands of years, so in order for us to catch up, it is going to take a lot time. If 3D printing can't provide an exponential benefit, its not going to penetrate the market. When you can make perfect T-shirts for 1 cent in Bangladesh, it is difficult to see how 3D printing can compete with this anytime soon

Q: What are the future projects, acquisition of new machines, materials to work and future prospects for your company?

A: I have a lot of things going on. New architectural projects, new investments, new inventions of technologies, new material development etc. It is all very interesting, but one thing I want to always make sure of, never keep on repeating yourself but keep on inventing new things.

Julia Daviy.

Q: Can you present yourself and your link with additive manufacturing?

A: I am Julia Daviy, and I am a 3D printed clothing designer and a clean tech specialist. Three years ago, I dove into the world of 3D printing software and hardware by taking each and every course I could find to gain the knowledge and skills needed to use this technology. My apartment was flooded with 3D printers and 3D scanners, different types of filaments and other materials, and I bought all the books and magazines on 3D printing that I could find. The real practical knowledge and better ideas came via everyday experiments and by making hundreds of mistakes. I started to learn and experiment with 3D printing for several reasons. First, I was looking for a sustainable waste-free way of producing clothing. Another reason is that, as I see it, the functions of clothing are changing. it is not just about beautifying our appearance anymore; it is about functionality- what can these clothes do for myself and my lifestyle? How can I improve clothing design to meet my everyday needs? Finally, I do not like the idea of wasting time on non-intellectual monotonous repetitive operations and the current involvement of millions of low-paid hard-working women and children in the traditional clothing production process. I hate hard logistics in the traditional fashion industry too. All of these things forced me to look for better technology to manufacture clothing. For the last decade, I have been working in clean technology, especially within the solar energy industry. My experience working in this new industry and solving challenges every day has prepared me to face new challenges in the development of 3D printed clothing.

Q: Can you tell us more about your first 3D printed clothing line?

A: I printed 8 looks for my "The Liberation Collection" on large-format 3D printers and one dress was created as a combination of the SLA-printed 3D pattern and organic ahimsa silk organza lining. Before starting work on this collection, I spent a year experimenting with different approaches to make 3D-printed clothes. I faced two main challenges - the first one was to make 3D-printed pieces of clothing as soft as possible with the existing level of technology developed. The second challenge was to create technology that would maximize the benefits of 3D printed clothing, like zero-waste manufacturing and minimised hand work. Working on my collection, I developed a zero-waste method for 3D printing clothing, where each garment is soft and flexible enough to wear for a reception, cocktail party or any other kind of event.

I also wanted my pieces to look like real garments you can find in the stores. I did not want to make the 3D printed apparel models too sophisticated, although that is one of the biggest temptations when you work with 3D printing- there are unlimited opportunities to create!

Q:What are the different steps to create a 3D printed garment?

A: In general, we have three main stages. The first one is the design, measurements, and 3D modeling of a ready piece of clothing using 3D modeling software. At the second stage we print the file or files for the patterns of the digitally ready pieces of clothing on 3D printers. Last, we do the final assembling, lining and other finishing touches required for the specific garment.

Q: What 3D printing technology do you use? What materials?

A: I love SLS technology but today it produces a lot of waste. So, I decided to advance my FDM 3D printing. We took one of the best large-format 3D printers in the market and started to experiment with the very flexible filaments and implementation of my approach - to 3D print ready patterns excluding the 3D printing of fabrics. In the process, we encountered numerous challenges and had to modify the machines each time to solve these problems. I am lucky to have some engineering knowledge, that helped a lot. And my partner is a great engineer, he did a lot to make that happen.

I am also continuing to experiment with SLA, although it does have its limitations.

I have tried each end every flexible material for FDM and SLA I can find. Today I use 70A TPE, it is very flexible. The manufacturer makes them for me on preorder, maybe they will launch it as a product for the designers, it's not easy to achieve the high quality of 3D printing without it. As for TPE, it's a good material for today, it has 100% recyclability and history of its use in traditional clothing production. With SLA, I experiment with flexible resin and silicon. Today, the materials are actually secondary, the main idea is to implement 3D printing and make it widely used. Once that happens the range of materials needed will be developed. I am sure that we will come to use biodegradable super flexible and textile-like materials - and that will happen quite soon.

Q: What are the main benefits of additive manufacturing for you?

A: For today, I see additive manufacturing as the only possible way for sustainable fashion industry development. 3D printing helps on many levels - from digitalization, easy and faster way from idea to prototyping and to a ready product. Less hard handwork and therefore, potentially, the exclusion of low-skilled manufacturing produced by humans and more opportunities to create and develop their creativity – not just for designers, but for everyone. Again, zero-waste and cruelty-free fashion - that is my dream that is coming true with every new step with the 3D printing of clothing. It is cool when you can contribute and supply this world with something really good on many levels. I feel that the younger generations understand this feeling, they understand that money "smells" and they want to make money smell good, and 3D printing permits us to do that too.

Q: How do you see the future of 3D printing in the fashion industry?

A: I cannot imagine a good future for fashion without the use of 3D printing. This is a much-needed step for future accomplishments such as digital logistics, the creation of smart clothing (clothing that will protect, heat or cool when needed) and much more.
To me, it would be a shame if we just take 3D printers and continue to utilize the old-style approach. We need to innovate; we need to use this technology to create something new. Therefore, we need to use 3D printing for good, for a sustainable and cruelty-free way of the clothing and accessory production.
Unfortunately, fur and leather are still widely used in the fashion industry. Those are the first materials that need to be absolutely replaced. They create enormous suffering for millions of animals as well as enormous water, soil and air pollution and severe illness. Moreover, these materials are boring and kill the creativity of designers.
Many designers like to say that 3D printing is still underdeveloped for its use in clothing production. Nevertheless, 3D printing technology will not develop itself. People will. We, the designers of 3D printed clothing, designers of new materials and designers of new 3D printers are making that happen. With every attempt, we are closer to the sustainable 3D printing clothing production that will be the end of an unsustainable process that is killing our planet. Most importantly, this amazing technology will help to unleash the creator inside every consumer.

Through the above revelations, we can see that both interviews believe in the power of 3D printing and the possibility of its implementation. At the moment Janne Kyttanen does not work so actively in the relation of fashion and 3D printing having embraced several projects since leaving the Freedom of Creation, the difficulties that he saw during his course made him realize the difficulties that came with the attempt to introduce the market, making it is difficult to overcome the low costs of current clothing production and its rapidity, therefore, that several other designers believe that this alternative will not replace but rather coexist with current techniques.

Julia Daviy most recently made business her research in 3D clothing printing, with her customizable skirt, the same has the aim of sustainability and all her work is very focused on this theme. Its implementation proposal also embraces the slow fashion economy, a concept that has been growing. Given the current landscape it is clear that these designers who really try to implement the use of 3D printing have to deal with various barriers added as reticence of the public, the market, other designers and "compete" with mass production.

Still, the growing number of businesses in this area tends to create a new market that will not have to compete directly with the aforementioned conventional, because the objective is to serve a public with totally different ideologies and consciousness, a public that embraces the new technologies, with strong environmental concern.

1.3.2. Other designers and companies with an essential contribution to the relationship between fashion and 3D printing.

Anouk Wipprecht is a Dutch designer who has astonishingly come from a mix of engineering and technology with 3D printing to create bustle with the spider dress (see appendix IX). The garment simulates the territorial instincts of a spider in the Amazon rainforest, using robotic arms that react according to the data that withdraws from the sensors of movement and respiration. As the user's breathing becomes denser, the sensors respond to it as a threat and make the robotic arms extend to protect. This defence device also works when the user is approached quickly and unexpectedly (Sabantina et al., 2015). Subsequently, the Intel-Edison Synapse Dress with the ability to record actions allows the user and others around them to be aware of the sources of stress in the immediate environment through an integrated sensor that tracks the level of attention of the user and indicates the concentration. Another sensor embedded in the dress monitors the proximity, where you feel your personal space invaded, the lights of the dress can emit up to 120 watts of brightness, and also incorporates a camera that captures images whenever the subject feels tenser or more-relaxed.

Also, the Open Source Dress garnered prominence due to its production process, in which Anouk joined the Austrian creative network Polaire, to invent a dress through a worldwide collaborative network of individuals with inspiration and interest in 3D modelling which allowed users all over the world would send design elements to the suit through a uniform connection. Anouk has also created coordinated performance pieces equipped with technology to enhance the Cirque du Soleil experience where the techno-tease and interactivity integration of their creations complement the stage environment through the parts controlled by the change of sounds and beats of the venue (R Kuhn & Minuzzi, 2015).

Finally, the Smoke Dress produced in polyamide and material similar to rubber by materialize has as particularity the release of a veil of smoke whenever someone enters the personal space of the user (see appendix X).

The Dutchman Maartje Dijkstra, also following the trend of wearables in which he has performed exciting pieces. Began to develop in 2014 a piece called "Hard Core Vein 2.0" (see appendix XI), where 3D technology was used, exploring new features and shapes inspired by the human organism, the prototype presents a feeling of a living organism to the user, since the material printed in 3D also contains a substance that circulates through the "vessels", as if they were veins (R Kuhn & Minuzzi, 2015).

Other creations that stand out are the parts of Neri Oxman and a group of MIT researchers who have created a technology for creating pieces digitally, using a multi-material, entitled "Wanderers: wearables". for interplanetary pilgrims (Wu et al., 2018). "These pieces have vascular structures and internal cavities that would allow the application of a modified bacterium for transforming oxygen or generating biomass, biofuels, and calcium, among others. The research in partnership with Stratasys resulted in four varieties of "usable skins" that potentially allow humans to survive on other planets under conditions that would be fatal, making these pieces a small habitat used on the body.

Syrian Nabil al Nayal pioneered 3D printing in the fashion world when he first used technology for the Royal College of Art collection in 2010. Since then he has continued to explore the potential of 3D printing and 3D fashion scanning. Doctorate at Manchester Metropolitan University explores the possibility of 3D scanners as a crucial part of the design process ("Nabil El-Nayal - Manchester Fashion Institute," n.d.).

And even Victoria's Secret brand in partnership with Shapeways incorporated technology into the 2013 collection (Pailes-Friedman, 2016). The result was a corset, wings and a hat, printed in lightweight nylon and then inlaid with millions of Swarovski crystals, each consisting of hundreds of snowflakes that intertwine to move like tissue, but sculpturally rigid, designed to serve in Lindsay Ellingson that was fully scanned.

Francis Bitonti is also a controversial name in this field but recognised mainly for in 2013, working with Ace Hotel New York, Shapeways and designer Michael Schmidt to build a 3D dress for the bourgeois dancer Dita Von Teese (Howarth, 2013). From 3,000 made pieces made with "laser selective sintering", in which a metal is built in layers of laser-fused plastic powder, the dress weighed 5kg, with each piece 0.5mm thick.

Nike has recently obtained the patent for a method for 3D printing at both structural and colour level of a product, where the focus is footwear. The technology considers the number of layers required to manufacture the product, the number of printheads passes and allows control of the printhead height from the surface in question, depending on the print stage. Although the context of the patent focuses on footwear articles, the technology can also be applied to any item of clothing or equipment which includes three-dimensional printing element such as hats, jackets, socks, shorts, supportive athletic clothing, gloves, non-woven materials, and other items (Tansy Fall, 2018).

As time goes by, interest in 3D printing is increasing, and it takes more and more designers to try to make their mark on history. There are several other names of designers and companies that have been sporadically developing pieces with this technology. However, the difficulties they face make several abandon the ambitious idea. The relationship between fashion and 3D printing is still in the cradle and only now beginning to move towards what could become a whole revolution of manufacturing.

Chapter 2. Design process and methodology.

The introduction of 3D printing has changed the whole concept of product development today and allows people not only to develop products but also to produce them, making traditional 3D design tools the utensils to design products to be printed (Jared et al., 2017).

With the introduction of 3D technologies, it is inevitable to change the traditional way of the design process, while in the "traditional" process we usually have the design, based on the seasonal trend of fabrics and market information, and combined with the inspiration of the designer; the manufacture of patterns; the demonstration and confirmation through the communication between designer and modeler and adjustments to create the final prototype; follow for mass production (Hällgren, Pejryd, & Ekengren, 2016; Kholiya, 2016).

The insertion of 3D printing technology will completely break down the ideas and steps of the original design, and make a change in the design and production, from the sketch drawing, and other two-dimensional images of the project as the patterns will soon be replaced by 3D modelling, where the clothes effect can be checked in 360 degrees through 3D software, obtaining the processes of sketching, modelling, pattern making, material choices, all in one single step: 3D modelling (Wang & Chen, 2014). In the traditional method after sample determination, the procedure is basically: confirming the design, pattern making, cutting, sewing, however, when using a 3D printer, the digital file will directly originate the final piece of clothing (Yap & Yeong, 2014).

The flexibility currently provided in product development through 3D technologies enables the creation of new geometries and integration of parts into the general product which, with the use of subtractive techniques, would have to be produced separately and assembled in the original product using screws (Woodson, Alcantara, & do Nascimento, 2019). 3D printing technologies can be used throughout the production cycle, from prototyping to complete production, although, mass production of standard products is not a popular application. Its ability to manufacture apart as a whole also makes it more cost-effective than traditional manufacturing technologies, as well as being able to produce parts that could not be created with the latter.

3D printing also changes the distribution of the products because they can be delivered anywhere, where you have the primary material and a printer available (Steenhuis & Pretorius, 2016). This will be disruptive to the way we produce today. Theoretically, a product manufacturer will no longer need extensive production facilities, since the product they designed can be "printed" in suitable locations around the world. Will also keep distribution costs low and make distribution and production planning more predictable (Thomassey & Zeng, 2018).

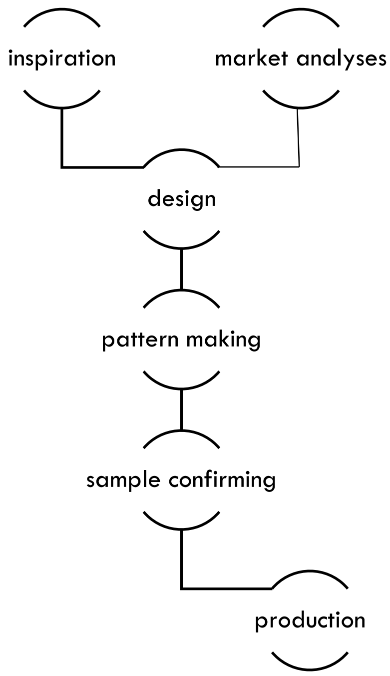


Figure 1. Traditional method.

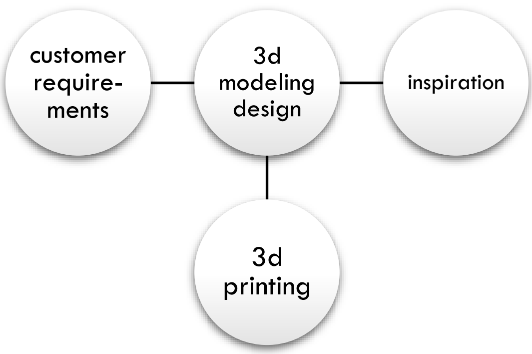


Figure 2. 3D printing method.

2.1. Advantages and Disadvantages of 3D printing.

The use of 3D printers has several advantages but as there are also some drawbacks, especially since it is a new technology that needs several improvements (Ford et al., 2016). However, these advantages and disadvantages can be crucial when we talk about the democratisation and implementation of these devices, so that their impact can be really studied and be thus reflected in a positive or negative change (LaMonica, 2013), both for the market and for the environment.

Some of the benefits of 3D printing are precisely related to the "nickname" of rapid prototyping that this technology quickly acquired, precisely because it is one of its greatest uses and where its implementation was initially more significant (Prakash, Nancharaih, & Rao, 2018). This technology allowed small batches of customised products to become economically more attractive than the traditional method of mass production, which was reflected in the ease of production of highly personalised prototypes or products (Attaran, 2017). In addition to the direct production of 3D CAD models that tools, and moulds are not required, and that designs in the form of digital files can be easily shared, making it easy to modify and customise components and products (Tofail et al., 2018). 3D printing allows consumers to not only print their pieces to repair purchased products, as several simple spare parts can be sold by downloading a file. The truth is that today consumers have become prosumers and are increasingly influential in the manufacturing process of products; this interaction allows them precisely the possibility of being micro-manufacturers (Attaran, 2017).

The addictive nature of the process enables material savings as well as the ability to reuse waste, thus reducing the impact which is precisely one of AM's key benefits over traditional manufacturing as well as cost, speed, quality and innovation/transformation (Oropallo & Piegl, 2016). Although AM is not likely to replace conventional production methods in the near future, it is already revolutionising many areas. The exponential growth of these technologies is undoubtedly one of the most supported forecasts (Justin Sullivan, n.d.).

3D printing allows consumers to not only print their pieces to repair purchased products, as several simple spare parts can be sold by downloading a file. The truth is that today, consumers have become prosumers and are increasingly influential in the manufacturing process of products, this interaction allows them precisely the possibility of being micro-manufacturers, just as retailers can design and customise goods without time long delivery time (Attaran, 2017). The demand for spare parts is one of the factors that differentiates AM in the capacity of distributing to more remote locations by distributors and local suppliers' services which results in the shortening of the supply chain (which it will be address more specifically ahead). However, the ease in obtaining various objects, the fast and efficient communication of design ideas; and the ease of producing and testing purposes, at a lower cost, before they go into manufacturing processes, as well as the profitability of the materials and more numerous benefits with the implementation of this technology, it is necessary to mention some concerns with this process, which over time will undoubtedly be perfected, but still makes us deal with many limitations.

