FASHION IN AN ERA OF 3D PRINTING

The Diffusion of 3D printing technology within the Fashion Industry

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Abstract

3D printing has started making its way into the fashion apparel industry. A number of designers are making use of the additive manufacturing technology to produce one-off complex designs; 3D printing services dedicated to fashion and design are emerging in the market, fashion schools are adapting their programs, incorporating laser-cutting and 3D printing and annual hi-tech fashion weeks are popping up around the globe.

Such a technology, which refers to the layer by layer creation of physical objects based on digital 3D files, has been described as having the power to disrupt and transform the manufacturing system as we know it. 3D printing transforms the design and development process by expanding spheres of possibilities, enhancing design quality and limiting development costs. It also incurs great consequences for manufacturing as it reduces transaction costs, resolves the scale-scope problem and fosters zero-waste production.

Using a technological innovation systems approach, this research attempts to understand the processes of diffusion of 3D printing technology, and the consequences this incurs for the usage patterns of resulting product and process innovations. More precisely, this research explores to which extent 3D printing transforms the design and production process for independent fashion designers and small fashion firms.

Keywords: fashion industry, design, manufacture, 3D printing, digital technologies, innovation systems

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1. Introduction

1.1. Introduction Research Problem and Question

Traditionally the fashion field has remained quite reserved when it comes to experimenting with digital technologies, with the hand and the machine often represented as discordant tools in the creation process. Despite this, a number of designers and other practitioners are transforming past tradition and leading the future of fashion. 3D printing technology has become one of the hallmarks of this birthing revolution. A number of famous designers and their labels have begun presenting 3D printed collections on the runway and big footwear firms such as Nike or Adidas have begun commercializing 3D printed shoes.

3D printing refers to a computer controlled fabrication process which enables the creation of a three dimensional object from a 3D model, designed using computer-aided-design software. First introduced as a rapid prototyping technique used for the production of models in the 1980's, the sophistication of the machine itself and associated softwares have allowed for the printability of parts and end-products.

Researchers have pointed out the transformative effects 3D printing could have on the design and manufacturing process. It is advanced that the technology increases efficiency and effectiveness of the design process, and promotes product innovation (Michalik & al, 2015). In parallel, it has been advanced that the technology also simplifies manufacturing processes by solving the scale-scope dilemma thus enabling the efficient production of small batches and customized products (Weller et al, 2015).

Despite the strong buzz around 3D printing, garments designed and produced using 3D printing technologies are yet to be widely commercialized. 3D printed garments, are to date, reserved to research catwalks, exhibitions and research laboratories.

1.2. Research Aim and Research Question

In consequence, the study will aim to introduce, discuss and assess the introduction, diffusion and usage patterns of 3D printing technology in the fashion industry. Practical considerations concerning the manners in which 3D printing is transforming design and production process shall be explored. The functional framework developed by Bergek et al (2008) to analyze the structure, dynamics and functions of technological innovation systems forms the methodological guideline and framework for this study. The systems approach offers a holistic, multidisciplinary, non-linear and evolutionary approach to innovation. Understanding the functions and such the development, diffusion and usages of technologies depends on the actions and relationships between actors of the given system. As such, it is through a set of semi-structures interviews with designers specialized in 3D printed garments and fashion consultants, experts and scholars researching 3D printing, that the research attempts to answer the following research question:

"To what extent is 3D printing transforming the design and production process of independent fashion designers and micro fashion firms?"

1.3. Relevance

While innovation and creativity are terms which are often used interchangeably, there is little research having been conducted on the process of innovation in the creative industries, especially from the standpoint of technological innovation. This existing gap in literature forms one of the main motivations for this thesis. Indeed, the results from this thesis offer insight into the processes of diffusion of technological innovation within the sphere of the creative industries and the consequences this incurs for the usage patterns of resulting product and process innovations. They also contribute to understanding the dynamics of technological innovation systems in general.

What is more, the study aims to critically analyze the advanced transformative effects of 3D printing in fashion. Indeed, in the press and media, a number of articles are putting forward the fact that 3D printing could be revolutionary for the fashion industry.

1.4. Research Structure

This thesis is divided into four sections: Theoretical Framework, Research Design, Results and Conclusion. The first chapter, Theoretical Framework, offers an extensive literature review of existing theoretical and empirical research having been carried out on the fashion industry, innovation, creative industries and 3D printing technology. It offers key concepts and theories through which to analyze the impact of new technologies in fashion as well as the functional framework used throughout the study. The second chapter, Research Design, gives insight into the research methods used, the units of analysis studied and the carrying out of data analysis. It also explains the empirical relevance and validity of the present study. The third chapter, Results, presents the findings of the interviews having been carried out and gives insight into the structure and functional dynamics of the technological innovation system studied. In the fourth concluding chapter the general research questions is answered based on the empirical findings and the theoretical framework. This final chapter also points out the studies limitations and offers suggestions for axes of future research

2. Literature Review

At the outset it is important to lay the framework for the proposed study through a detailed review of the existing literature in order to identify key theories and concepts deemed relevant to the research topic. Four main areas of interest will be clarified and conceptualized:

- The first section will concentrate on the fashion industry. Attention will be brought to the economic characteristics of fashion products, the structure and spatial organization of the industry as well as the design and production processes which characterize it.
- The second section presents 3D printing and its affiliated technologies, as well as its deemed transformative effects on design and production.
- The third section focuses on theories of innovation with a particular attention for the innovation systems approach.
- Finally, the fourth section explores literature on the reception and diffusion of innovations in the creative industries

2.1. The Fashion Industry

Researchers agree that fashion has continued to remain a marginal field in academia (Kawamura, 2011). According to Godart (2010) this is the result of fashion's ambiguous and complex nature. However, according to Caves (2000) this is significant of the creative industries as a whole. The difficulties in measuring creativity and culture, often entail lack of data on the subject.