Although we are in the so-called "democratization era" of 3D printing, the initial investment in acquiring a printer and materials is still significant (Schniederjans, 2017), working with CAD requires knowledge, the software is expensive and quite complex to learn. In addition to the complexity of the process, printers require materials, and more elaborate software, continuous maintenance of the equipment, such as cleaning the printer after each use, replacing used parts and so on. Resistance must also be considered since parts printed in 3D are mostly not as sturdy as the parts produced traditionally. The layer-by-layer production technique is both an advantage and a major weakness. In processes such as injection molding, parts are very resistant, since the material has a relatively consistent structure (Goodship, 2015), whereas in layered construction, this does not "fuse" well in the Z-axis as in the X and Y planes, which causes in pieces an effect similar to a wall of Legos®, with superimposed blocks, in the downward pressure seems strong, but to exert force laterally results in a break "in the layers." The surface finish is another aspect that really differentiates itself by the lack of shiny and smooth appearance, since the pieces usually have a matte finish, filled with irregular lines across all layers, of course, post-processing still exists, but this usually involves work with sandpaper or other and chemicals such as acetone, techniques that remove details and tolerance in the parts.

The materials turn out to be expensive compared to the low cost of the pieces coming from countries such as China. For customisation, if to the goal is to print a standard product, the expense is substantially more significant, as well as speed as printing time can take hours, even days, and thus, the process is not worthy in most cases. Of course, the process speed can be increased, and thinner layers can be made, but in such cases, the quality of the final product drops dramatically.

There are also drawbacks indirectly related to 3D printers, such as 3D scanning that is still quite weak, and only reproduces the surface of the objects, not it's inside. In addition to obtaining very abstract and unreliable results, apps and scanners are not good-enough quality, or when it is performed with a professional optimal scan, it is considerably expensive. And yet, the difficulty in dealing with 3D design software leads to a search for libraries full of STL files with errors and several problems in printing.

Apart from that, there are various types of 3D printers and materials, and each one comes with huge benefits as well as inherent difficulties. The future of 3D printing for consumption depends on people's potential to create, invent and share ideas, this will continue to grow in areas such as prototyping, low volume production, medicine, the aerospace industry and a long list of purposes but as a day-to-day practice, the society will have to wait a while.

2.2. Sustainability

Sustainability is somewhat abstract and can be achieved through various changes, one of the main points for sustainable manufacturing is to create products through processes that minimize negative impacts on the environment, as well as conserve energy and natural resources, also being safe for employees, communities and consumers, as well as being economically viable. In a sense, environmental, social and economic factors are the three main pillars of sustainability (Thomassey & Zeng, 2018).

While subtractive manufacturing processes remove material from a raw part to achieve the desired product, additive manufacturing processes generally add content to produce the desired part. Besides, many of the raw materials can be recycled or reused by minimising material waste. 3D printing can also reduce the carbon footprint of products by reducing freight costs due to the possibility of sending the projects in digital (Bogue et al., 2018). Files being printed at a location closer to the recipient also affect complex supply chains with vendors around the world and have reduced excess production, which has consequently reduced the cost of the stocking (Ford et al., 2016; Gebler et al., 2014).

Through 3D printing, it is also possible to project objects with fewer components and materials used to reduce the total energy of the product's production processes. Also, the designer can create hollow objects that maintain the same properties, but instead of being 100% filled, they may have only support structures for the surface of the object, thus reducing environmental and economic costs.

Chapter 3. 3D printing process and systems.

3D printing is a technique that allows the construction of three-dimensional structures and solid objects by adding layers through the deposition of a material in the print bed, following the design of a 3D file, usually an STL file[3]. Although other file formats can be used for different types of applications, the most common format is STL. The material is then deposited layer by layer, which quickly solidifies and generate the desired object.

There are many types of 3D printing technologies presently available commercially or early in development (Balletti, Ballarin, & Guerra, 2017; Schniederjans, 2017). However, each additive manufacturing technique requires a specific kind of material: these may be filaments, photosensitive resin for powdered material, etc. Depending on the final application for each object, these can be printed through three main categories of 3D printing technologies: Extrusion where a filament, usually plastic, is melted and deposited on the 3D printer's compilation platform to form the layer object by layer; the Liquid Photosensitive Resin (SLA and DLP) is cured by a laser or a projector to create the object directly into the resin tank of the 3D printer; o Powder (SLS, SLM, DMLS ...): A powdered material is sintered or fused by a laser, the powder grains are glued or fused (sintered) to obtain a solid structure. 3D printing is still relatively embryonic, so it is not surprising that new technologies are continually emerging and attempts to print with new materials.

3.1. Polyjet

PolyJet uses ultrafine layer photopolymer blasting on the construction platform, where the layer is cured by UV light (see appendix XII) immediately after being expelled (Vanderploeg, Lee, & Mamp, 2017). The gel-like backing material, designed to withstand complicated geometries, is subsequently removed by water jet ("What is PolyJet Technology for 3D Printing? | Stratasys," n.d.). This technology also allows flexible printing due to materials such as Agilus30, photopolymer with superior resistance to rupture, able to withstand repeated flexes and folds, similar to the rubber simulates the appearance, the sensation and the function of the same or materials like the Tango that simulates thermoplastic elastomers with flexible

[3] An article about the use of stl files https://link.springer.com/article/10.1007/s001700050049

qualities and produces flexible and soft prototypes that require shock absorption, vibration damping or a non-slip surface (“Find Materials and Filaments for 3D Printing | Stratasys,” n.d.).

3.1.1. SLS (Selective Laser Sintering)

The SLS process consists of a vessel containing the polymer powder heated to a temperature below the melting point of the polymer (Prakash et al., 2018). A coated sheet deposits a skinny layer of the powder material on the build platform and then a CO2 laser beam sinters the powder and solidifies a cross section of the part (see appendix XIII). The building platform descends after each layer to create the piece in height, the non-agglomerated dust remains to support the element, eliminating the need for supporting structures (Ligon, Liska, Stampfl, Gurr, & Mülhaupt, 2017).

Once the object is finished, the block is removed from the printer, and it is separated from the non-sintered powder and cleaned with compressed air. This technology also allows printing with flexible materials, which also makes it a possibility to consider for the printing of clothing.

3.1.2. CLIP™ (Continuous Liquid Interface Production)

This process consists of a liquid photopolymer resin tank. Where part of the background is transparent to ultraviolet light (the "window"), an area through which a beam of ultraviolet light illuminates the precise cross-section of the object causing the liquid to solidify (Tumbleston et al., 2015). The object slowly rises to allow the buoyancy of the resin and constant contact with the object's bottom (see appendix XIV). An oxygen-permeable membrane sits below the resin, which creates a "dead zone" (persistent liquid interface) preventing the resin from attaching to the window (photopolymerization is inhibited between the window and the polymerizer)(Bureau, n.d.). Some of the resins used may also produce rubbery and flexible looking objects.

3.1.3. ACEO

While there are some methods for 3D printing with silicone in the industry as extruders capable of dispensing silicone, but the thicknesses of the layers are very low. Picsima is a company that has developed a 3D silicone printer, but after years of research, there is still no commercial version. Meanwhile, WACKER has developed a study and created ACEO, a new brand dedicated to 3D silicone printing, under the "drop-on-demand" principle, in which a printhead delivers silicone drops onto a substrate and then the material is either cured with a UV light (see appendix XV). For complex geometries, cavities and protrusions, the process uses an "environmentally safe" carrier material that is washed with water. Another technique that can help deal with the flexibility required for clothing (“ACEO® - 3D Printing With Silicones - Technology & Material,” n.d.).

3.1.4. (SLA) Stereolithography

This process uses mirrors, known as galvanometers or galvanometers (x-axis and one on the y-axis) to point a laser through a print area, curing and solidifying the resin as it progresses (see appendix XVI), dividing the design layer by layer keen on a series of points and lines that are given to galvos as a set of coordinates (Gornet, 2017). A high-power laser hardens the liquid resin contained in a reservoir to create the desired 3D shape. In short, it converts the photosensitive liquid into solid 3D plastics (Bensoussan, 2016).

A similar technique that is usually bundled with the SLA is called digital light processing (DLP), a kind of evolution of the SLA process, using a projection screen instead of a laser.

3.2. Potential printers specific for the fashion industry.

Additive manufacturing has progressed not only regarding filaments and design techniques but also on the level of the equipment itself. Three new printers could turn out to be very important in textile production. Until a year ago regardless of the technology, prints had a maximum size, based on the allowed volume of the machine in question. The appearance of new devices with a different movement system enables the printing of infinitely long objects. One of these machines is the Infinite Build Demonstrator from Stratasys (see appendix XVII), a vast and complex device with the FDM extrusion technology, turned sideways, where substantial single pieces can be produced quickly (Stratasys, n.d.). Also, a Dutch company presented a very similar model to what had already been discussed in the RepRap forums, the Blackbelt 3D (see appendix XVIII). The inclined table top printing mechanism allows printing to occur as the conveyor moves the print, exposing a more vertical surface for printing (Blackbelt, n.d.). This belt-driven 3D continuous printing technology can also be used for mass production. Another company introduced a very similar printer, RobotFactory announced the Sliding 3D printer (see appendix XIX), which uses a conveyor belt and angled extrusion approach.

3.2.1. FDM (Fused Deposition Modeling)

Like any other 3D printer, FDM machines create a solid layer by layer software that "slices" models created in three-dimensional drawing applications (see appendix XX). The extrusion head works similar to a funnel which decreases the thickness of the filaments to values below 1 mm depending on the nozzle (Bensoussan, 2016). The filaments are heated in the ejection path, more than one extrusion head can be used to increase the speed of manufacture of the solid and to work with filaments of different colours, allowing the printing of coloured solids. As the heads move under two axes and deposit the feedstock on the support base, the machine draws each of the layers, which are two-dimensional impressions taking into account that the thickness is minimal. Repeatedly after the manufacture of each "slice", the base on which the solid is laid falls precisely to the same extent as the thickness of the layer or the head rises, so that another layer can be added by gradually building the solid.

3.2.2. Filament materials

There are several particularities that we can expect from filaments, and these must be chosen according to our needs and the product to be developed, we may wish a metallic finish, high resolution, antistatic, biodegradable, gloss in the dark, electrical conductivity, durability, elasticity, flexibility, hydrophobic, fire retardant, electrical insulator, magnetic, reflective, abrasion resistance, water, flexion, lightning, impact ... and a multitude of characteristics (Kietzmann et al., 2015; Melnikova, Ehrmann, & Finsterbusch, 2014). Referring only to the most common types of filaments that have been applied in fashion printed in 3D, let's start with PLA, a biodegradable plastic obtained from natural resources such as starch extracted from corn, beet, and wheat (Farah, Anderson, & Langer, 2016). Of the most used materials, it does not release harmful gases, and it is the most accessible materials to print on the FDM technology printers, it allows to obtain brighter objects than with ABS and at the same time rigid and resistant, it is a permanent and odourless polymer. It should be drilled, painted or sanded like ABS (Haider, Völker, Kramm, Landfester, & Wurm, 2018). It can be treated with compounds such as tetrahydrofuran, dichloromethane, and chloroform and also does not have excellent compatibility with cyanoacrylate adhesives, so it is ideal to use adhesives based on silicone, xylene, and polyurethane.

The ABS has as outstanding mechanical properties its strength, toughness, and opacity. It has the ability to absorb water, is a polymer composed of three blocks, acrylonitrile, butadiene and styrene, termed terpolymer, each of the three blocks contributes with different characteristics: acrylonitrile rigidity, resistance to chemical attacks, hardness and stability to high temperatures; butadiene, temperature toughness when it is low and impact resistance; and styrene, mechanical strength, stiffness, gloss, and hardness (Türk, Brenni, Zogg, & Meboldt, 2017). This can be machined, polished, sanding, drilling, painting and glueing with extreme ease, maintaining an excellent finish.

Nylon or also called polyamide (PA) is a very common synthetic plastic, and this can be hard or hard, even soft and flexible (Hashemi Sanatgar, Campagne, & Nierstrasz, 2017). However, its best features are strength and durability. Like most other filaments, regardless of their main composition, mixtures of materials may occur, and all types of additives and mixes may be sought for new properties and serve a variety of purposes.

a) TPE (Thermoplastic elastomers)

Thermoplastic elastomers (TPE) are a class of copolymers (a polymer made from more than one type of monomer) but are not thermosetting like the typical elastomers; they are thermoplastic (Gijsman, 2011). Therefore, they do not need a curing or vulcanisation process and present elastic behaviour similar to rubber and thermoplastics processability (Dizon, Espera, Chen, & Advincula, 2018). The reprocessing capability addresses the limitation of recyclability of thermoset rubbers, so there is a little processing waste, and these can still be remelted and reprocessed to recover the waste material, generally grinding the items to make a TPE kernel that is mixed with Virgin TPE to maintain the quality of the filament (Brown, 2017; El-sonbati, n.d.). The three main types of TPE are block copolymers, rubber/plastic blends and dynamically vulcanised rubber / plastic alloys.

Some of the appealing properties in TPE include excellent processability, colourability, chemical resistance, softness, recyclability, and good flexibility. However, the material is highly expensive due to the high processing cost and is more temperature subtle than other elastomers; the durability of TPE is also quite low.

b) TPU (thermoplastic polyurethane).

TPU stands for thermoplastic polyurethane, i.e. it is a thermoplastic elastomer, a block copolymer form (contains soft and hard segments), it has many favourable properties such as elasticity, transparency, resistance to oils and resistance to abrasion, can be coloured through several processes and is also extremely flexible, mainly due to the composition of hard and soft segments (Rigotti, Dorigato, & Pegoretti, 2018). The smooth sections are generally polyether or polyester types, but this depends on the application. Soft polyether segments are essential to withstand humid environments, while soft polyester segments are important in oil resistance. However, the TPU has a high hardness when compared to other types of thermoplastic elastomers and when burning releases, a very strong odour. Products made of TPU look more rugged and have high friction ("Introduction to Polyurethanes," n.d.).

While TPE stands for thermoplastic elastomers, TPU stands for thermoplastic polyurethane, typically the TPE has less hardness and releases a slight aroma when burned, unlike the TPU which releases an intense odour. While TPE objects offer a softer, more delicate touch and appearance, TPU products look more aggressive with strong attrition, as well as providing high chemical resistance and high abrasion resistance.

3.2.3. Shore Scale.

Shore hardness scale was designed to measure the hardness of a material, usually polymers, elastomers, and rubbers (“Shore durometer explained,” n.d.). The higher the number on the scale, the higher the resistance to recoil and thus the harder, while lower values indicate less strength and softer materials. The range was well-defined by Albert Ferdinand Shore, who established a suitable device to measure hardness in the 1920s.

There are several durometer scales used for materials with different properties. However the most common are the ASTM D2240 (“ASTM D2240 - Standard Test Method for Rubber Property-Durometer Hardness | Engineering360,” n.d.) type A scales for softer materials and D for harder materials. However, the ASTM D2240-00 test standard requires a total of 12 scales, reliant on the proposed use: types A, B, C, D, DO, E, M, O, OO, OOO, OOO-S and R Each scale results in a value between 0 and 100, and the higher the value, the harder the material.

The developed device dubbed the "durometer" (CRGI, 2018) as many measures the depth of an indentation in the material created by a particular force on the standardised presser foot. The basic test requires the application of force consistently, without shock, and measuring hardness (depth of recoil).

Type	Extra Soft / Soft (Chewing Gum)				Medium Soft (Pencil Eraser)			Medium Hard (Windshield Wiper Blade)							Hard (Skate Wheel)			Extra Hard (Bowling Ball)		
Shore A Rubber, Soft Plastic & Polyurethane		10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Shore B** Rigid Rubber				6	12	17	22	27	32	37	42	47	51	56	62	66	71	76	81	85
Shore C** Rubber & Plastic						9	12	14	17	20	24	28	32	37	42	47	52	59	70	77
Shore D Hard Rubber & Plastic						6	7	8	10	12	14	16	19	22	25	29	33	39	46	58
Shore O** Soft Rubber	8	14	21	28	35	42	48	53	57	61	65	69	72	75	79	84				

Figure 1. Relation between different shores scales.

Part II

Practical development

Chapter 4. Design Process.

4.1. Recycling process and filament production.

Since the beginning of the project, in which it was understood that the main raw materials applied in fashion by 3D printing were "plastics"[4], and that recycling was a vital element to consider. The raw material for the manufacture of fabrics printed in 3D is based on composite polymers of natural or synthetic origin (Ligon et al., 2017). Through the use of temperature, where the objects change from solid state to a pasty liquid state (molten) and thus can be reprocessed.

4.1.1. Separation.

Therefore, once the plastics have been collected from the most diverse materials, they need to be separated according to the polymer from which the residue is made. Therefore, at the time of reprocessing them, there is no degradation due to materials incompatibility. There is a symbology to identify the categories of recyclable materials to facilitate the process of separation and selection of these materials before being reprocessed (ISO 14062)[5]. For plastic materials, there is still a specific symbology that defines the plastic materials according to the polymer. Also, it is possible to distinguish the polymers through the burning process, where the flame acquires different colours according to the composition of the material and also characteristic odors. Another of the forms used for this previous selection is also to dip the plastics in a container with water, and even with alcohol or salt, varying the densities of the liquid and observing which plastics float and which sink. For both methods presented, some tables facilitate the distinction of the composition. However, plastics recycling has a learning curve similar to 3D printing, and it is through trial-error and continuous observation that the results become more evident.

The separation process is essential to obtain good after-filament quality since the polymer blend makes it more complicated both for subsequent recycling and for determining the melt temperature and other crucial characteristics in the process. The separation is also sometimes hampered by the lack of identification of the plastic through the legislated symbology or by the presence of other composites and additives that are not the predominant

[4] To know more about identification of plastics, polymerization, materials, equipment, processes, additives and recycling of plastics in a simplified way see the page https://plastics.americanchemistry.com/default.aspx

[5] More information about this norm in https://link.springer.com/content/pdf/10.1007%2Fs11367-010-0228-8.pdf

composition, are hidden, and there is a later difficulty of recycling because it does not obtain a reliable identification.

4.1.2. Trituration.

After separation, it is necessary to be aware of contaminants, i.e. any dirt or dust contained in the collected materials ends up in the filament, so it is imperative to wash and dry the plastic before grinding. During the process, it is necessary to destroy/cut the impressions in pellets smaller than 5mm so that it is possible to extrude later. After letting the material be crushed, it is strongly advised to use a filter to select the granules of suitable size and those that need to pass back into the crusher until they reach the desired size. Each material has different behaviour's, when subjected to the shredder blades, some materials offer some resistance because they are too hard, which makes it difficult to crush, being necessary an equipment with enough power. On the other hand, materials such as TPU and TPE are sometimes even more complicated to grind due to their elasticity, resulting in a crushed rubber effect, which is hard to shred.