Despite this, fashion has become a topic of interest for a number of different academic fields ranging from business and economics to sociology and philosophy, thus making fashion a cross-sector and multi-disciplinary concept. Indeed, the definition of fashion is complex and ambiguous. It refers to both the clothing industry and a specific phenomenon of social change. In the context of this study, fashion shall be defined, understood and analyzed under an industrial and sectorial perspective.

2.1.1. The Fashion Industry and the role of Creativity

Fashion is to be understood as both a creative product and a commercial and economic process. The fashion industry, in this way, shares a number of specific characteristics with other creative industries. Creative industries can be described as "having their origin in individual creativity, skill and talent and centering on the generation and exploitation of intellectual property and aesthetic originality" (Miles and Green, 2008, p.12). Most often the value of the creative product is based on the content, the cultural meaning it produces or the experience it creates (Miles and Green, 2008). As such creative products contain a high degree of both expressive and functional value (Koppchen, 2015).

In the body of existing literature, researchers agree that the creative industries exhibit a set of key economic characteristics. According to Caves (2000) creative industries are marked by high levels of demand uncertainty, strong worker involvement, necessity for diverse and differentiated skills, differentiated products, vertically differentiated skills, strong time constraints and durable rents. Another dimension can also be added to Cave's list of economic properties. As most creative activities produce information goods, they incorporate a relative quantity of intellectual property (IP) which often matters more so than the material component of the good (Barrère and Santagata, 2003). As such, issues relating to copyright protection are central to creative goods.

Fashion as a core creative industry thus incorporates most of the aforementioned characteristics. Christopher and al (2004) explain that fashion markets are marked by high volatility of demand, short life cycles, unpredictability and high-impulse purchasing. Barrère and Santagata (2003) offer a clear analysis of the materialization of creativity in the fashion industry. They argue that the global diffusion of production techniques has led to differentiation on the basis of creativity. Competition thus operates in the spheres of creative content, quality and product originality. Designers have at their hand a multitude of creative choices allowing them to play on the originality and aesthetics of the given product. What is more, consumption in the fashion industry privileges creative and symbolic element of the product over its functionality. This is linked to the idiosyncratic and patrimonial character of fashion goods which confer to fashion consumption a dimension of social belonging, which is inherent to the logic of demand in the creative sectors. Finally, fashion products incorporate a strong element of intellectual property (IP), with the novel idea of the design mattering more so than the material product itself.

Barrère and Santagata (2003) add a second layer to their analysis. If creativity can be understood as a subjective element incorporated into fashion products, the organizational and industrial component of creativity is also to be considered. Indeed, fashion firms must promote high levels of creativity within their organization all the while assuring economic efficiency and profitability. The tension between artistic and economic values have been emphasized in the literature on creative and cultural industries. Caves (2000) emphasizes the existing contradiction between the principle of "art for art's sake" which motivates creators and creatives and the necessary humdrum operations. Because of the creative nature of cultural goods, managers must find ways to promote creativity and reconcile artistic ambitions with the economics of the given industry (Lampel, 2000). Within the fashion industry, creativity exists alongside an industrialized and labor intensive manufacturing model (Koppchen, 2015) which is crucial to its economic survival.

2.1.2. The Fashion Market: Size and Structure

Fashion as a commercial industry plays a great role within the general economy. Indeed, the global apparel market is valued at more than 3 trillion dollars, thus accounting for 2% of the world's Gross Domestic Product. The fashion industry can be broken down into a number of different sectors (Jacomet, 2010). At the core of the industry figure the textile industry destined to apparel production as well as apparel itself. Around this core aggregate the sector of accessories in which feature the shoes, leather goods, jewelry and watch sectors. In parallel to this sectorial break-down of the market, the fashion industry can also be segmented into three broad categories or markets according to the axes of price and creative content. These categories are: haute couture, prêt-à-porter and mass-market chain producers. Haute couture houses are major fashion houses generally run by internationally recognized designers. Prêt-à-porter or Ready to Wear can be understood as designer wear clothing. The latter refers to stylish, high quality wearable designs. Most often ready-to-wear is found in designer shops, independent stores and exclusive department stores (Easey, 2009). Finally, mass-market or street fashion englobes cheaper, less exclusive fashions.

A tier-view of the market is however over simplistic. Segmentation and categorization within the industry are becoming less and less clear-cut (Barrère and Santagata, 2003). A number of transformations have blurred the lines of the pre-existing fragmentation. Segmentation use to be exist along a vertical axe of quality, with haute couture goods dominating the market and other fashion markets offering commonplace, cheaper and lesser-quality versions. Nowadays, segmentation also exists along a horizontal axe which is linked to trends and customer base. This has given way to what Barrère and Santagata (2003) coin "a mosaic of markets". Indeed, between the three categories mentioned there exists many strata and price levels.

While certain large fast-fashion brands and luxury brands seem to dominate the industry, the fashion industry is mostly made up of small to medium-sized firms. In their study conducted on the American Apparel Industry Doeringer and Crean (2005) show that the apparel establishments are on average made up of 27 workers.

2.1.3. Fashion Supply Chain

The fashion industry is also structured by the number of diverse actors which take part in the production process of a garment. The body of research on the fashion industry's value chain agrees that over the years the industry has adopted a fragmented production process, marked by a number of sequential stages which aren't necessarily coordinated by a single firm (Koppchen, 2015). The fashion supply chain can be broken down into four main subsystems: a manufacturing system responsible for the production of material and apparel, a creative system which designs the products, produces merchandising and underpins consumer tastes, a managerial system which is responsible for the organization, control and coordination of the sourcing, manufacturing and distribution of apparel, and finally a communication system which delivers product information and advertises apparel (Craik, 2009). According to this chain, a number of actors can be identified function to the roles they play. Firstly, manufacturers, also called vertical producers are responsible for the production and purchase of materials, the purchase of designs as well as the manufacture, distribution and retailing of garments (Craik, 2009). The size of manufacturing firms is varied with large scale factories exist alongside small and artisanal enterprises. Besides manufacturers, are wholesalers and contractors. Wholesalers commission the manufacturing process often to contractors who themselves subcontract the manufacturing work from a range of jobbers to medium sized cut-make and trim firms to individual workers (Craik, 2009).

While certain companies still produce all products in-house, many prêt-a-porter and mass-consumption firms are no longer involved in the garment manufacturing assembly process, as most of this step is outsourced. As was pointed out by Gereffi and Memedovic (2003, cited in Koppchen, 2015), the latter can be coined “manufacturers without factories” with garment assembly being separated from the design, creation and conceptualization process.

2.1.3.1. Creativity and Design

In the fashion industry, there exists two main design configurations, which are derived from two radically opposed visions (Abecassis and Benghozi, 2008). The first, the “designer-creator” model, is derived from the traditional model applied in Haute Couture houses. Products are signed by an internationally recognized designer, thus giving products a symbolic value. In the second model, the “anonymous creator” model, products are signed by the fashion brand itself, thus making fashion designers substitutable and unknown.

The process of designing a piece of fashion varies widely across the industry. From designer to designer, firm to firm or market segment to market segment no process is the same (Sherman, 2014). However, most begin with research. While mass market companies often rely on large teams to conduct market research and monitor trends and sales, smaller designer firms or independent designers often use personal methods for inspiration (Sherman, 2014). Once a concept has been elaborated, firms or designers must began materializing their idea. To do so, methods differ. While some designers still opt for sketching or draping on live models, many designers have begun switching to computer-aided-design software. This is the case for most important fashion brands. In the next stages designers will begin experimenting with fabrics in order to arrive at final prototypes. Mass retails will often scrap half of what they’d design during the development phase (Sherman, 2014). Small and micro firms are often more economical. Once prototypes have been made, designs need to be manufactured and produced.

2.1.3.2. Manufacturing and Production

Every designer and company has a different manufacturing and production scheme (Sherman, 2014). While some produce locally, many choose to produce overseas as production costs are significantly reduced. Technology plays a crucial role in the outsourcing of production.

It allows firms and designers to communicate easily with the different actors of the manufacturing process. Sending design files or design specifications becomes an instant process (Sherman, 2014). While some large brands have their manufacturing process consolidated, most small to medium sized firms call upon small independent manufacturers. Because of distance, quality control and monitoring of garments can become difficult. This is why most firms hire local partners to act as liaisons in the country of production. A lot also make use of specialized monitoring softwares to track the evolution and transportation of fabricated garments. Once, garments are produced, they must be distributed. While many large brands distribute directly from offshore manufacturing to retail, small to medium sized firms as well as independent designers do the distribution themselves or through sales representatives (Sherman, 2014).

Technology thus plays a major role in the production of a piece of fashion. Not only is it used in the design and creative process, but it is also crucial to the manufacturing and production of the end product. The production of a fashion piece involves a great number of processes which allow for the materialization of an abstract concept (Koppchen, 2015). This is why according to Weller (2004, cited in Koppchen, 2015): "industrial development is not separate from aesthetic development." In order to speed up development, production and manufacturing processes as well as communication between different actors, innovation plays a crucial role in the fashion industry.

2.2. 3D Printing: An Innovation

In recent years, the fashion industry has shown growing interest for 3D printing technologies and its affiliated 3D designing softwares. Traditionally the business and engineering communities have formed the foundation for the research on the issue of 3D printing and have provided the theoretical and empirical framework through which to analyze the adoption and impacts of 3D printing on the industrial sector.

3D printing is understood as one of the components of the digital revolution and is considered to be able to "revolutionize the industrial world" (Maric et al, 2016) by transforming the existing manufacturing process. To date, the technology has successfully been used in industries such as aerospace, healthcare and design and has sparked interest in many other domains (Petrick and Simpson, 2015).

Most researchers have touted 3D printing's main potential as its ability to influence the way companies produce and deliver products to customers. Studies point out the many avenues 3D printing brings about for both product development and design as well as production in terms of performance, innovation and growth. (Michalik et al, 2015).

2.2.1. What is 3D printing?

The first 3D printer was introduced in 1986 by Chuck Hall, under the aegis of his company, 3D Systems. Since then a number of new technologies have been introduced and a large number of firms have entered the marketplace. Initially 3D printers were sold by industrial 3D printing manufacturers to large R&D based organizations (De Jong et al, 2012) which were able to afford high prices and required premium products. However, with the patents for these technologies beginning to expire a number of firms, most of which were start-ups began entering the market, with a concentration on the lower end of the market. Companies thus started offering cheaper machines making 3D printing an option for medium to small sized firms, self-employed designers and engineers as well as schools (De Jong et al, 2012).