4.1.3. Extrusion.

When the extrusion process starts, it was kept in mind that what goes in comes out, that is, dust, dirt and other debris. After the granules obtained in the crusher are thoroughly cleaned and dried, they are placed in the extruder where they are melted by heating and threaded into a spiral screw where the continuous filaments are formed, which need to cool after passage through the nozzle. During the research, the Filastruder was used, similar to a single screw industrial extruder, whose main difference is the type of screw since the industrial extruders have a conical central section to increase the shear and the compression. The fact that the "domestic" extruder has a constant cross-sectional area, mainly due to the cost, causes it to operate at a significantly lower pressure.

There are several types of equipment to make filament "domestic" version, there are interesting equipment like ProtoCycler, Filabot, and many others, as well as communities of makers who interact to recycle plastics, one of these communities, is "Precious Plastic[6]", which served as a clearing portal for the practical process of this project. During the production of the filament, attention must be paid to the heat history of the material, since the more times the material is heated, the weaker it is because each heat cycle breaks the polymer chains, it is then recommended to mix virgin material to maintain the quality of the content. During the

[6] To know more about this project visit https://preciousplastic.com/

extrusion process, one of the significant difficulties is because the inserted material is granules larger than 5mm and that can screw and cause clogging, as well as too powder-like material that tends to stick. However, the most considerable difficulty in the domestic recycling process is still to maintain a constant diameter of the filament, so there are tolerances between the different materials. Immediate cooling after extrusion as well as filament winding is also critical to producing a more homogeneous filament in thickness.

When dealing with the extrusion of flexible materials there has been an increase in difficulty both in maintaining a constant diameter and an adequate consistency, the need for immediate cooling becomes even more critical as the hardness of the material decreases. While during extrusion of TPU 95A it was possible to produce a consistent filament, as the hardness was gradually lowered, it became more complex to control the entire extrusion process. The hardness tested during this project were 95A, 82A, 70A, and 60A. It was also possible to denote a superior difficulty with the TPE about the TPU.

4.2. Modelling.

Just as it was introduced in the chapter on the design process, this project also had to deal with the changes inherent in the exchange of the traditional modelling process for 3D modelling. There is several software that allow us to model in 3D, in a first approach we opted for programs with a smoother learning curve and with a more intuitive interface such as SketchUp, because the use of 3D software and the difficulty in working with them is one of the critical barriers that fashion designers face when trying to get their way in 3D printing.

At the beginning of the project, pieces were developed with different methods, some designed to be modular and others to be a whole. Initially, the first structures were created to resemble the mesh, which consisted of the truth in small interconnected modules. These modules were based on open source archives and the work of designers such as Janne Kyttanen who from the beginning of the quest for the creation of 3D printed textiles relied on this technique to obtain some malleability. After the module was created, it was only necessary to repeat the module to generate the mesh patterns.

We quickly came across the limitations of SketchUp, so we tried to use other programs, namely Blender, Maya and Rhino, however, the difficulty in learning to deal with the interface, the few time to learn about this programs and the complexity of the computers that we had available to run the programs quickly forced us to look for another solution. The modelling of mesh modules and the creation of parts as a whole was then developed with the help of a mechanical engineer who designed the parts according to the characteristics required for the project. However, to convey what has intended it was necessary to resume the traditional design processes and to use panels, sketches, 2D modelling, digitalisation, draping, and sewing.

For the creation of a full dress in 3D, a sculptural and conceptual piece, this piece was directly designed by the industrial design technician in Autodesk Inventor through the information provided in the technical drawings. Due to the size of the final piece, it has been subdivided into components to fit the print area available in the printer and with grooves to perform a subsequent assembly of the final product. For the creation of a sweater already given the use of flexible materials the process was changed so that our limited knowledge about this technology was optimised. To do this, the sketch of the piece was created, then the piece was made through the moulage process, once the moulds were obtained, a copy of them was made in raw fabric again but this time to sew a prototype. After the realization of the prototype and subsequent adjustments, the molds were corrected and then scanned. As soon as a digital part file (.jpg) was created, we were able to insert it into SketchUp and draw the mold based on the decal, to later add the thickness of the "fabric".

This whole process was also necessary due to the lack of experience with the 3D modeling software and also due to the lack of programs designed specifically for the creation of fabrics and molds for 3D printing, so we had to adjust the existing programs more directed to other areas to use it as intended and bypass some limitations. When we started designing to use flexible materials, the creation of tissue structures suffered considerable changes in drawing form. With the intention of testing only shapes for fabric structure, we ended up finding a high-speed and effective solution through Illustrator which is a program often used by fashion designers and with which it becomes easier for them to interact based on their knowledge , it was only necessary to create the design of the pattern module for the fabric, multiply it and adjust the pattern, after which it was only required to export in .dwg format. Once the file was created, the data was imported into SketchUp, and with the use of plugins like MakeFace, the drawing quickly became something easily manipulated by the program, which in some cases, depending on what is intended, goes only by give prominence to the created drawing. When the goal is to create moulds digitally, to overcome all the material part of the creation of the prototype mentioned above can also use programs such as Marvelous Designer or Lectra's Modaris also commonly used in the textile industry, then just export the files, do some file conversions and quickly becomes a manageable file for printing on a 3D printer. Once the pattern and the mould are produced, easily integrates the design on the mold to leave this in the exact format.

All of these processes can be simplified if there is a better domain of 3D software, but the scarce time and lack of computers available in the project with the capacity to support the programs led us to look for other approaches, that in addition to simplifying the methods for more designers to launch themselves in 3D printing, also appear as an excellent alternative to the lack of software for creating 3D printing apparel.

4.3. Photogrammetry, scanners.

During this project, as we went into 3D printing and the whole new world of technologies and possible ways, the idea came to scan people to create clothes made totally fitted to the body, as Francis Bitonti did for Dita von Teese, even because it would be a level more personalised modelling, as well as the possibility of converting several objects into equipment or facilitating the process of designing various items.

However, due to the inability to get a scanner to search for the high costs, apps were used on the Android and iOS systems to test the possibility of a more domestic and affordable way. After placing the object on a rotating platform under checkered backgrounds, as recommended by the applications and information obtained previously, both methods failed widely, the result is very far from expected, and the scanned objects did not correspond to the real object given the considerable lack of detail. Another approach was to try to photograph the object in an environment by having the camera rotate around the object for the software to map the dots and create a more accurate representation, but the result was equally weak.

Then proceeded with a more manual and sophisticated method to try to recreate the objects following a little the process used by the apps but performing all the steps. Many photos were taken from all directions possible to allow the software to find the same elements present in several photos to recreate the physical space, that is, to estimate the three-dimensional coordinates of surface points using images of a single physical object taken from different angles to enter into specialised software. For our experiences, a DSLR was used, and between 50 and 80 photos were made for each object and although some images were eventually discarded by the program did not find enough similarities. During the shooting phase there are a few points to keep in mind as you do not move the object or its surroundings between the images, try to capture the object's overlap ideally at around 80%, avoid hard shadows, keep the object as a significant part of each image and still avoid reproducing very bright or transparent parts.

After the images have been taken, they have been entered into the software so that it can look for features that are visible in several photos; then through the positions and orientations of the camera, a 3D point is created that corresponds to the 2D element in the picture. Although there are already several photogrammetry software, the problem is that most programs are too expensive or inadequate in features in the free version. During the project, it was tried to use the Colmap that did not enable the execution of the task because the software was below whenever the photos were loaded, we proceeded to 3DF Zephyr with the limitation of 50 photos in the free version. Lately, also was made a brief attempt in Revit but it similarly fails. For post-processing, the output data would be used the Meshlab. However, we can not overcome this part of the process because of the difficulty in executing the software, one of the apparently plausible explanations is that the calculation is quite demanding on the hardware and may not be feasible due to the extremely long computation times, it's also possible that application interface depends on NVIDIA CUDA, which does not run on AMD graphics cards.

4.4. First Experimental Phase: Rigid Materials.

After the entire modelling and conversion process was completed, the .stl files obtained were entered into the Cura software to create a file with the code read by the printer, in which case the data were converted to gcode. Just as the research on 3D printing began, it was necessary to know the filaments beforehand. They are fundamental in the whole process, and they must be kept in mind even during the modelling of the object, which will be the final material. The printer used during this research was Anet A8, a low-cost desktop printer but with a reasonable print area, since 3D printers do not produce models by themselves, the type of material used will determine if the model obtained meets the needs and functionalities.

Initially, the research focused on the rigid materials and the design of parts as a whole or through modules, the reference materials used by other designers were fundamentally Nylon powder, and the printers used were the SLS. However, once we have studied the various technologies, it was seen the enormous potential that FDM technology could provide us and also the low investment represented compared to other methods. FDM printers had also been used in some attempts to "make textiles" which was already a safe starting point to start exploring. The first material tested was acrylonitrile butadiene styrene, or ABS, the most widely used filament. However, its use depends on a machine with a suitably heated desk at about 60 °C, some knowledge of a printer's behaviour and the reaction of the materials, mainly to tame such a warp (causing material shrinkage) of the printing layers and the object relative to the table.

It was quickly realised that the choice of material was not adequate because although a very durable and durable material, as well as a longer life expectancy, we were faced with difficult impressions, a table that did not warm enough and the emergence of cracks due to the lack of environmental control capability which caused a too rapid cooling. Particularly with the modular parts, the need for the mesh to resemble a fabric and therefore be as light and thin as possible required a very strong material so that the printed modules were smaller and the thin layers which could give higher malleability due to the greater number of modules and more connection points that translated into zones that gave possibility of movement.

However, the handling of ABS was not to represent an easy entry into the world of 3D printing which led us to try the other best known and widely used filament, PLA. Some characteristics such as the possibility of printing on a cold surface and higher print speeds, made this first phase of learning the PLA as the filament of choice for subsequent prints, to compensate for some aspects of resistance was used a greater filling of the pieces. Still, this alternative was not the ideal one, the modular parts were very fragile which translated into a need to increase the scale of the mesh and the printing walls, obtaining heavier and less malleable results, besides the material with the time began to exhibit deformation with heat, as in a slightly longer exposure of about 40 ° C. The fragility of the parts also led to the constant breaking of some modules during the handling and also the post-processing as we will explain later, brought added difficulties. In spite of dissatisfaction with the materials, the attempt to reproduce textiles was not satisfactory insofar as the result, albeit with some malleability conferred through the connections of the modules, was not at all suitable for daily use, the discomfort of stiffness, washing difficulties, difficulty in locomotion (see appendix XXI). Still the need for auxiliary supports in the printing and the inability to properly finish the material left the mesh with an unpleasant texture for contact with the body. The fact of the ease of deformation at low temperatures was also a weighing aspect to go in search of more viable results.

4.6. Second Experimental Phase: Printed into the fabric.

As soon as we came across the restrictions of the meshes and pieces produced in the first phase of experimentation, both the inadequacy of the materials and the forms used showed the need to choose another path. It was then that the idea to print directly on the fabric, based on previous studies (mention the Japanese and MIT). However, the initial aim of all research was the creation of fully printed fabrics, which led to questioning whether it would be a suitable route since it was somewhat of a backward step in the research because the base material would already be a fabric. even so, the search continued in this direction, keeping in mind that the front took us to an important part would be the solution for printing in particular trims, such as buttons.

The second phase of experimentation consisted of placing various types of fabric as a base for printing, fastened securely under the printing base with a hook for the printer to hold the fabric. The first intention was to actually print directly onto the fabric, which was not feasible for reasons such as the inability of the filament to attach properly to the surface. The tissue samples used were tulle, chiffon, organza, synthetic skin and chambray. it was possible to verify however that as the fabric was more "bumpy" the filaments penetrated the groove and held better, in addition to that the more "peeling" the fabric had less adhere the filament. One to two layers were printed under the printing table, the printer was paused, and the fabric was inserted under the printing, in the case of fabrics such as tulle, organza, and chiffon, the natural aperture in the fabric construction allowed printing directly and that the next layer melted with the former being possible to conclude the height impression, in the case of the denim and fabrics with more closed structures it was necessary to open a few holes to allow this fusion between the layers on both sides of the fabric. In some cases, depending on the base fabric used, it is possible to print directly on it as long as it is securely attached to the table and at low speeds, as long as the printer is configured properly for this task. The result of the prints shall then be a kind of stamping with relief that has many uses, whether for customising textiles as directly print trims and fasteners or even spikes and other props and also represent stamped with durability (see appendix XXII). As you can imagine, however, the printed area creates a rigid area that, in the case of stamping, causes a certain discomfort in its use. The market already has some options in terms of flexible filaments, and it was at this moment that the need to integrate them was realised. When the same "prints" previously printed on PLA directly on the fabric pass through at the same time but this time with a flexible material, a new window of possibilities opened for this investigation.

4.7. Final Development – Flexible materials.

The market already has some flexible filaments options that even not being ideal for application in clothing, can someway serve as a starting point for a specific development for the area. In this chapter will be addressed the follow-up of the research for the creation of fully printed 3D textiles with the introduction of various flexible filament hardness's. The wide range differs between levels of flexibility, mechanical performance, visual quality and processability, and each brand, and different hardness of material requires an adjustment of the printing parameters and various changes, so it takes several tests until you find the correct configuration for each of them.

4.7.1. 95A shore.

The introduction of learning with flexible filaments began with the so-called semi-flexible ones. Most filaments available in the market range from hardness 80-95A and within this range there are several possible choices. The first approach was with a filament 95A, a good introductory test given that its deficiencies are diminished by its degree of hardness, that is, even if it is considered a hard material, it can be printed rigidly while maintaining the properties flexible, suitable for grooves requiring a degree of flexibility but still needs structural stability and can be printed on a Bowden type extruder.

Printing with this material was very similar to that obtained with PLA printing, but to allow for some difficulties that could arise with the use of other flexible filaments. Although the filament does not break as the PLA in the way to the extruder, this will stretch which causes feeding difficulties, nothing too worrying. However, the extruder "drooling" has made the importance of so-called retraction and the added difficulties for post processing since it cannot be sanded or diluted with acetone or other usual chemicals. In this first approach was printed the same type of structures designed for the PLA, connected sets of modules.

While their texture improved in relation to body contact, during printing these modules were often "glued" so that it no longer had the malleability function at the connection points, it was still easy to see that the use of the modules and these interconnections would be unnecessary because flexibility would already be achieved through the choice of material. We started to create new "standards" but without the needs of this mesh of modules, approaching the approximate 2D format of the fabrics (see appendix XXIII), which although they are 3D objects, the size of the thickness is so disproportionate and small that it makes it a particular point of view (overturned). To obtain fabrics in a 3D printer, this dimension will be fundamental in several aspects that will be detailed below. Tissues were produced with variants of thickness between 50 and 500 microns, measurements below 50µ were rendered totally unfeasible due to the brittleness of the material as well as above 500µ became too rigid, heavy and structured to be interpreted as an alternative to a conventional fabric. It was also necessary to make adjustments in the filament flow to fill inconsistencies, depending on the sample produced and the total filling quantity of the part, a variable flow between 200% and 400% was used with this filament, this so that the fabric can be completely sealed and without printing flaws, which give rise to places that are suitable for the rip.

4.7.2. 82A shore.

As soon as we wanted to introduce flexible filaments, the objective was to acquire the most similar appearance possible to the traditional fabrics, so that although the first attempts were made with a semi-flexible, we always intend to advance to the flexible. Known as the most flexible filament on the market and previously used by designers such as Danit Peleg, Comme des Machines and Julia Daviy, a filament of the well-known brand Recreus was tried for its Filaflex flexible filaments with a hardness of 82A. Here it was noticed the long road still ahead and a lot of learning to be done and obstacles to be overcome. From the first printing attempts with this new toughness that we face an aggravated filament feeding problem, flow, dropped wires in moving, lack of filling gaps in the printing and many other problems. In parts, constant retraction and extrusion cause under extrusion by having to "reload" the hotend with more filaments after each retraction, which sometimes grinds up to the material preventing it from extruding. This subextrusion translates into inconsistent, irregular or poor lines and subsequent poor quality and flaws. Excessive filament friction causes more pressure on the drive gear causing filament supply problems. Both excessive friction before and after the drive gear condition the results.

The most flexible filaments are hygroscopic, which means that if they are wet, they will pop and sizzle if extruded with the presence of dampness. These pockets of water vaporize instantly, leaving voids in the impression so that in addition to the extra care in preserving these filaments, it is also sometimes necessary to dry the filament in an oven for one and a half hours at 60 ° C and store the spools in cartons preferably sealed with silica or even rice that can absorb humidity from the filament.

Another constraint with the printing of flexible materials is the speed of printing that reduces significantly about the hard materials; it is not possible to completely 120mm/s to consider 30mm/s an already fast printing. Speed interferes at various levels and can cause problems such as inconsistent infill; curling perimeters. If there is a gap between the drive gear of the extruder (or the shaft of the plate) and the hot end inlet orifice, the filament may bend, and as soon as the buckling process begins, the filament will find an outlet of the extruder side, jamming some axle motors in the process, hence the importance of filament path restriction. From the extruder gear to the nozzle opening, there should then be no place for the filament to want to exit.