3D printing otherwise coined additive manufacturing is a computer-controlled fabrication process which enables the creation of a three dimensional solid object from a model. 3D printing builds by addition. Normally when making an object, one begins with a fabric or material whereby segments are removed to arrive at the end product and design. With 3D printing layers are built one atop the other as the printer releases material from a container or cartridge to create a 3D object.

Using a computer-aided design program (CAD), engineers or designers create and modulate a 3D model to be generated by computer (Sun et al, 2016). From this model it is necessary to create a "build path" which specifies each movement to be made by the printer, when to start printing out the specific material and at what rate. To do so the designer must make use of a separate program. Through the later, the 3D model is transformed into a series of 2D slices thus informing the printer where to solidify the starting material for each slice (Sun & al, 2016). Every layer printed out represents one of the digital slices generated through CAD. Making use of a binder, a laser or an electron beam, the 3D printer will solidify the material along the programmed build path (Petrick and Simpson, 2013). Today, a number of different printing processes exist such as stereolithography (SL), Polyjet, fused deposition modelling, laminated object manufacturing (LOM), Prometal or selective laser sintering (SLS) (Wong and Hernandez, 2012).

3D printing was first introduced in the 1980's as a rapid prototyping technique used for the creation of models and prototypes. With the sophistication of the technology itself and advancements in terms of printable materials, the creation of finished products were made possible. The advancement of 3D printing was also the result of the evolvement of other technologies such as computer-aided design (CAD), computer-aided-manufacturing (CMC) and computer numerical control (CNC). With the possibility to print out end products, companies and designers are no longer limited by the physical constraints of traditional manufacturing thus enlarging the sphere of design possibilities (Michalik et al, 2015). This then opens up avenues for both product enhancement and business model evolution (Michalik et al, 2015).

2.2.2. Transformative Effects of 3D printing

Indeed, a number of researches have been conducted on the potentialities brought about by 3D printing for design and development and manufacturing in general.

The existing body of literature on 3D printing agrees that the technology will increase the efficiency and effectiveness of the design process (Michalik et al, 2015), reduce design constraints and accelerate and simplify product innovation (Weller et al, 2015, Michalik et al, 2015). 3D printing allows firms to save time in the development cycle by eliminating delays between design creation and prototype, by reducing work and costs needed for design iteration and by increasing communication, organizational alignment and decision making (Michalik et al, 2015). 3D printing also allows firms to reduce transaction costs thanks to the insourcing of prototyping, as well as design iteration costs. Finally, 3D printing ameliorates final product and quality design and performance by reducing barriers to concept testing and experimentation. With faster prototyping, it is possible for designers and design teams to go through more design and review cycles throughout the development phase of a product (Michalik et al, 2015). When applied at the production stage and no longer solely to prototyping, 3D printing allows for ground-breaking innovative products as production is no longer constrained by the physical limitations of traditional manufacturing (Michalik et al, 2015). Indeed, 3D technology is supposedly capable of producing any 3D model, allowing products to be designed according to their wanted function rather than according to manufacturing technology constraints such as mold and tooling constraints (Weller et al, 2015).

3D printing also brings about many advantages in terms of manufacturing and supply chain management. It promotes customization as new design alternatives can be created without the need for investments in setup, tooling or machine changeovers. As such, the marginal cost of reproduction is close to zero thus resolving the scale-scope dilemma imposed by traditional manufacturing technologies. Products can be produced and sold efficiently in small batches (Michalik et al, 2015). As a result, 3D printing also limits concerns relative to stock. Inventories become obsolete when it becomes possible to produce according to make-to-order processes (Weller and al, 2015). Finally, 3D printing enables localized production. With 3D technologies, design and manufacturing can happen anywhere thus reducing transaction costs.

Overall, 3D printing technology is thought to have the abilities to transform the existing design and manufacturing process (Weller et al, 2015, p.43). Economically, 3D printing will significantly affect the costs of flexibility and individualization as well as capital costs and marginal production costs (Weller et al, 2015).

2.2.3. Limits to 3D printing

Despite there being great hope about the future of 3D printing, the existing body of literature agrees that 3D printing still faces many challenges. The marginal costs of production continue to remain higher with 3D printing than with conventional technology. This is linked to the cost of material used and the consumption of energy by the machines (Weller et al, 2015). The lack of material also raises questions in terms of quality and can discourage engineers, designers and firms to opt for 3D technologies. However, researchers advance that once more suppliers enter the market for 3D printing such costs will begin to decrease.

In addition, 3D printing poses problems in terms of designers' abilities and capabilities (Michalik et al, 2015). If on one hand the ability to design viable products and bringing them to manufacture is enhancing the demand for qualified designers, faster and simpler prototyping as well as easy to use 3D softwares are opening up doors for automation and non-professionals (Michalik et al, 2015).

Another issue linked to 3D printing technology relates to intellectual property. As was mentioned, the expiry of patents over many of early 3D printing technologies made available low-cost and high-performance 3D printers. The expansion and accessibility of the technology has brought about many questions in terms of IP. IP law in its current form guarantees protection over 3D files and designs. Copyright protects the originality of the work, industrial design rights protects designs' aesthetic appearance and patents protect its technical functionalities (Malaty and Rostala, 2017). IP protection issues arise from the use of personal 3D printers, as it becomes possible for hobbyists to download unauthorized blueprints or 3D models and print them alone at home (Depoorter, 2014). Today, many blueprints are distributed freely online and can be replicated and printed out by all those having access to the file (Depoorter, 2014). So, just as streaming enabled cheap counterfeiting for the music, publishing and movie industries, 3D printing enables decentralized piracy, meaning that consumers can obtain counterfeits cheaply without having to pass through commercial counterfeits (Depoorter, 2014). Today, 3D printing is not submitted to particular IP laws. In the current digital age, copyright laws are under revision, with policy makers under pressure to re-evaluate the role of copyright protection (Towse, 2010). With innovations being rapid and unpredictable, it takes legal systems time to adapt to newly introduced technologies and the consequences they entail in diverse industries. What is more, because of the aforementioned unpredictability of new technologies, it is difficult for legislators to predict or anticipate the effects of given technologies (Depoorter, 2014).