As all these recurring problems have been noted, the importance of the filament storage care, as well as the urgency of acquiring a direct extruder, has been realised. Then most of the problems reside in the settings, so several adjustments are needed until the printing is consistent. It is, in fact, more complicated with the flexible impression due to the amount of threads/cords that the nozzle leaves in the displacement movements, in part due to the high fluidity index that the TPEs materials present, however in solving this problem we must activate the retraction that will cause underextrusion among others. It is a circle of effects that makes the solution to a problem, the source of a new one. One of the reasons why the arrival of "flexible printed fabrics" was so arduous, the first few months of samples resulted in a complete waste of material that fortunately we had already taken care of and created the recycling process. Gradually we became aware of the definitions that fit our purpose, and the samples began to look pleasing, the first printed fabrics hovering around 400 microns thick, which we gradually lowered to 60 microns (0.06mm). From the adjustments in the settings, a vast amount of new structures was created playing with overlays, effects, gradients, and textures as well as flexibility and resistance (see appendix XXIV). This was the glimpse of what we were hoping to achieve. However, the enthusiasm of seeing the ideas materialize reveals the need to question how far we could go: how to increase elasticity for adaptability to the body, how to increase comfort, decrease the plastic appearance, create absorption needed for contact with the body that transpires and how to resemble more and more traditional fabrics to aim at a correct hypothesis of implementation and for people to wish this material.

Although the results were pleasing, the desire to go further and find aspects to be improved soon came to fruition. It was necessary to look for several solutions both at the post-processing level as we will see later, as well as to obtain materials with other characteristics that the market had not yet provided.

4.7.3. 70A shore.

In order to find filaments of lesser hardness, a lengthy investigation was made, and we come in contact with the most varied suppliers around the world. The adjacent difficulties to print with lower hardness and even with 82A diffused in such a way that users stopped trying to use, just as companies gave up producing. This was a serious barrier to transpose that took us in two different ways, from the acquisition of the raw material to the manufacture of our filaments with low hardness not yet available in the market until the intensive search for the truly more flexible filaments in the market. In addition, information on these lower stages of hardness becomes virtually non-existent in the sense of 3D printing with FDM technologies, and even in forums that are more predisposed to pushing boundaries and testing new materials, there are very few reports of these materials.

Recreus has a filament version with a diameter of 2.85mm with a hardness of 70A in only one colour: clear. As the focus of the research dwell on how far it is possible to go with what exists in the market, it will only be reported the investigation conducted with purchased filaments. This filament 70A is designated ultra-soft and disclosed by the company as the most elastic material currently on the market and is manufactured in a single diameter of 2.85 mm because of the high elasticity requiring a larger section to provide more thrust during extrusion.

When printing began with this filament, all of the difficulties mentioned above with filaflex 82A multiplies. This is one of the points that leads us to understand the difficulty of companies choosing not to invest in lower hardness. Since problems with fluxes, speed, fill, under extrusion, cooling of the material, everything has become much more complex, because this material resembles in appearance and texture to the silicone. With the same genre of fabrics and techniques designed for 82A printing, it has been tested with this new filament and adjusted all the necessary settings to get the best quality possible with the available equipment. One of the most important aspects to take into account and which had already been verified on a smaller scale with filament 82A was the need to balance the filament flow. This is because taking into account aspects mentioned above as the difficulty in feeding the machine because the filament when being pulled goes stretching and does not enter the required amount, it can help immensely increase here the value of the flow that we verified that value as high as 1000% to a suitable layer. However, there is a relationship between increasing the flux and decreasing the thickness of the layers to provide an appropriate fill. Still shortening the spacing between the lines and adjusting the flow, there were small flaws that when the fabric was exposed to certain forces began to rip through these places. Dealing with samples of 60 microns thick we obtained really elastic and malleable parts with an impressive trim, however it was necessary to activate the ironing option to allow the extruder to pass under the previously printed layer leaving only an insignificant amount of new material (10% of the flow of 0.06mm). This layer will move perpendicular to the front and thus homogenize, to be "erased" the print lines, which generated more susceptible areas to tears. When the previous layer has an excess flow, however, this is minimum when the next layer is to homogenize the texture will actually drag the material and create the opposite effect to that desired. Once satisfactory results have been obtained (see appendix XXV) in the printed structures we realize that within the current market, after setting everything correctly, this is a viable option for fashionable implementation that represents several advances compared to the commonly used filaflex of 82A although it entails greater difficulties.

4.7.4. 60A shore.

The use of filament 70A appeared to be the end of the line within the filaments available on the market today, until we found a filament from Makeshaper. This was indeed an extremely flexible material, even with a high degree of fill. The results of the prints were much softer, elastic, with pleasing and less plastic appearance (see appendix XXVI). Interestingly, contrary to what was expected, it was found to be easier to configure the printing and extrude than the TPE 70A material, perhaps because it is a TPU.

However, it was only possible to obtain a minimal amount because when we discovered this material, it was already to be discontinued. was sold only in black and white but the acquisition of the company by KeeneVilagePlastics stopped production of this material. We have contacted members of both the former company and the current company and were informed that after joining these companies, they are currently investigating and working on filaments with similar hardness's to introduce in the market.

Only an added difficulty was reflected in this material when you want to get a 100% filled layer a warp appears, and the lines of passage take off each other. This would currently be within what is traded, the most suitable filament for the manufacture of textiles, however, its discontinuation and lack of alternative solved by the holding company, makes the filaflex 70A the best version available. Nevertheless, it was a filament whose results in terms of elasticity, resistance, and touch allowed to get as close to the objective. Even with only 60 microns, it is possible to obtain good results while fabric and still maintain resistance.

4.8. Filament Manipulation.

This topic will cover filament manipulation performed only on commercial filaments, excluding all experimentation around the process of recycling and manufacturing original filaments.

The "acetone bath" where the imprints were placed in a sealed container, lined with cotton soaked in acetone, were applied to both the ABS and PLA rigid filaments to create a chemical "melting" of the material, as a function of the change in the surface. This process although it removes the details to a certain extent in the ABS, provides a smooth effect on the final part but also gave rise to the "glue" of some of the structures that were trapped instead of interlaced. In the PLA, the material did not change the surface, but the consistency of the material changed drastically to a rubberised and a very fragile material. The same was repeated in both materials but replacing the acetone with other corrosive and aggressive liquids like the alcohol, and diluent. The final effect did not differ much, obtaining similar effects, however they are more inadequate than the use of acetone.

This technique is mainly used as post-processing and although it has also been applied for this purpose, it was applied in an attempt to corrupt the polymer bonds and to obtain more flexibility in the material, although it has mainly resulted in the degradation and embrittlement of the structures. However, although the application of these chemicals in the flexible filaments is not recommended, the possibility has been tested. Acetone vapor had no effect except for leaving the material more susceptible, but when these liquids are employed with the use of a certain pressure, "scrubbing" the material, the surface "polishing" is removed by eliminating the plastic sheen, in excess causes wear of the material. The material may still be subjected to a Vaseline mixture after acetone vapor, and placement of the flexible structure in a container having this blend at about 110° C partially restores some of the corrupted flexibility in the vaporization.

Table 1. Filaments properties

	82A[7]	70A[8]	60A[9]
Composition	Polyurethane thermoplastic, benzene-1,3-dicarboxylic acid	Polyurethane thermoplastic, benzene-1,3-dicarboxylic acid	Thermoplastic urethane, propanol, oxybis-dibenzoate, colourant
Printing temperature	225-235°C	215-235°C	215°C ± 5°C
Printing Speed	20-40 mm/s	20-40 mm/s	20-40 mm/s
Density	1,14 g/cm^3	1,08 g/cm^3	information not available
Elongation at break	665%	900%	information not available
Abrasion loss	23mm^3	45mm^3	information not available
Retraction parameters	3,5-6,5 mm	3,5-6,5 mm	information not available

4.8.1. Dyeing.

The manipulation of the materials either under the use of temperature or chemical components, among others, is recurrent to allow the alteration of certain characteristics usually to suppress the weaknesses of the material used.

[7] More information about this filament in datasheet https://cdn-3d.niceshops.com/upload/file/FILAFLEX_TECHNICAL_DATA_SHEET.pdf

[8] More information about this filament in datasheet https://cdn-3d.niceshops.com/upload/file/FILAFLEX_70A_TECHNICAL_SHEET_MSDS_2017.pdf

[9] More information about this filament in datasheet https://flexionextruder.com/wp-content/uploads/2017/03/60A_TPU_Black_MakeShaper_SDS.pdf

Materials used during most of the research and with which we tested more manipulation was precisely the TPE and TPU with different compositions of additives. Bending over the filaments obtained results greater impact and approximate the target (see Table composition of materials). Samples obtained from these products came in black (82A), white (60A) and transparent (70A). Although the breadth of available colours is increasing substantially when related when the colour diversity of each colour and the importance of them in the fashion industry, it was realised the need to discover the dyeing process for these materials. It was then necessary to know the material as thoroughly as possible and perform various tests to achieve some viable results.

The high compaction and internal cohesion of the filament makes it very difficult to penetrate the dye also due to its chemical structure, depending on the degree of orientation of the molecular chain alters its dye adsorption power, ie due to its very compact and oriented crystalline chain, diffusion of the dyes is difficult, so that dispersed dyes need to be used, without ionic groups and applied in dispersions. These dispersed dyes are applied in aqueous dispersions, the dispersed particle size is 0.5 to 1 µ. They have very limited solubility in cold water (only a few mg / l). The samples were then subjected to a dyeing process equal to the polyester, with about 1h30m to 120 ° C, disperse dyes have been used. Having access from the dyeing laboratory then becomes possible to dye without any innovative particularity, it is actually quite simple, however, the dyed samples have been tested several times and transferred the colour to the staining contacting surface.

Another alternative tested was the application of colour with permanent paint after printing the samples, however, there was still colour transfer to the surfaces although to a lesser extent. The colour was then incorporated into the filament prior to printing so that the dye would "mix" with the material during the extrusion process, solving the issue and obtaining solid colours. Whether this alternative dye addition is performed manually before the filament enters the extruder or during the production process of the filament leads to another difficulty, multicolour printing.

4.9. Japanese System KES-F (Kawabata Evaluation System).

In order to obtain measurable values and translate what we observe for numbers, it´s used the KES-FB measurement system instruments to calculate the primary expressions of touch for the type of tissue studied in order to quantify the touch quality.

This system consists of 4 modules that together measure 16 physical parameters. "These parameters characterize the mechanical behavior of tissues submitted to low demands, which contribute to the objective evaluation of the "touch" whose sensation is linked to deformation to the touch." (Engenharia, 2007).

Six samples with different characteristics were then subjected to analysis. Due to the poor quality of the available printer values such as fabric thickness may not be accurate. There is also a considerable surface roughness due to irregular printing and the thickness is not the same throughout the sample, these factors condition the results, however, it is important to obtain a first quantification of the "touch" of these tissues to begin to obtain an idea of what we are dealing with and provide values that support a possible implementation. In some of the equipment it was not possible to obtain data on some samples, due to the fragility of some, and even the immense elasticity and the friction. It should also be noted that "ironing" imparts significantly more resistance to the samples as discussed above, as well as influencing the degree of elasticity.

Table 2. Samples analysed in Kawabata Kes-fb

	1*	2*	3*	4	5*	6*
Size of sample (mm)	180x180	180x180	180x180	150x150	180x180	180x180
thickness	200µ	60µ	100µ	80µ	100µ	60µ
Shore scale	95A	60A	95A	70A	82A	95A

*these samples were subjected to ironing[10]

MODULE: KES-FB 1

In this case the fabric is in fact a melt of material being indistinguishable from the web of the web whereby they both have the same values. The printing layers can in this case be similar to this web / weft concept by similarly creating cohesion and interlacing points.

A) Property: Tensile (We were unable to evaluate this parameter)

"This test measures the tension developed in a fabric when subjected to a uniaxial tensile force towards its yarns (web and weft). This property is related to the ease with which the crimping of the yarns in the fabric can be removed, which in turn is related to the mobility of the yarns inside the fabrics." (Broega, Elisabete, & Silva, n.d.)

B) Property: Shear

"This test measures the tension developed in a fabric when subjected to a pair of opposing but most coterminous forces thereto, until it reaches a predetermined angle. This

[10] When the topmost layer is finished, it repeats it without moving the print head higher. The head moves in a denser zig-zag pattern (customizable, default 0.1mm) with much lower extrusion multiplier. This helps smooth out any surface irregularities and gaps on the topmost layer, hence the name: "ironing"

property mainly depends on the degree of mobility of the web / weft relative to each other. The ability of a fabric to accommodate cutting stresses is what differentiates it from any other material of the same type, such as paper or plastic films. It is this property that allows it to take forms that are more complex than two-dimensional and can be shaped to the contours of the body when applied to clothing." (Broega et al., n.d.)

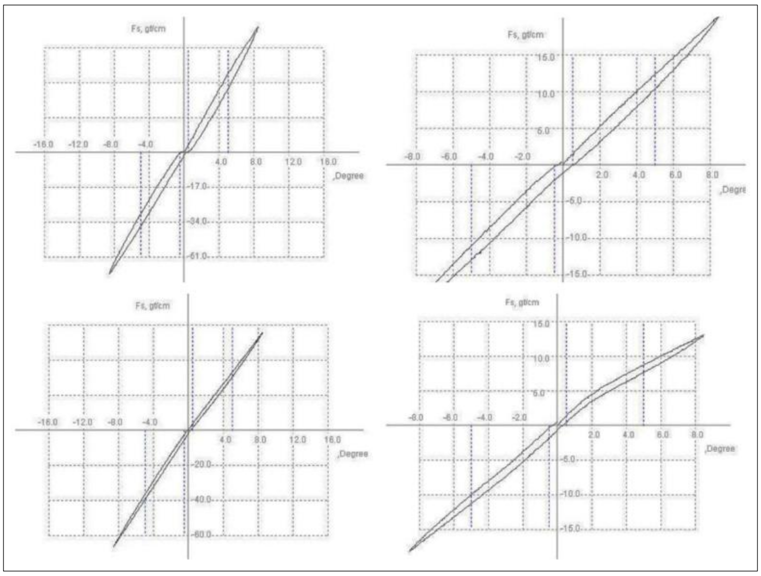


Figure 2. Comparison of the shear parameter in samples A, B, D and E.

MODULE: KES-FB2 (Property: bending)

"This test measures the tension developed on a fabric when subjected to a moment of bending force. It allows to study the behavior under flexion in simple request conditions with a constant curvature of approximately 150º (distributed by the right and averse of the fabric). The bending moment and the curvature - bending moment relationship are determined." (Broega et al., n.d.)

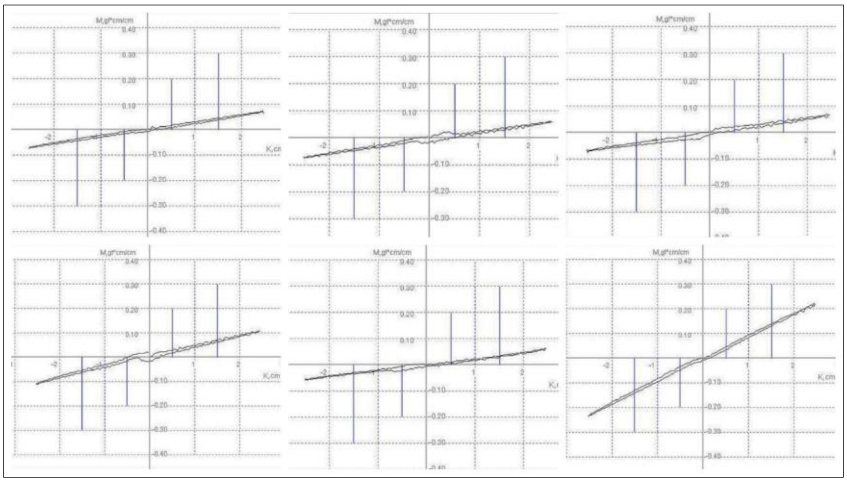


Figure 3. Comparison of the flexion parameter in samples A, B, C, D, E AND F.

MODULE: KES-FB3 (Property: Compression)

“This test measures the tension developed by a fabric when it is subjected to a normal pressure exerted on its surface. The factors that can affect the compression are: the type of fiber, the structure of the fabric and yarn, the crimping of the yarn in the fabric and, mainly, the finishing of the fabric (pressing, scissoring, batting, etc.)” (Broega et al., n.d.).

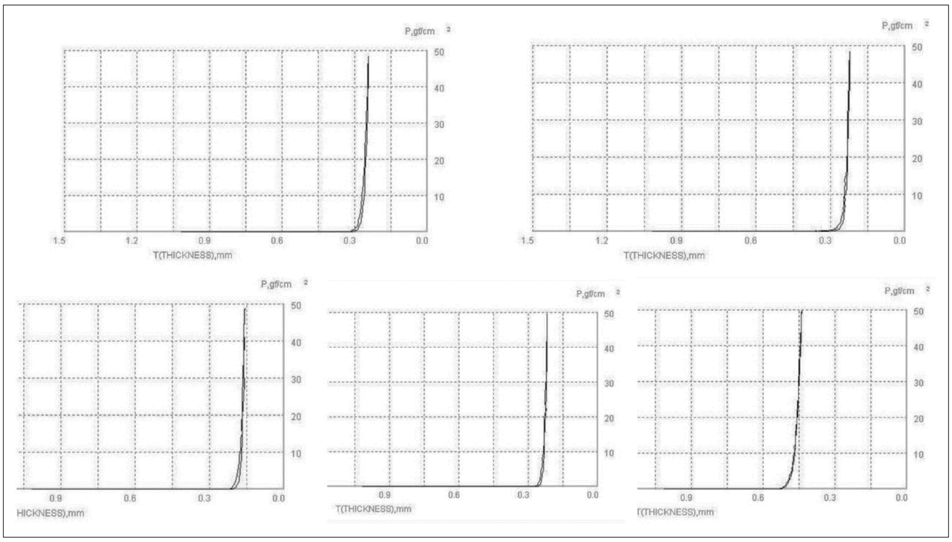


Figure 4. Comparison of the compression parameter in samples A, B, C, E and F.

MODULE: KES-FB 4 (Property: Surface)

“This module allows to measure the parameters of the properties that characterize the surface of the fabric that are studied under the physical aspect (average friction and its linear deviation) and geometric (linear deviation of the thickness). the module consists of two sensors in which one makes the reading of the friction parameters and the other of the roughness parameters, simulating the human finger” (Broega et al., n.d.).

This was the most complicated tests to perform due to friction and the fabric constantly getting stuck and rolling, and the results are not at all analytical.

Table 3. Parameters units in the Kawabata system, International System and Modaris 3D Prototyping program; Conversion of units; Sample data A, B, C, D, E and F.

Units	Kawabata	Modaris 3D	SI	Conversão k→m	Silk Modaris Warp/Weft	A Kawabata	B Kawabata	C Kawabata	D Kawabata	E Kawabata	F Kawabata	A Modaris	B Modaris	C Modaris	D Modaris	E Modaris	F Modaris
B	gf.cm²/cm	1e-6 N.m	10^{-3}N.m	x 98	0,741/0,343	0,0920	0,0176	0,0435	0.0207	0,0251	0,0283	9,016	1,725	4,165	2,029	2,460	2,773
EMT	%	%	%	-	4,35/16,7	canvas											=
LT	-	-	-	-	0,795/0,812	canvas											=
WT	g.cm/cm²	N/m	J/m²	X 0,98	0,849/3,326	canvas											
G	gf/cm.°	N/m.°	N/m.°	X 0,98	0,172/0,172	7,23	2,19		2,54	7,43		7,085	2,15		2,49	7,28	
2HG5	gf/cm	N/m		X 0,98	9,81/9,81	3,50	1,25		2,13	7,25		3,343	1,22		2,09	7,11	
MIU	-	-	-		0,164/0,156	0,288	1,950	0,499		0,072	0,683	0,288	1,995	0,499		0,072	0,683
Weigth	mg/cm²	Kg/m²	g/m²	X 10	0,032	canvas											
T (0,5gf/cm)	mm	gf/cm	mm														=

After all the conversions, a simulation of the samples applied on a simple blouse with canvas fabric was performed through the data obtained in Kawabata.

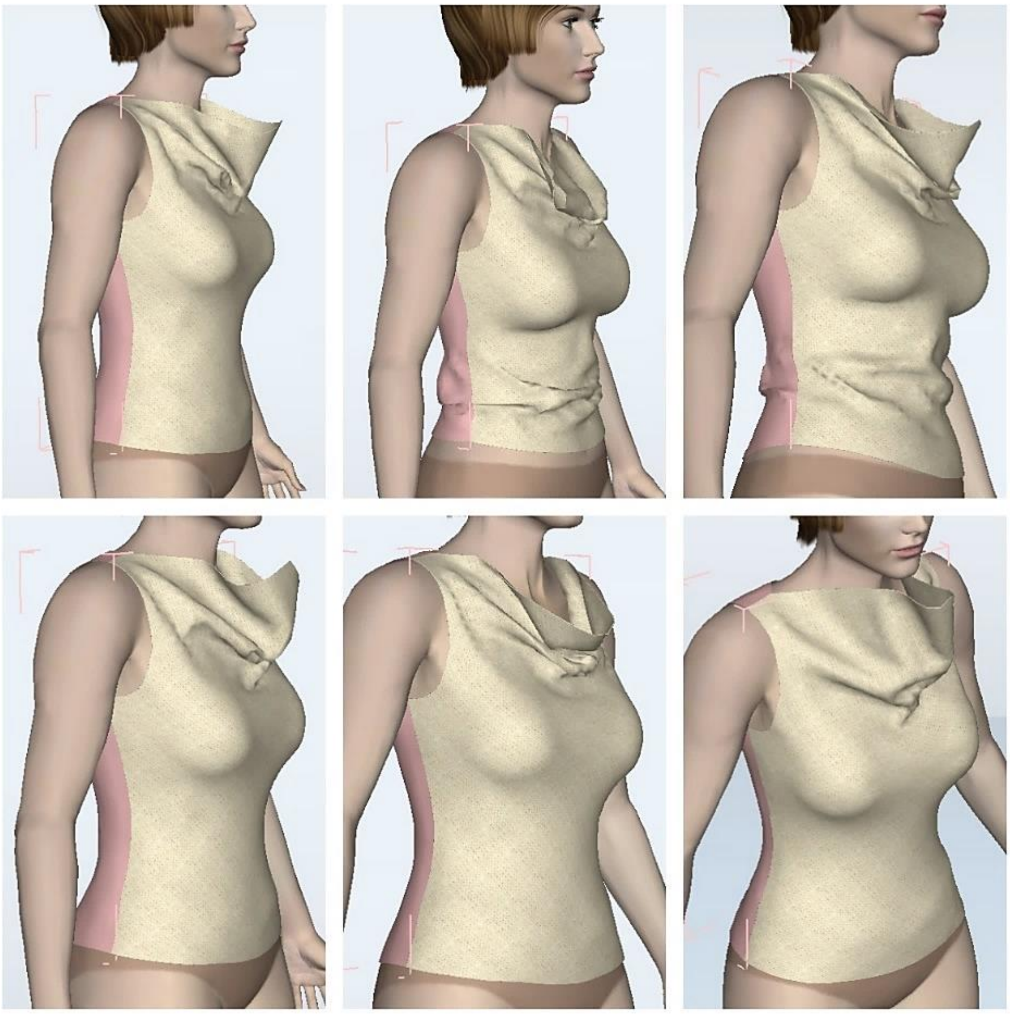


Figure 5. Translating all these numbers into a simulation for more concrete observation of the real differences.

Through these images we can get a clearer view that samples B, E and D show a better drape than the others. The piece of clothing, a blouse, was because of the difficulty in setting the collar in front, so that the results became visible more easily.

Chapter 5. Textile structures: traditional weaving and knitting.

When trying something new, there is a group of pre-acquired knowledge that allows formulating this hypothesis and conceiving the idea. So, it was with this research, in which the attempt to create fabrics made in 3D printers, was based not only on the fundamentals of 3D printing but also on the foundations of the textile industry. The first attempts to recreate textiles with a 3D printer were based on the interwoven knitting, as the first materials used were rigid, which gave some structure malleability. This approach was the first to be tried soon by Janne Kyttanen, and consequently several tried the same way. However, the actual limitations of the current printing equipment do not allow much more simulation being that the existing technology is one of the biggest obstacles. However, this may not be a real challenge, we may have to disassociate the new printed fabrics from traditional fabrics. They are different at so many levels that it may not make sense to try to correlate. While in the reproduction of knits, each loop is printed on a scale much larger than those obtained on looms, when trying to reproduce the fabrics the difficulty is even greater because the equipment does not allow all that interlacing and that a thread goes over and under of another thread. Still, if we think objectively, this interlacing of wires is solely and exclusively to form a cohesive network and allow the wires to not loosen. This can be easily transposed to 3D printing when we accept that the important thing is these melting / cohesion points that allow a mesh and that there is no shredding. With this in mind, the overlap of printing layers and the definition of the angles thereof corresponds to the fabrics and meshes, thus allowing thicknesses as small as that of conventional fabrics and without creating huge loops resulting from the attempt to replicate the conventional process.

5.1. “Sewing” and post-processing of 3d printed fabrics.

The parts realised in 3D printing with FDM technology usually have a rough finish due to the height of the printed covers themselves, problems of flow, resolution of the machine, speed of impression, among others. There are already several solutions to achieve a smooth and glossy finish, however, again most of it is focused on rigid materials and the post processing of flexible materials is still practically null because of the adversities it represents. In this sense, a number of recurring practices of the post-processing of the rigid materials were tested in the flexible materials, as well as some experimental practices.

Drawing the pieces already predestined to the assembly is often a solution, as well as gluing the different components to compose the final piece. However, the assembly method applied to the fabrics can be extremely complex, time-consuming and counterproductive due to the very small size of the pieces and the enormous amount to constitute a fabric. The bonding suffers from the same problem, with the aggravating fact that each material needs specific types of glue and yet it is always a point more susceptible to tearing or breaking.

Making fills in structures printed with flexible materials is not impossible but it is a totally unwanted result for a fabric, the aspect is always very rudimentary, be it done with paints or even with the use of filament through the 3D pen. Sanding the parts is totally unfeasible, although it can be a good alternative in certain rigid materials, in the flexibles it simply degrades the material and the effect is totally the opposite of the desired one.

In FDM technologies it is still a bit complex to print several colours, so a commonly used alternative is colouring after printing. In the case of fabrics printed in 3D this will generate a lot of problems like colour transfers, blur painting, and it is not at all recommended. In fact, the most successful post-processing methods were precisely the experimental ones like welding and sewing. Which is quite adequate considering the end use and the industry in which these "tissues" are intended to be inserted.

5.2. Fundamental characteristics of FDM desktop.

This sub-chapter will address some of the equipment's constraints to successful printing. Most FDM systems combined with the printer's own characteristics with the slicing software allow adjustment of various process parameters such as nozzle and construction platform temperature, construction speed, layer height and speed cooling.

One of the first conditioning factors for printing and even for the design process is the available construction size of a 3D printer, usually around 200 x 200 x 200 mm, in the desktop versions, so that, inevitably, a model large parts need to be divided into smaller parts and then assembled, welded, glued or sewn.

Another constraint for printing and for its quality is the height of the layer that normally ranges between 50 and 400 microns. The thinner the print layer, the more smooth and detailed the object will be, while a larger height produces parts faster and at lower cost as well, but a lower, more rough quality. Due to the additive nature of 3D Printing, the thickness of each layer determines the resolution of a print in a manner similar to the number of pixels that determines the resolution of a television. The lower height of the layer usually results in parts with smoother surfaces. The disadvantage is that the lower the layer height, the longer it takes to complete an impression, ie, this factor is also directly related to the print speed.

That is, layer height is an important design parameter that affects the print time, cost, visual appearance, and physical properties of a printed part. Often, the visual difference between the parts printed at 100 μm and 200 μm is very small, especially in rigid materials, but in the flexible the situation is different. However, the part in 100 μm will take twice as long to print (the 3D printer will have to plot twice as many cross sections).

Also the diameter of the nozzle will influence not only the amount of deposited material but the quality of the print and consequently the final time of execution. The smaller the diameter the more detailed and also the final piece will be delayed.

There are still aspects such as flow that are determinant during printing but are more related to slicing software than to the printer.

Chapter 6. Sensory quantitative Data.

The primary goal of product development is consumer satisfaction, so it makes sense to subject the product to consumer perceptions through preliminary contact. Thus, it became imperative a sensory analysis (Nogueira, 2011) of samples obtained at an early stage, to study the perceptions, sensations and consumer reactions to the characteristics of products, including acceptance or rejection. In order to evaluate the interpretation that a consumer would have when exposed to 3D printed textiles, without being aware of the type of materials involved, a sensorial analysis was performed, where a questionnaire was provided along with 6 samples of printed fabrics. The objective was the interaction of the individual with the material and perceive how different it considers the samples of the fabrics that it uses in the quotidian, as well as if it is strange the material and realizes that in fact there is something different there from the common materials to which it normally has access.

The questionnaire was anonymous and as an identification only asked for age and occupation, so that the results of tolerance to new clothing materials could be compared according to the age groups, and to understand the perception of individuals related to the textile sector regarding the samples, as well as the response from a broader public. The samples provided were carefully selected so as not to reveal too much of the work already done and progress made, so that respondents only had access to printed samples without colour effects, special finishes, manipulations or elaborate structures. As well as no sample of the material 60A and our own filaments was given, as it represented precisely the largest points of advancement.

Six samples were then available (see table 4) along with questionnaire in paper format (see appendix XXVII). People were randomly approached in the geographic region of the Castelo Branco and Braga districts. Each respondent then had access to the paper version of the questionnaire along with the 6 samples that could be used and observed. On average, each respondent took approximately 30 minutes to complete the questionnaire, and for each observation required, they returned to consult the samples provided and try to quantify their perception of them. We obtained 54 responses that provided the results presented in the following graphs.

Table 4. Table of the samples used in the questionnaire.

	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F
thickness	100µ	60µ	100µ	150µ	150µ	200µ
shore	82A	70A	70A	82A	70A	70A

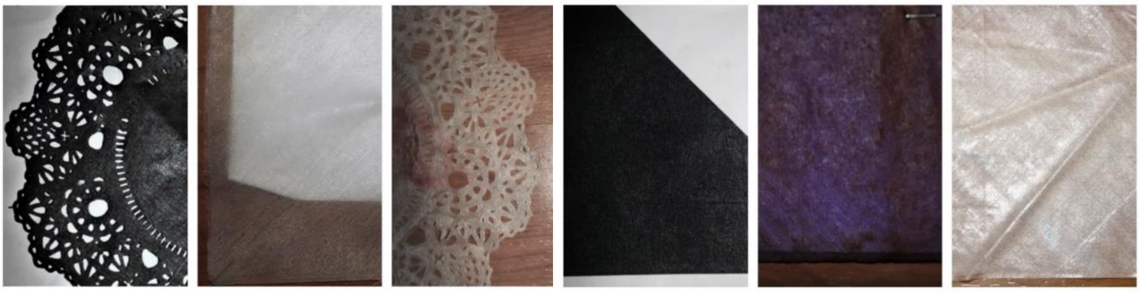
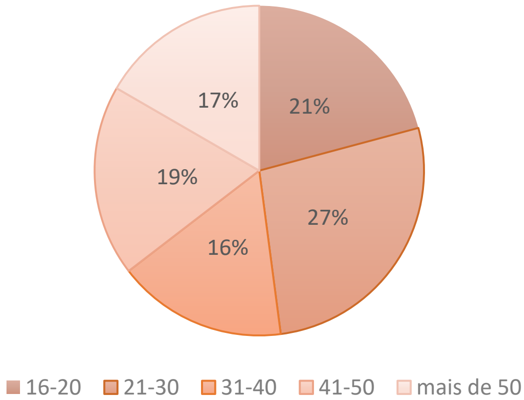


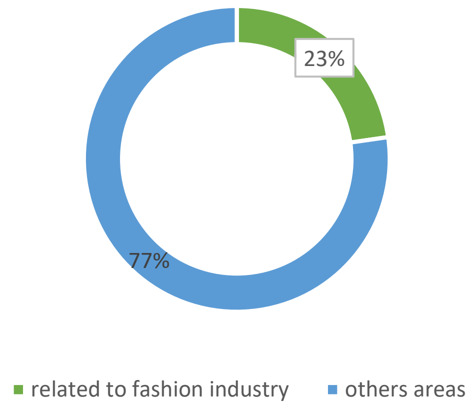
Figure 6. Samples used for the questionnaire.

The first data obtained through the questionnaire was the segmentation of ages, without large disparate differences, which shows a uniform distribution of opinions among the various types of consumers, knowing how important this is for marketing targeting and target audience analysis (see graphic 1). Nevertheless, there is a predominance of responses from a younger and more receptive novelty among the 16 - 20 and 21-30 age groups (see graphic 1). This audience sample is also directly influenced by their willingness to integrate research and their interest in the product.



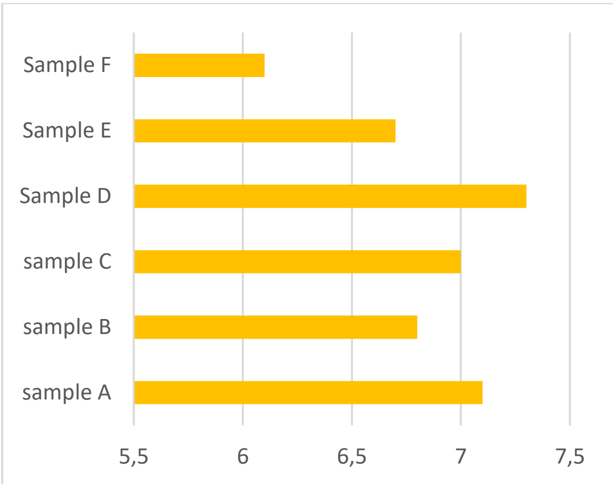
Graphic 1. Distribution of the age groups of the questionnaire.

The profession was also distinguished in order to obtain a relationship between the responses of members of the textile and fashion sectors, such as designers, seamstresses, textile engineers, fashion professors and other consumers with no direct connection to the textile industry, in order to provide an appreciative opinion only as consumers of clothing (see graphic 2). In fact, a greater reluctance of people related to the textile area to the samples was expected due to their greater knowledge of materials, however, this did not happen, being unanimous the acceptance of the samples and the positive feedback of the respondents in general.



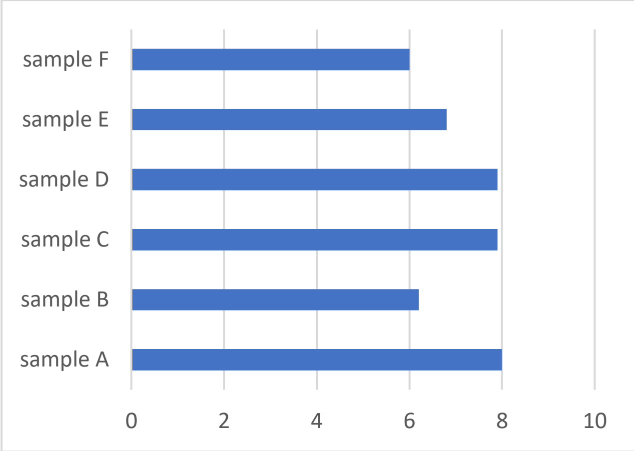
Graphic 2. Professional occupation of respondents

In the first question is asked to quantify on a scale of 0 to 10 the pleasantness of the touch of each sample. The average response for each sample is shown in the chart below. As it can be verified the sample D is the one that has greater acceptance in terms of touch, nevertheless it is important to note that the average classification of all is positive.