2.3. Innovation Studies

In order to understand the possible changes brought about by the technology which is 3D printing, it is crucial to explore the concept of innovation.

Innovation was unexplored in academia till the 1960's when it began to be recognized as an independent field of study. Today research on the role of innovation has multiplied, with a tendency towards cross-disciplinarity (Fagerberg, 2003). Innovation is defined in a number of different ways depending on the theoretical perspectives taken.

2.3.1. Defining Innovation

In his guide on innovation, Fagerberg (2003) offers a synthesis of the existing research having been carried out on the subject and puts forwards a number of key elements in order to define the concept of innovation.

(1) **Innovation vs. invention**: A first distinction is to be made between innovation and invention. While invention is the "first occurrence of an idea for a new product or process" (Fagerberg, 2003, p.3), innovation refers to the "first commercialization of an idea" (Fagerberg, 2003, p.3). The transfiguration of the invention into an innovation requires a number of prerequisites: the combination of different types of knowledge, skills, facilities, market knowledge, a functioning distribution system and sufficient financial resources (Fagerberg, 2003, p.3).

(2) I**nnovation is the result of a lengthy non-homogenous process**: a single innovation is very often the result of long process which involves a number of interrelated innovations.

(3) **Innovation typologies**: a third distinction is to be made between different types of innovations. Schumpeter distinguished between five types of innovations:
- Product innovation
- Process innovation
- Supply innovation
- Market Innovation
- Organizational Innovation

The focus in economics has mostly been on two of these sub-categories, them being: product and process innovation. The first refers to the introduction of a novel product while the second refers to the introduction of a novel method or process of production. However, it is important that the other categories of innovation remain considered.

(4) **Degrees of innovation**: A fourth distinction is to be made between the different degrees of innovation. As such, innovations can be classified into typologies function of their level of radicalism:

INCREMENTAL / MARGINAL INNOVATION	RADICAL INNOVATION	TECHNOLOGICAL REVOLUTION
Continuous improvement of existing technologies or products	Introduction of a completely new type of product or process which has the ability to successfully invade and overwhelm the established technology	A cluster of innovations that together may have a far-reaching impact in a large range of industries or the economy as a whole

Table 1: Degrees of Innovation, Source: own elaboration

(5) **Structural impact of innovation**: Schumpeter used the term "creative destruction" to define the phenomenon by which innovation "revolutionizes the structure from within, incessantly destroying the old, incessantly creating the new one" (Schumpeter, 1942, cited by Fagerberg, 2013, p.11). Research has shown that technological innovation affects both firms and market structure as a whole. When a radical innovation occurs, a new market is created. New firms emerge, enter the market and transform the competitive environment (Utterback, 1999). Radical innovations thus revolutionize the entire production and distribution chain, the management structure and the organizational structure of the given industry.

2.3.2. Systems Approach

Another fundamental aspect of innovation studies is the general agreement that "innovation does not occur in a vacuum" (Fagerberg, 2013, p.16). In other words, firms do not innovate in isolation but interact and collaborate with a number of organizations such as suppliers, competitors and customers, the behavior of which is shaped by institutions that act as either incentives or obstacles to innovation (Edquist, 2006). When the pattern of interaction between these different actors becomes more or less stable, the term innovation system is used (Fagerberg, 2013). An innovation system designates the body of "actors, networks, and institutions contributing to the overall function of developing, diffusing and utilizing new products and new processes (Bergek et al, 2008, p.408).

A systems approach to innovation has been gained popularity and has been adopted as a more appropriate approach to innovation by a large array of researchers (Bergek & al, 2008). The SI approach has a number of advantages compared to other theoretical perspectives. In his Handbook on Innovation, Edquist (2006) summarizes these forces. The SI approach does not approach innovation as the result of exogenous forces but rather as the result of the production of new knowledge or the combination of old elements of knowledge in new ways. It also offers a holistic perspective on innovation, meaning that it attempts to encompass a large variety of different factors and determinants of innovation (Edquist, 2006). What is more the SI approach understands innovations as being influenced by a number of components (actors) and their existing and complex relations. Institutions are also recognized as important determinants of innovation. Moreover, the SI approach offers a historical and evolutionary understanding of innovations thus excluding the notion of optimal systems of innovation. If such a view is more complex, it offers a more realistic understanding of innovation processes (Edquist,2006). In all, the SI approach allows for an all-round, comprehensive, holistic and historical understanding of innovation thus making it particularly relevant for the study of a wide array of categories of innovations.

In literature, an array of different innovation systems have been elaborated: from national systems of innovation, to regional innovation systems, to sectorial systems of production, to technological systems (TIS). In the context of this thesis attention will be brought to the technological innovation systems approach which concentrates on explaining the diffusion and development of a particular technology.