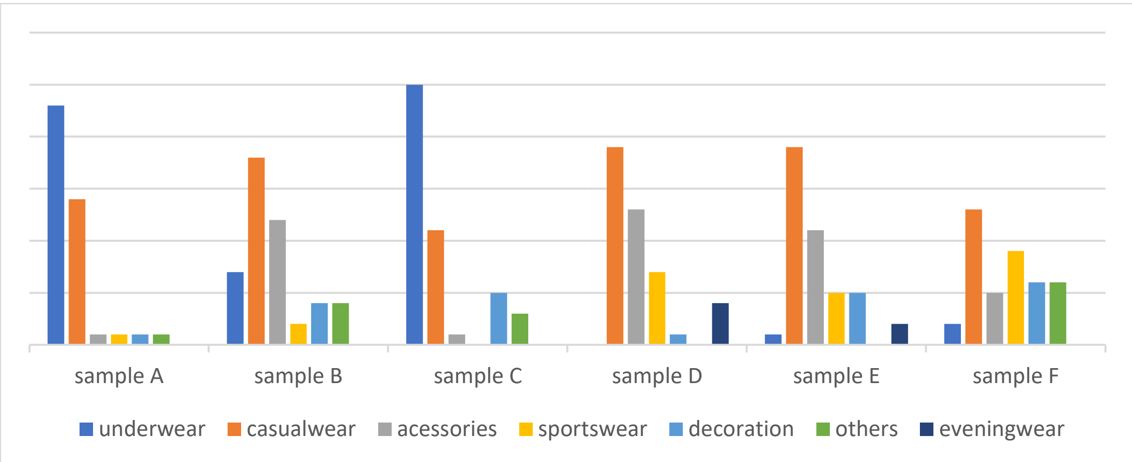
Graphic 3. Average classification of touch in each sample

In the second question, again through the scale of 0-10, we are asked to quantify the visual aspect of each sample, to ascertain another factor equally in the choice of clothing: the aesthetic appeal. Again, sample D, as well as the A and C show the best acceptance of the consumers. Also, in this aspect the F sample is the worst performing and is at the average threshold of the scale, being the closest to an average negative evaluation.



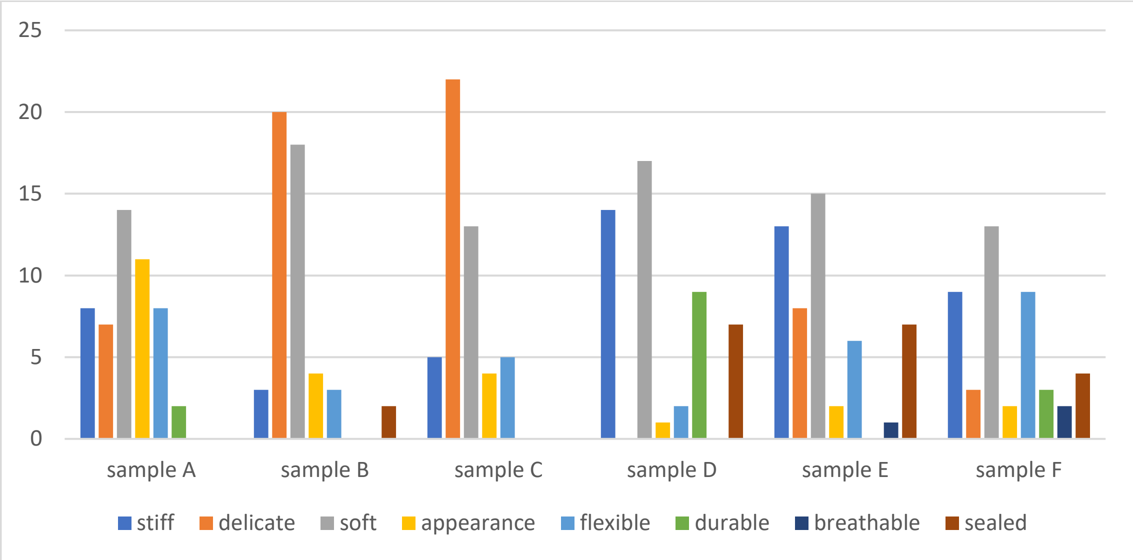
Graphic 4. Average classification of visual appeal

In the third point, the more abstract questions are left, and one tries to perceive according to the textile knowledge of each respondent, as a clothing user in general, in what type of clothing do they think these samples could be used or even judged who already uses this material and in which certain clothing groups. The responses were analysed and grouped into categories according to the use suggested by the respondents. In the answers obtained it is possible to verify that when the category is underwear, the public associate characteristics such as comfort, softness and soft touch. In the category of decoration and sportswear, the main features highlighted are waterproofing, just as the association of synthetic skin appears immense times in the category of accessories and decoration. The graph shows that most of the samples are considered for everyday use, which in our view is very important and in fact reveals a perspective of adopting this material. Sample A and C present a high number of responses in the category of underwear that translates into the consideration of being the most comfortable samples.



Graphic 5. Categories attributed by the respondents to each sample

When asked about the points that stood out most in each sample, whether these were positive or negative, the results were as follows:



Graphic 6. Main features attributed by the respondents to each sample.

Samples B and C stand out immensely for their delicacy which also goes against the comfort associated with them previously, and their use in underwear. In general, all are still considered soft in reference to comfort and pleasant touch. Sample A is still visible in appearance and is also the most unanimous sample in features. Sample D also presents a considerable number of responses in the durable attribute. All are still considered flexible, an attribute that from the beginning of the research worried us, by all the characteristics associated, and that clearly was an aspect emphasised in the sensorial analysis being possible to notice an accomplishment in this aspect. finally, the final questionnaire and opinions about the samples were a questionnaire and a simple direct question at the heart of the problem: would you use this material in your clothing? Would you buy clothes made of this material? Of the 54 respondents, only 3 responded "maybe", and the choice was divided with 21 people responding negatively, although 11 of these 21 reported that they wouldn't use only some of them. In the majority, although not absolute, people reacted positively, and we can already speculate on a real implementation being that the acceptance is not as unwanted as the speculated.

Conclusions

In this dissertation, we attempted to develop an innovative approach focused on the development of new technologies in the context of its use in the textile sector. All this research aimed to prove not only the possibility of creating real printed textiles but also to remove the application of fashionable 3D printing as conceptual and to deepen even viable results for everyday use. We can conclude that the results exceeded expectations as we observe with satisfaction our contribution to the development of a new textile typology. Yet, there is still a long way to go and this first attempt can be considered as a beginning of the "3D Textiles Era".

Based on all the information obtained on the subject, we soon realised that some authors deviate from the hypothesis of designing 3D printed textiles, some support with some caveats, but in a general context, the progress made in this direction is still scarce and much of it is reticent about a real possibility of implementation. Based on the literature review, it was also verified that when 3D printing is applied in fashion, it is practically always in a conceptual context, which still further fuels the view that this is an unfeasible alternative.

Contrary to some of the initial assumptions, throughout this research, the results indicate that it is possible to produce truly usable and totally 3D printed textiles, even with the current technology, where there aren´t machines and materials more specific for fashion applications, specifically clothing.

An important point to consider is that we only use a desktop FDM printer, based on literature review, several methods can still be studied to replicate this type of results or even go further, ACEO, SLS or even FDM printers like sliding 3D can provide even better results by taking into account some of its specifications.

As Valtas (2016) states in his study, these textiles initially appear plasticised or rubberised and do not own the absorption property (yet, and not completely true), so far the results contradict Valtas' (2016) assertions that these textiles cannot be treated with ease, and also cannot be sewn, washed or even ironed. In fact, the samples obtained were all subjected to more than 50 washes in a typical washing machine, seams were tested on traditional sewing machines and even some can be ironed at low temperatures (preferably with a vegetable paper over the top or some fabric). Actually, we prove not only that 3d printed fabrics could be easy maintenance, but also it is possible to carry out a wide range of manipulations in the filament or the printing in order to colourise and to surpass the scarcity of available colours, as well as to remove the gloss of the impression, among others. Even in the dyeing process, we obtained results that support the ease with which they are dyed as any polyester fabric. Another important point to note is that when the samples were analysed in a system specifically designed to characterize the touch and replace a sensorial analysis such as the Kawabata system, the data obtained were introduced in a 3D simulation program, and the result resembles other conventional fabrics.

When it states that modelling software is not ready for garment modelling, it is also partially true, but the study we have developed does indeed prove that there is already some ease in adopting existing software for textile production.

Sensory analysis can also lead to the generalization of results limited by the small number of subjects analysed, but should not be devalued, it is intended only to exemplify a small panorama that opens the possibility of people actually coming to acquire printed clothing. In this perspective, it was proved that, even in the case of samples without large manipulations, consisting essentially of a fabric as basic as possible and in neutral colours, without any dyeing or finishing, the inquiries showed interest and a very positive opinion. The reliability of these data can be clearly conditioned by the geographic sample, with all data collected only in Portugal, so that a larger scale of analysis can be carried out in the future.

Based on the results of similar studies, we can assume that the basis for the success of our study consists in the low thicknesses created, similar to conventional fabrics, as well as the structures developed from the beginning inspired by traditional weaving and knitting. In fact, according to authors like Wang (2014) we also believe that printed textiles do not come to replace traditional manufacture but rather to coexist, which does not avoid them from being inspired by conventional fabrics, does not mean that they will be copies of them.

According to the hypothesis of Mikkonen (2014) and Pei (2015), we also confirm that this is a good solution for wearables and try to incorporate electronic components in the wardrobe, as well as for the incorporation of garments such as trims.

Throughout all the experimental phases were recognised the failures and necessities to reach a more appealing textile, reason why we constantly challenge the limits not only of the equipment's as of the materials, this perseverance took us not only until filaments "rare" and difficult to obtain , as it enabled us to understand which way to go.

Based on all the data collected by the samples, the sensory analysis, interviews, Kawabata system, questionnaires, we can assume that this is a feasible line of study for the production of 3D printed textiles, which still remains at a stage very related to customization and without much attention to making everyday use accessible, as well as a future method of mass production must also be taken into account. Besides that this approach could have a good impact on textile sustainability, through the maximum reuse of the material, shortening of the distribution process, it should be emphasised that without awareness there is the possibility of resulting in the opposite problem: deregulated production of plastics and disposed of in inappropriate places that make recycling impossible.

We conclude therefore that it is not only possible to produce 3D printed textiles, as it is possible to have only current materials and technologies, yet we must develop printers, software and materials more oriented to the textile application in order to develop the sector and implement the use of this technology by a greater number of designers.

Research limitations and future research suggestions.

The results are positive, and it was clearly further than originally anticipated when we thought that it would not be possible to pass from the printed fabrics to rigid materials or at most use the FilaFlex, but it is still important to recognize the limitations of the work, with the aim of perfecting a project that we believe is useful and capable of helping industry and consumers.

In this sense, there were several obstacles that we have encountered that have limited us, such as the lack of a printer, the poor quality of the printer, constant malfunctions and, above all, the lack of economic support for all the research. At the level of the computer part we find several problems like the lack of suitable software for the process, the lack of preparation to use them, and once again not having the computers with the characteristics necessary to run the programs.

It was not so much a limitation but derived from the constraints to which we were subject, it was also the poor quality of the samples obtained and the impossibility of testing some of the theories and ideas developed.

The lack of study of the area and the inability to relate to professionals of the same, being the development of this area in Portugal still almost null, led us to an exhaustive process of self-learning from software to printers and materials, was a true beginning of the zero, taking into account that when the project started we did not even know what a 3D printer was.

Several resources are needed to execute a project of this kind, the lack of necessary investment, both at the training level and at the material, has often made the task seem impossible. Still the research represented obstacles, with a scarce revision of literature, due to the novelty of the theme. And although some articles mentioned some of the techniques we applied, the work was essentially exploratory. Despite the time we had for the realization of this project, we felt that much more could be done and deepened so that time has become very little, this being a study that can occupy a career. Despite the different difficulties faced both at the level of human resources, materials and investment, as well as the various limitations of equipment and information available to date, we consider the research to be successful and have a great positive impact, whether to continue in future research, as well as the creation of a process that makes implementation possible at the present moment, although improvements must be made.

The critical spirit that characterised this project made us achieve all the results obtained, as well as anticipate several options for continuation.

First, we identify the poor quality of the samples obtained and this is a point to improve considerably, as well as a greater number of tests can be done in the level of dyes and several other manipulations, but we also intend to trace DNA of each tissue with further analysis in the Kawabata system and other devices.

Another important aspect of this new typology is the ability to incorporate electronic systems, LED's, fibre optics, sensors, microcapsules ... it offers a multitude of alternative applications, both for technology and for quality of life. The properties that can be introduced in these textiles exponentially increase the development of wearables as well as the development of textiles with medicinal properties and applications for physiotherapy.

In addition to the proportional applications for accessories and footwear, we must take into account the large number of types of fabrics that can be "reproduced" or better adapted to 3D printing, such as pleats, prints, double-faced, several other simulations, we believe that for each type of fabric or manipulation of the same, there will be a corresponding in 3D printing. In order to deal with one of the main problems pointed out by several authors, in the future we also want to introduce various types of fibers in order to obtain the desired absorption of these textiles.

Another key idea is not only to keep research focused on the recycling of plastics and reuse in 3D printing, but also to reproduce all these results with bioplastics, the idea is to discard the production of more plastic and only deal with the recycling of what is already in circulation, and to ensure that all new products are actually made with bioplastics, so that even in the event of irresponsible use by consumers, disposal of these products does not have harmful effects on the environment.

The great challenge will be to achieve flexibility, strength, consistency, good quality and absorption in a different approach to plastics, so we need to be able to produce filaments through these natural compounds and modify the entire process to handle this new material. Almost like a fresh start, this stage focuses even more on the process of sustainability and embraces the component that can from the beginning, be created by virtue of the textile application.

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Appendix I - Textiles structures by Freedom of Creation.

Image retrieved from: https://www.3dsystems.com/blog/foc/foc-textiles-to-permanent-collection-at-moma?utm_source=freedomofcreation.com&utm_medium=301

Appendix II – 3d printing pieces from Escapism Collection.

Image retrieved from: https://weburbanist.com/2013/05/01/high-tech-to-high-fashion-upscale-3d-printed-designs/

Appendix III– Skeleton dress by Iris Van Herpen

Image retrieved from: https://ruwimgt.pw/iris-van-herpen-skeleton-dress.html

Appendix IV- Queen Ramonda costume from Black Panther movir, by Julia Koerner

Image retrieved from: https://eluxemagazine.com/fashion/black-panther-costume-designer-julia-koerner-is-a-3d-design-goddess/

Appendix V - 3D printed skirt by Julia Daviy.

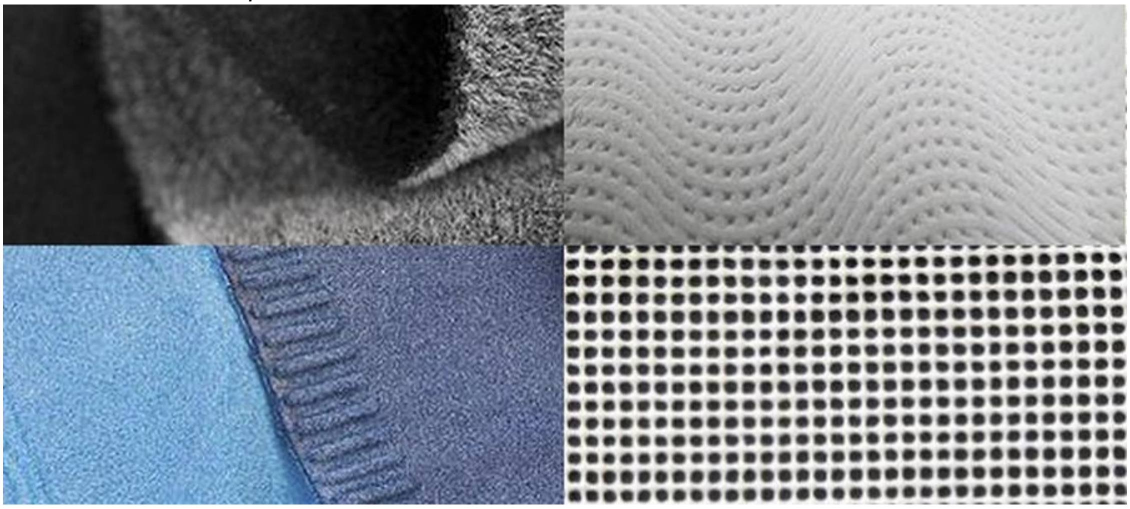
Image retrieved from: https://wtvox.com/fashion-innovation/zero-waste-3d-printed-skirt/attachment/wtvox-3d-printed-skirt-01/

Appendix VI. 3D printed textiles by Comme des Machines

Image retrieved from: https://www.instagram.com/commedesmachines/?hl=pt

Appendix VII – Textiles from TamiCare

Image retrieved from: https://portal.engineersaustralia.org.au/news/3d-printed-smart-textiles-allow-one-step-manufacture-wearable-tech



Appendix VIII – Danit Peleg collection's

Image retrieved from: https://danitpeleg.com/catalog/

Appendices IX and X. Spider’s dress and Smoke dress by Anouk Wipprecht

Image retrieved from: https://medium.com/@darameja/3-questions-to-the-spider-dress-creator-anouk-wipprecht-about-technical-challenges-and-future-of-9bb8bc65a227

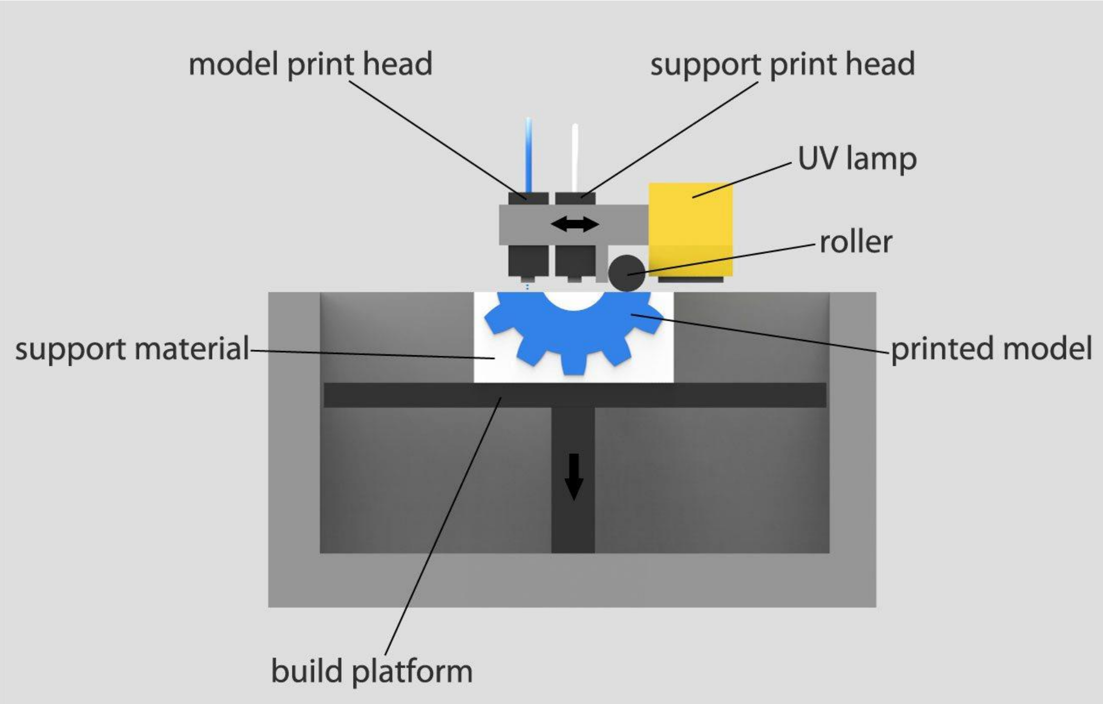
Image retrieved from: https://uttutextiles.wordpress.com/2013/08/22/the-smoke-dress-by-anouk-wipprecht/

Appendix XI. Hard Core Vein 2.0

Image retrieved from: http://2016.tecart.nl/portfolio/maartje-dijkstra/

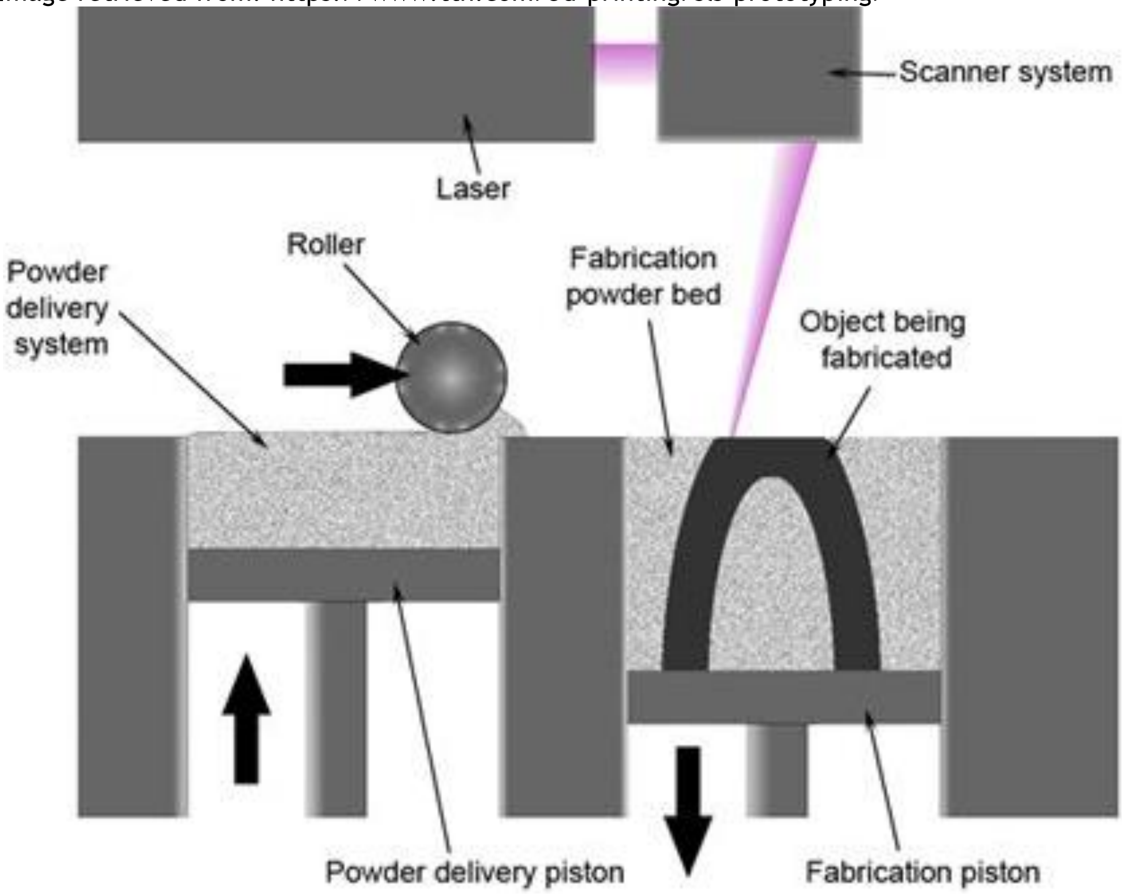
Appendix XII. Polyjet technology

Image retrieved from: https://www.tth.com/3d-printing/objet-prototyping/



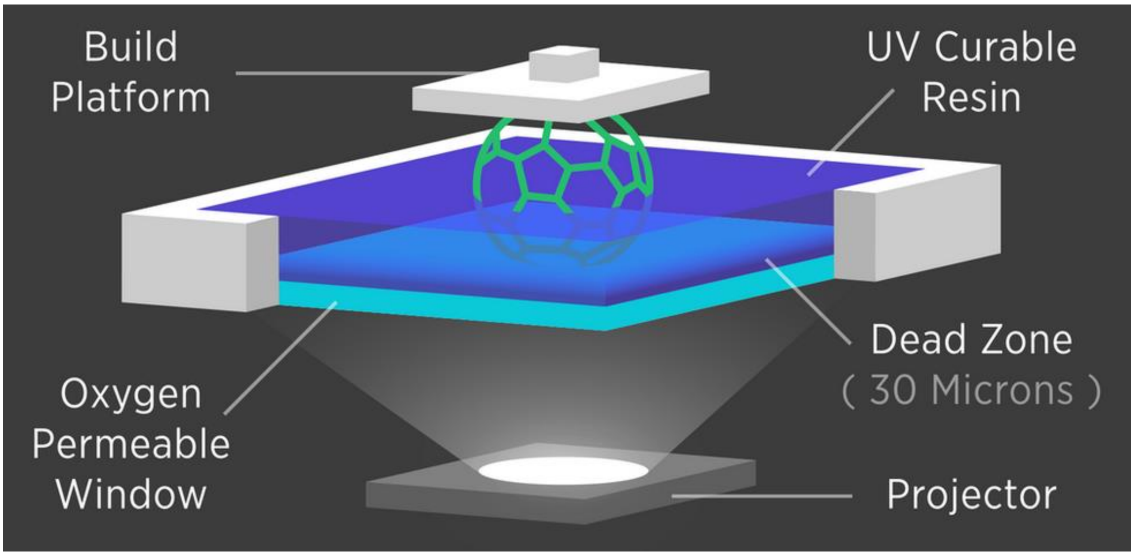
Appendix XIII – SLS technology

Image retrieved from: https://www.tth.com/3d-printing/sls-prototyping/



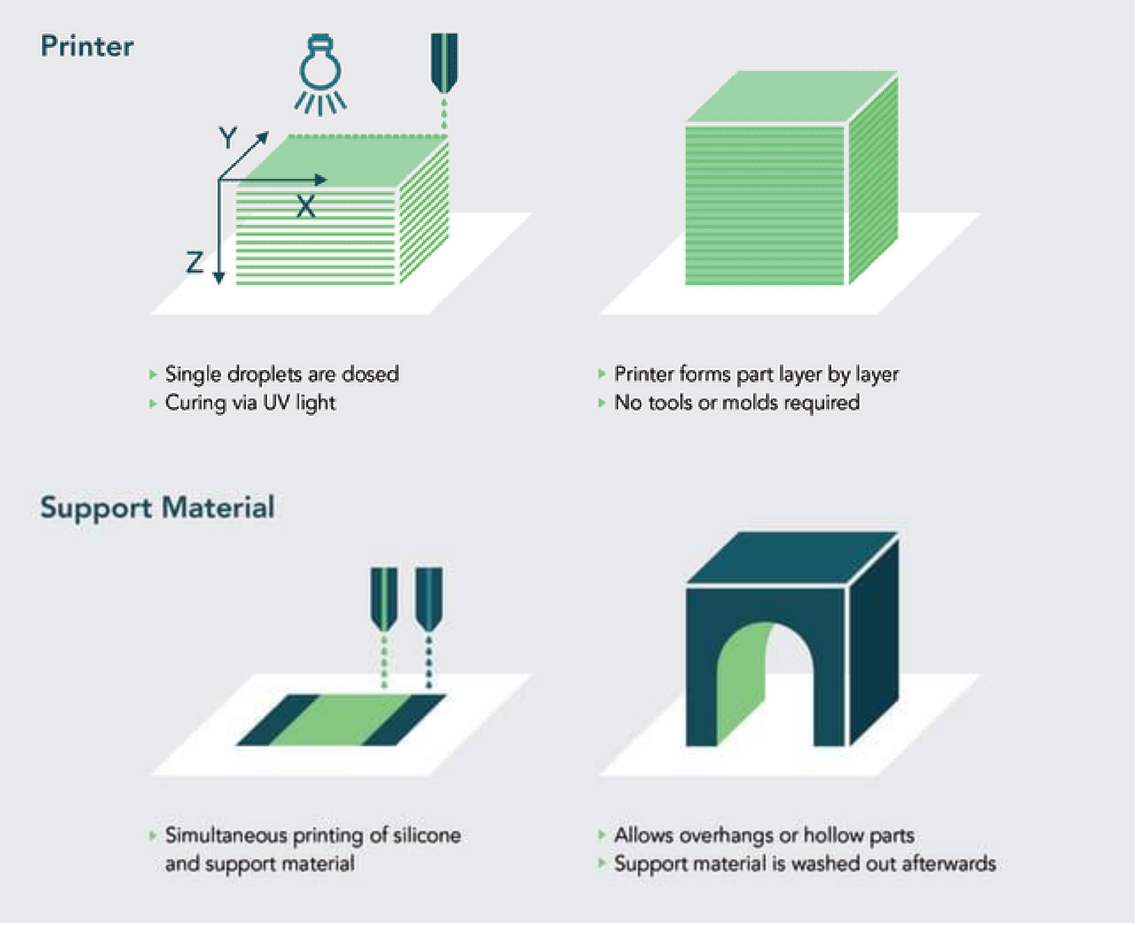
Appendix XIV. CLIP technology

Image retrieved from: https://3dprint.com/51566/carbon3d-clip-3d-printing/



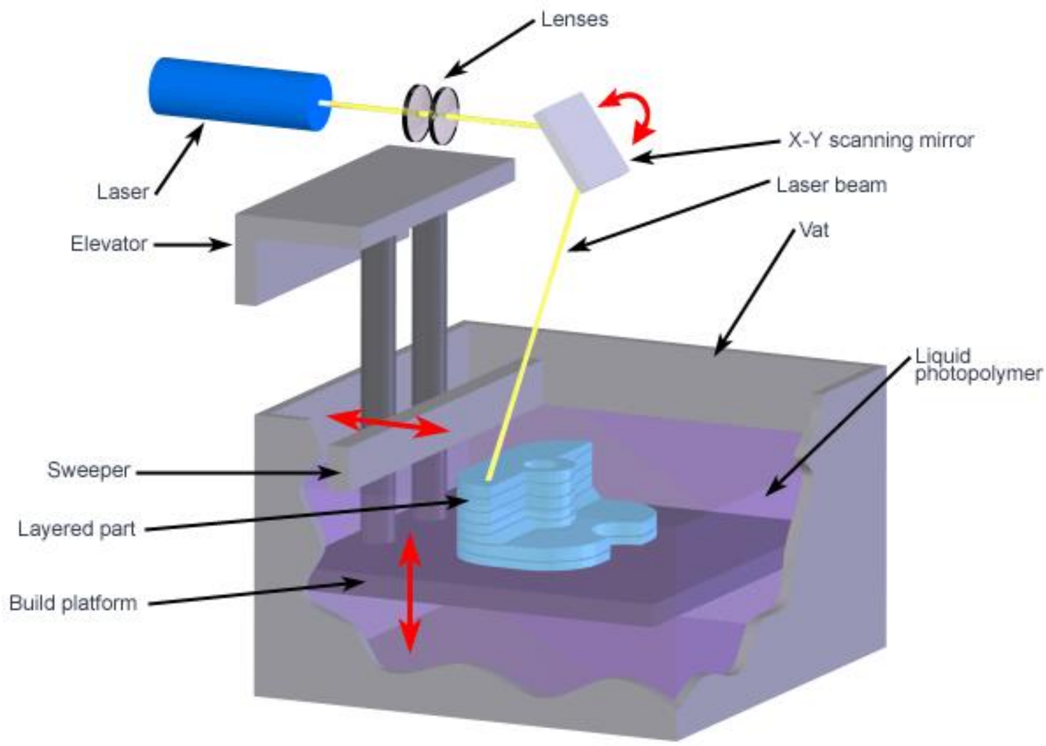
Appendix XV. ACEO technology

Image retrieved from:
https://www.engineering.com/3DPrinting/3DPrintingArticles/ArticleID/14219/WACKERs-ACEO-Brings-Silicone-3D-Printing-to-the-Public.aspx



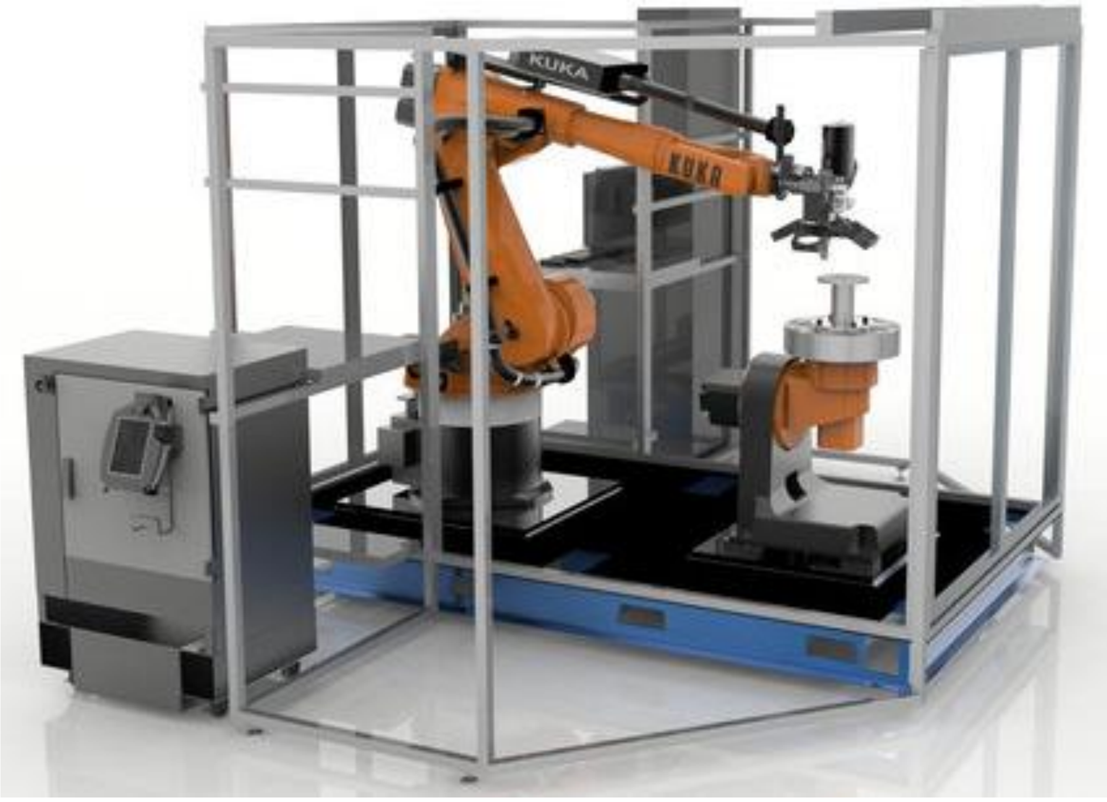
Appendix XVI. SLA technology.

Image retrieved from:
https://www.engineering.com/3DPrinting/3DPrintingArticles/ArticleID/14219/WACKERs-ACEO-Brings-Silicone-3D-Printing-to-the-Public.aspx



Appendix XVII. Infinite Build Demonstrator from Stratasys.

Image retrieved from: https://www.computerworld.com/article/3112144/stratasys-unveils-mega-robotic-3d-printers-to-build-large-parts.html



Appendix XVIII. Blackbelt 3D.

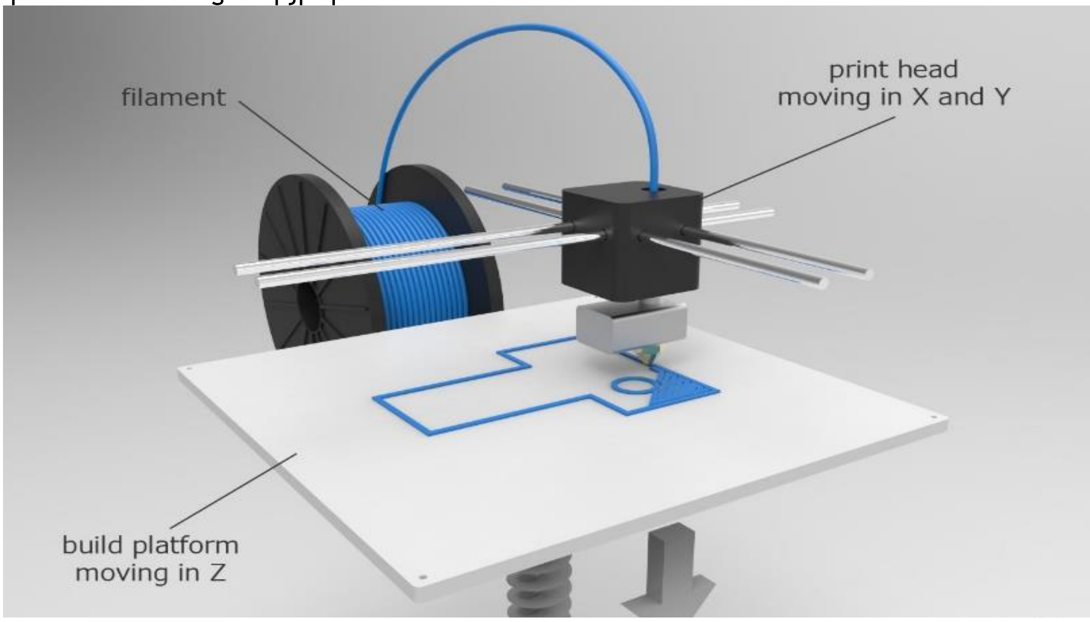
Image retrieved from: https://blackbelt-3d.com/blackbelt-3d-printer-desktop-version

Appendix XIX. Sliding 3D

Image retrieved from: http://lnx.robotfactory.it/en/sliding-3d_en/

Appendix XX. FDM technology.