2.3.3. Diffusions of new Technologies: The Technological Innovation Systems Approach

Technological diffusion defines "the process by which the market for a new technology changes over time and from which production and usage patterns of new product and productions processes result" (Stoneman and Battisti, 2010, p.734). Generally, when a new product or process technology appears, the number of users and owners of the given technology increases. This is what can be referred to as the diffusion of a new technology. It is important to distinguish between product technology and production process technology and the relations existing between them. A new product technology refers to a new technology which is introduced and produced by a firm. A new process technology is a novel method of production and can result from a previous product technology innovation. In the case of 3D printing, we are faced with a new technological product (3D printers) which has led to novel production process technologies (Stoneman and Battisti, 2010)

In order to analyze the diffusion of the new product and process technology that is 3D printing, the research makes use of the technological innovation system framework developed by Bergek and al (2008). A Technological Innovation System can be defined as a "set of actors and rules that influence the speed and direction of technological change in a specific technological area" (Hekkert et al, 2011). The authors offer a step-by-step approach through which to analyze innovation systems. Their proposed framework captures the dynamics of key processes, coined "functions" which influence the development, diffusion and usage of a new technology. The functions have been established by synthesis of existing literature and theoretical perspectives on the systems approach (Bergek et al, 2008). Existing literature on innovation systems reveals a general agreement on a set of key processes or functions within the innovation system (Bergek et al, 2008).

Bergek et al's (2008) framework for analyzing a technological innovation system shall be used as it offers an in-depth step by step process to exploring and understanding the dynamics and development of a given technological field. As such, this section shall present in detail the scheme of analysis advanced by Bergek et al (2008) which shall later act as the analytical framework for this research:

The steps of the analysis are defined as follows:

(1) **Defining the TIS**: The first step to analyzing a given system is defining the system in focus in order to set the boundaries of the study. Doing so implies a three sub-step process which encompasses:
    - Choosing between knowledge field, product or machine tool as a focusing device
    - Choosing between depth and breadth: level of aggregation of the study, range of applications in which the technology is relevant,
    - Choosing the spatial domain: local, regional, national, international

(2) **Identifying the structural components of the TIS**: Firstly, the actors need to be identified. This can be done by observing industry associations, through a patent or bibliometric analysis as well as through interviews with technology or industrial experts. Secondly, one needs to pinpoint networks, be them formal or informal. Several types of networks exist from those orchestrated in a formal fashion to complete a specific task, to more informal networks such as buyer-seller relationships or education-industry links. Thirdly, institutions need to be discerned. Institutions refer here to "culture, laws, norms, regulations and routines" (Bergek et al, 2008, p.413).

(3) **Establishing an "achieved" functional pattern by analyzing the system's seven key functions:** The first step of the functional analysis is to study what is being achieved in every one of the functions created by Bergek et al (2008). These functions are as follows:

FUNCTION	DEFINITION
KNOWLEDGE, DEVELOPMENT AND DIFFUSION	Function at the heart of the TIS, it is concerned with the breadth and the depth of the knowledge in the system, its evolution and the ways in which it is diffused
INFLUENCE ON THE DIRECTION OF SEARCH	In order for a TIS to develop, the involvement of actors is crucial. For the latter to take part in the system there needs to be sufficient incentives, pressures, expectations, relevance, entrenched bottlenecks to stimulate participation. The combination of these elements influences the evolution and diffusion of knowledge within the TIS.
ENTREPRENEURIAL EXPERIMENTATION	A TIS develops in uncertain conditions. Entrepreneurial experimentation, which relates to the experimentation taking place, is a phenomenon which helps reduce this uncertainty. It comprises of: new entrants, different applications, breadth of technology used and the nature of complementary technologies.
MARKET FORMATION	For emerging TIS' there may or not be an existing market. Generally, when an innovation is introduced the market that follows goes through three distinct phases: (1) nursing market, (2) learning space (3) mass market. This function

	encompasses the analysis of both the state of development of the market and the mechanisms which drive its formation.
LEGITIMATION	Legitimation refers to overall social acceptance and compliance of relevant or related institutions. Legitimation is to be understood as the result of "conscious actions by various organizations and individuals in a dynamic process of legitimation which may eventually help the TIS overcome its liability of newness" (Bergek et al, 2008, p.417). The legitimacy function encompasses: (1) the strength of legitimacy in the system, (2) the way it influences demand, legislation and firm strategies, (3) what or who influences legitimation.
RESOURCE MOBILIZATION	For a TIS to evolve a number of resources need to be mobilized. These resources can include human/competence capital, financial capital and complementary assets such as complementary products, goods, services, networks and infrastructures.
DEVELOPMENT OF POSITIVE EXTERNALITIES	A number of externalities arise when a TIS enters the market. These externalities can be pecuniary or non-pecuniary. They can, for example, comprise: emergence of pooled labor markets, emergence of specialized intermediate goods and services, information flows and knowledge spill-overs (Marshall, 1920, cited in Bergek et al, 2008).

Table 2: Overview of the functional pattern developed by Bergek et al (2008),

Source: Own elaboration

(4) **Assessing the functions' performance and defining a "desired" functional pattern:** After having studied how the systems functions, it is necessary to assess how well the functions are performed. In other words, this step refers to the measuring of the relative "goodness" of a given functional pattern in order to then define a "desired" functional pattern. In Bergek et al (2008) framework, this assessment can be done through the two following steps:

ASSESSMENT BASES	DEFINITION
THE PHASE OF DEVELOPMENT	There is a distinction to be made between a formative and growth phase in the development of a TIS as the definition of the concept of functionality differs between

	phases. As such, it is important to determine the TIS' phase as so to analyze the functional pattern and the ways in which can improve. A formative phase is characterized by a rudimentary structure and generally involves: short time lapses, uncertainties regarding technologies and market applications, undeveloped price/performance relationship, unarticulated demand, absence of reinforcing features and weak externalities. As the TIS expands, it shifts into the growth phase characterized by a focus on system expansion and large-scale technology diffusion, formation of bridging markets and mass markets and the subsequent need for resource mobilization.
COMPARISON BETWEEN TIS'	It is important to compare the focal TIS with other existing TIS' in order to understand how the latter are performing and thus to both grasp what reasonable desired functional pattern can be achieved and to identify TIS' critical functions.

Table 3: Overview of methods of assessment of functional patterns,
Source: Own elaboration

(5) **Identify mechanisms that induce or hinder evolution towards the desired functional pattern:**_ The next step to the framework constructed by Bergek and al (2008) is the identification of internal and external mechanisms and factors which come into play and influence the dynamics within the Tis as well as the overall development of the system.

(6) **Specifying key policies associated with the aforementioned hindering or inducing mechanisms:** Bergek et al (2008) research being aimed at offering a practical scheme of analysis for policy makers, the sixth step of the scheme concentrates on the extraction of possibly relevant public decisions for the stimulation of the given TIS. Indeed, policy should be aimed at amending poor functionalities and weaknesses in the system as so to promote strengthening mechanisms and remove weakening ones.

As the study at hand does not aim for any public policy application, the last three steps shall be ignored and removed, with the first three steps forming the analytical framework for the aimed research.

2.4. Innovation in the Creative Industries

In order to assess the possible impact of 3D printing in terms of fashion, it is crucial to turn to the existing literature on the role of innovation in the creative industries as well as past example of adoptions of digital innovations in this particular sector

2.4.1. Innovation in the Creative Industries

The terms “creativity” and “innovation” are often used interchangeably, creativity being synonymous with the creation of new ideas, concepts and thus innovation. However, there have been few studies conducted on the phenomenon of innovation in the creative industries. Most studies define innovation in the latter as involving either content, aesthetics or experience. This is linked to the intrinsic nature of creative goods, which derive their profitability from content. According to Stoneman (2010) innovation in the creative industries is soft innovation meaning it is mainly concerned with production innovation and product differentation. However, changes occur in the aesthetic and intellectual dimension of the product. For the fashion industry, Bianchi and Bartolotti (1996) use the notion of “stylistic innovation”, which refers to product innovations which change the form without necessarily changing the function or the production methods.

According to Caves (2000) technology has little to do with innovations in the creative industries. Innovations that entail new techniques often require that a new set of conventions be espoused which translates as high costs of adoption. As such, these innovations often run short courses as they incur high costs for the production of creative goods.

Despite this, a number of researchers have pointed out that innovation in the creative industries goes farther than solely novel aesthetic, quality or content. Handke (2010) for example differentiates between “content creativity” which could be understood as aesthetic innovation, “humdrum innovation” which relates to changes in the operational routines and “technological innovation”. In a NESTA (National Endowment for Science, Technology and the Arts) commissioned report, Miles and Green (2008) carry out a study on hidden forms of innovation in the creative industries, notably the design industry. They show that innovations in the design industry are often under-represented as they are not captured by the traditional process and product innovation indicators. Contrary to what is traditionally advanced, the design sector undertakes a wide range of innovative activities such as: business model innovation, product innovation and technological innovation. Organizational and process innovations are often ad-hoc, meaning they are managed by specialized committees for a limited time frame and are directed at solving a perceived threat in the general environment. Product developments and innovations often come close to formalized R&D processes. What is more innovation within the design industry is often evolutionary, meaning that agencies and firms are on the lookout for innovation opportunities (Miles and Green, 2008).

2.4.2. Innovation in the Fashion Industry

As we have mentioned earlier, novelty is crucial to the fashion industry. However, if novelty can be mentioned in terms of innovation, the industry's drive for change is not necessarily concurrent with innovation (Koppchen, 2015). According to Koppchen (2015) fashion is characterized by the phenomenon of marginal differentiation, which as defined by Jacobs (2007, cited in Koppchen, 2015) "is a concept quite close to incremental innovation, but without the latter concept's connotation of improvement". One could call this stylistic innovation. New products involve new aesthetics, stylings or fabrics which do not require new technology (Richardson, 1996, cited in Koppchen, 2015). As such, a new fashion good is not necessarily better than the last "it does not necessarily lead to a higher degree of wellbeing, except possibly the wellbeing found in the newness itself and a larger degree of choice" (Jacobs, 2007, cited in Koppchen, 2015). As such, fashion is marked by a continuous cycle of change and new product development without necessary improvement. It is change for the sake of change. The only way in which the product is improving is that it fits with the trends of the time, the *zeitgeist* (Koppchen, 2015).

If style and continuous style change is central to the fashion industry, researchers have pointed out the crucial role of innovation in the contemporary fashion market. There have been numerous technological and digital innovations introduced in the fashion industry (Unay and Zehir, 2012) such as a computer-aided-design or the development of certain fabrics and fibers. These new technologies have stimulated product innovation and led to transformations in terms of speed and quality of manufacturing (Unay and Zehir, 2012).