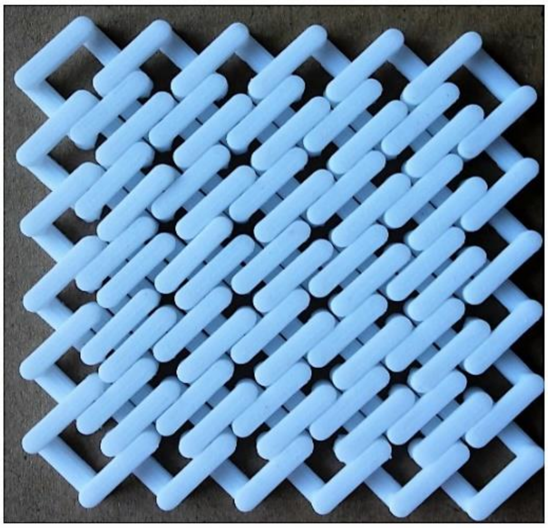
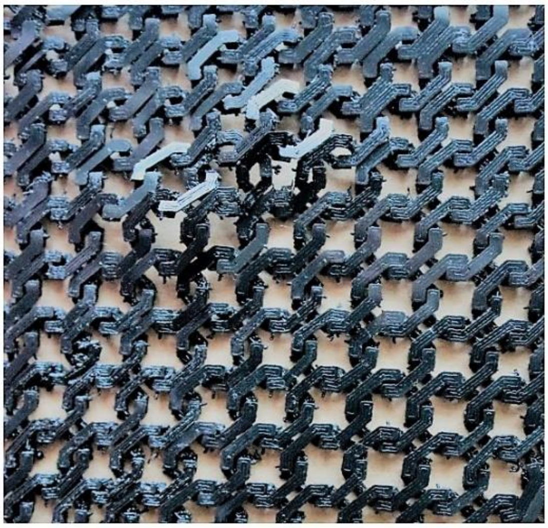
Image retrieved from: https://www.additive.blog/knowledge-base/3d-printers/fdm-fused-deposition-modeling-fff-pjp-lpd/



Appendix XXI. 3D printed textiles with rigid materials “IUR”

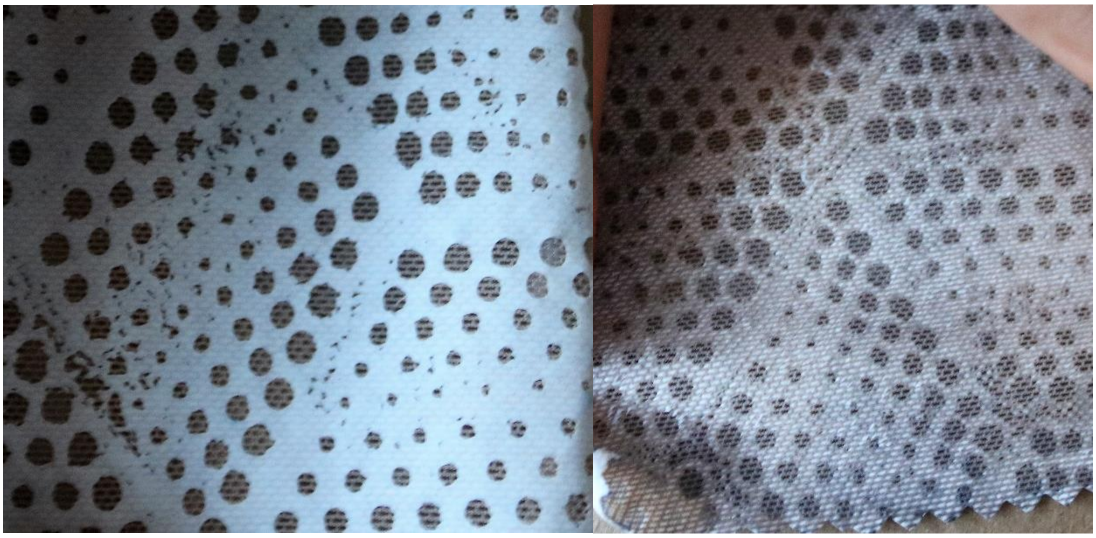
The collections of textiles developed with rigid materials in mesh format I dubbed "IUR". Some of its main properties are strength, hardness but also malleability.



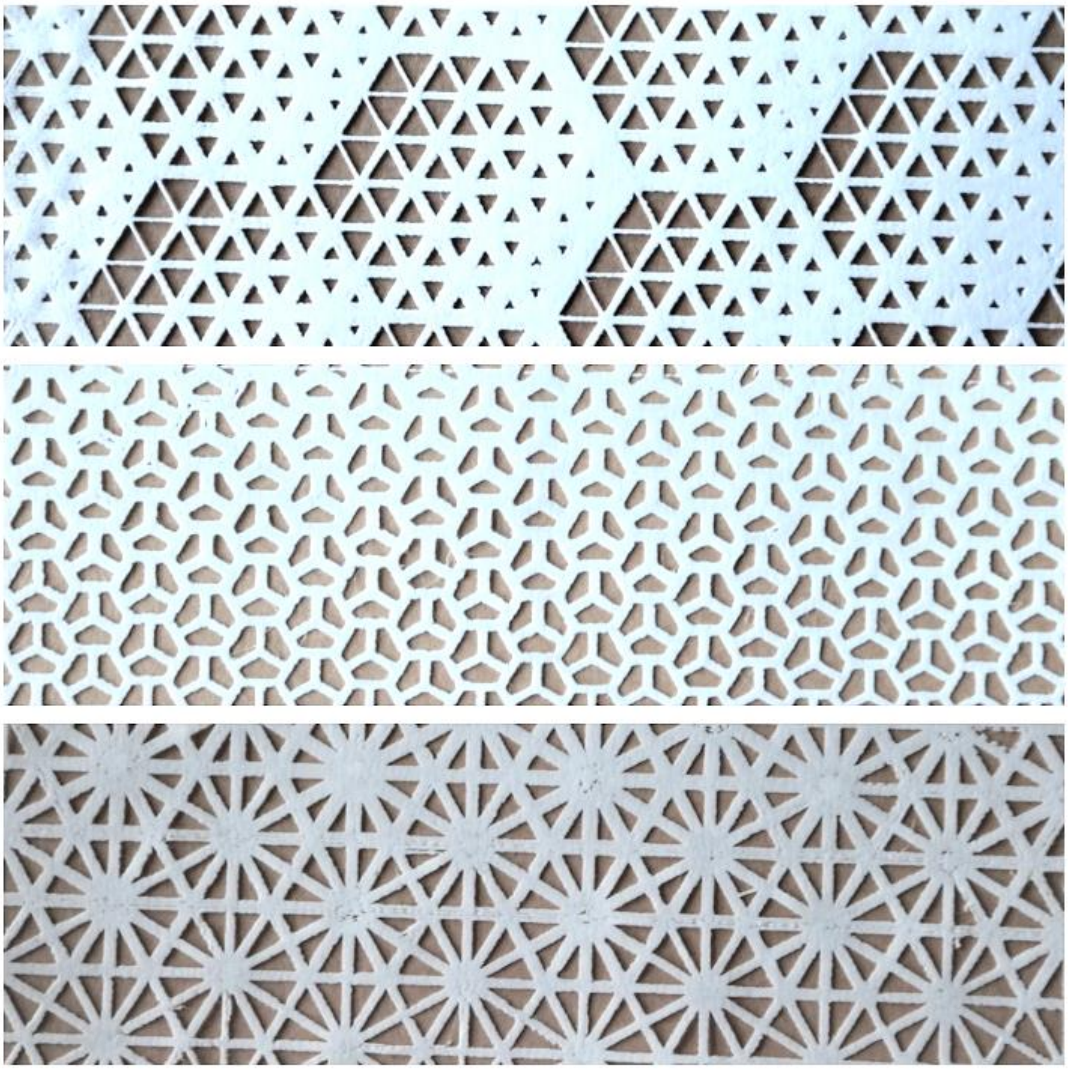
Appendix XXII. 3D printing under fabrics “ELOISE”.

The fabrics developed with 3D printing on them, I dubbed "ELOISE". This is characterised as a fusion between the world of conventional textiles and technology, which results in an open door to a new path in the textile sector, without abruptly detaching from the fabrics to which we are accustomed.



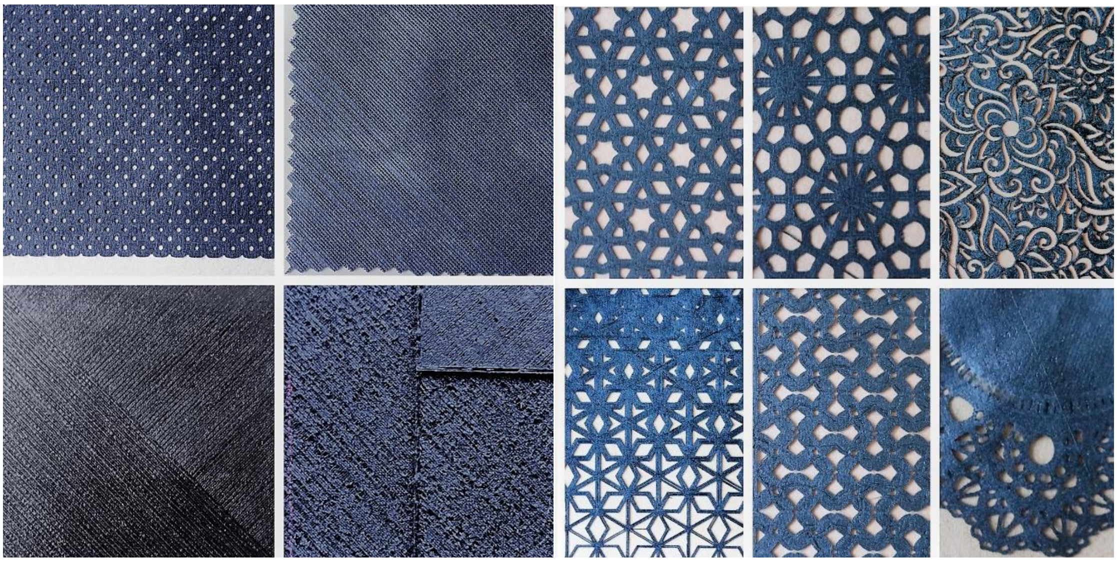
Appendix XXIII. 3D printed fabrics “JOSE”

With the introduction of flexible filaments, we obtained the first fabrics totally printed in 3D, where we can already see the flexibility, suitable for contact with the body and a full-bodied material, which still presents a great stability, so we call the developed tissue line "JOSE".



Appendix XXIV. 3D printed fabrics “MISSONE”

The range of filaments 82A was the one that occupied us the longest and the most difficult to overcome, for all the limitations that arise when printing with flexible filaments. Still, it was also what allowed us to better understand the operation of the material and to succeed with the remaining filaments. The collection of fabrics developed with this filament that we call "MISSONE" was the most experimentation suffered. These fabrics are characterised by good flexibility as well as good final appearance. Within this line derived others like pleated fabrics that we call "SANDRA" and even carded fabrics that we call "DEOLINDA".

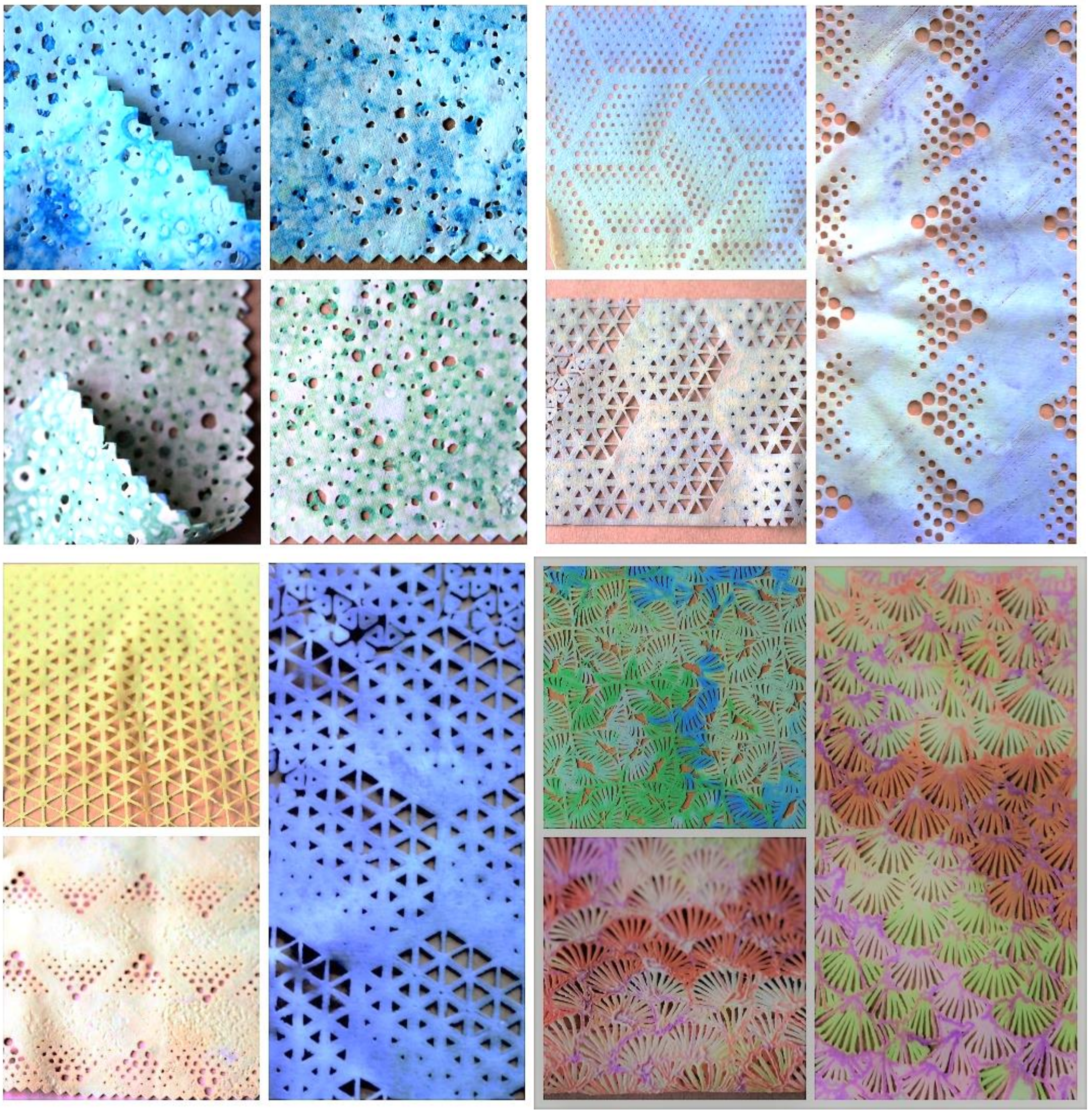


Appendix XXV – 3D printed fabrics "BENIM"

This textile collection developed with 70A filament is very flexible, easy to dye and always with a certain translucent appearance.

Appendix XXVI – 3D printed fabrics “MISU”

The collection of fabrics titled MISU presents the most comfortable and flexible range of textiles of all. Within the same, there were several aspects such as the double-face fabrics "ANA", a range of gradients tissues of the sub-collection "SARA", as well as a wide range of vibrant colours of the collection "BIA" and even patterns like prince of Wales and pied-poule.



Appendix XXVII - Questionnaire

Questionário

Análise visual e táctil de têxteis

(este questionário é totalmente anónimo)

Profissão: ____ **Idade:** ________________

Analise atentamente as amostras que lhe foram fornecidas e responda às questões colocadas com base na experiência táctil e visual.

1. Numa escala de **0 a 10** classifique cada amostra tendo em conta a agradabilidade do toque (sendo que **0** significa **não gostou** e **10** significa que **adorou**.)

Amostra A	⓪	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
Amostra B	⓪	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
Amostra C	⓪	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
Amostra D	⓪	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
Amostra E	⓪	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
Amostra F	⓪	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩

2. Numa escala de **0 a 10** classifique cada amostra tendo em conta o aspeto visual (sendo que **0** significa **não gostou** e **10** significa que **adorou**.)

Amostra A	⓪	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
Amostra B	⓪	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
Amostra C	⓪	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
Amostra D	⓪	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
Amostra E	⓪	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
Amostra F	⓪	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩

3. Tendo em conta os seus conhecimentos sobre têxteis, diga qual é o **tipo de tecido/malha; composição do material ou em que tipo de peças** costuma ver o material que julga ser cada amostra. (Exemplo: penso que seja uma ganga, acho que é algodão, parece o tecido das camisas...)

Amostra A ____

Amostra B ____

Amostra C ____

Amostra D ____

Amostra E ____

Amostra F ____

4. Das amostras apresentadas **diga aquilo que mais gostou em cada uma e em que aspeto podia melhorar.** (Exemplo: a amostra A tem bastante elasticidade, mas poderia melhorar a absorção/ a amostra B parece bastante confortável, mas propensa ao rasgo)

Amostra A ____

Amostra B ____

Amostra C ____

Amostra D ____

Amostra E ____

Amostra F ____

5. Por último, diga-nos a sua sincera opinião geral sobre as amostras e se usaria no seu vestuário, se comprava uma peça feita a partir dos materiais das amostras.

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Agradeço imenso o seu tempo e disponibilidade para responder a este questionário