The introduction of digital innovations in the fashion industry began with computer-aided-design. In the context of this thesis, the adoption of CAD systems is relevant to understanding the implementation and development of new digital innovations within the fashion industry. While the fashion industry remains quite timid in terms of computer usage, CAD plays a crucial role and represents great implications for manufacturing and product design and development (Easey, 2009). CAD programs allow designers to draft patterns, to design fabrics, embroidery of embellishments but also, for the most advanced software, to 3D model garment design. These programs allow a reduction in waste in both time and material. Thanks to their precision in terms of models and patterns time to market is reduced. What is more, the softwares' precision also reduces fabric wastage as designers can experiment virtually, with virtual fabrics. Finally, CAD softwares promote customization and personalization thus responding more closely to consumer demand and preferences. CAD makes it possible to reproduce designs and patterns for different garments rapidly and quickly and accordingly to individual customer sizes.

3. Research Design

In this chapter the empirical setting is defined. The first section highlights the choice of methodology, and the logic behind the research strategy used. The second section explains the methods for data collection and specifies the sample selection. The third section describes the methods for data analysis. Finally, the fourth section discusses the reliability and validity of the strategy chosen as well as its limitations.

3.1. Methods

This research aims to explore and assess to what extent 3D printing is transforming the design and production processes of independent fashion designers and micro-fashion firms. To do so qualitative methods of research were used. A qualitative strategy can generally be understood as a research strategy that focuses on words rather than on the quantification of collection and analysis of data (Bryman, 2012). As such it is a method which allows for a deeper and more profound understanding of processes, which is particularly relevant in the case of this study. What is more, it is generally broadly inductive, meaning that it allows theories to emerge from data. All the while remaining inductive, this study is more precisely abductive. While there are elements of induction in the abduction process, the latter can be distinguished from the former in that it relies on participants' worldview (Bryman, 2012). Theoretical understandings of the people and contexts studied are grounded in their languages, meanings and perspectives (Bryman, 2012).

Parallel to the qualitative research methodology used, this thesis makes use of a technological innovation systems approach to answer the research question. A TIS approach offers a holistic, multidisciplinary and evolutionary approach to innovation. The functional framework developed by Bergek et al (2008) to analyze the diffusion, development and usages of a new technology was used. The latter which captures seven key processes, all of which play a fundamental role in the dynamics and development of the TIS, guided the analysis.

3.2. Units of Analysis

The first step described by Bergek et al (2008) in their framework is the identification of the innovation system in focus, which translates as a three step process: choosing between knowledge field, product or machine tool, choosing depth and breadth of the SI, choosing the spatial domain. This allows one to establish the boundaries and perimeter of the study. This research shall concentrate on 3D printing as a machine tool in the specific domain of fashion. Fashion here is narrowed down to include apparel/garments, footwear and hats thus excluding jewelry. The analysis is in no way spatially limited as the number of actors currently using such a technology are extremely limited and spread out all over the globe.

The second step of the framework is then to identify actors, networks and institutions. Within this research, the main unit of analysis consists of independent fashion designers and micro fashion firms. These units of analysis were chosen on the basis that the use of 3D printing is limited to smaller fashion firms, large firms either being out of access or solely using 3D prototyping. Designers using 3D knitting, a technique different to 3D printing, have been excluded from the analysis. Other units of analysis consist of fashion consultants, experts and scholars. Such a method allows for the cross-checking of information from multiple sources in order to limit bias, as well as for the search for regularities in the research data and the production of accurate results for certainty. These units have been chosen as they are at the forefront of the technological changes taking place in the fashion industry.

3.3. Sample Size

Before addressing data collection and analysis, it is necessary to describe the chosen sample. The paper makes use of stratified purposive sampling. The units have been chosen because of their relevance relative to the research question (Bryman, 2012). A number of typical cases are chosen within two sub-groups of interest: fashion designers, fashion experts, scholar and consultants. Due to the limited time scope of this research as well as to the small number of actors making use of 3D printing in fashion or conducting research on the technology, a sample of seven interviewees was carefully selected (n=7). The participants are not localized in a single geographical area, this because of the rarity of actors actually specialized in the use of 3D printing for the design and production process. As such, participants are spread out over Europe and the United States.

3.3.1. Fashion Designers

The main focus of the sample was to identify designers researching, creating or producing 3D printed garments. The population of designers making use of 3D printing for garments is extremely small thus explaining the size of the available sample. Despite this, criterion was applied in order to select the sample. All designers have conducted projects where 3D printing was used to produce wearable garments or fabrics. Designers solely using 3D prototyping technologies were excluded from the analysis. This limited the analysis to independent designers and micro fashion firms. The sample was also selected using the snowball sampling method whereby relationships and communication with initially targeted participants brought about contact possibilities with other potential respondents. The following individuals constitute the final sample of fashion designers (more information on their projects and the conditions of the interview can be found in sections 7.1 (appendix 1) and 7.2 (appendix 2)).

(1) Maartje Janse is a Netherlands based fashion designer currently conducting research on the use of flexible fabrics for 3D printing at Makerversity. Other projects also include a 3D printed t-shirt with an integrated bra-structure, zero-waste pattern cutting and bacteria dying.

(2) Hoon Chung is a London based fashion designer, creator of the first ever 3D printed wearable shoe. He is currently working on customizable and detachable shoes. He is also planning a conference on 3D printing.

(3) Noa Raviv is a New York based Israeli fashion designer famous for her “Hard Copy” collection using 3D printing which was featured at the 2016 Met Exhibition “Manus x Machina”. She is currently working on new collections without the use of 3D printing.

(4) Cedric Magne is the owner and founder of BiTs Tailor, a Paris-based web and brand content agency which offers customizable 3D printed products.

3.3.2. Industry Experts

The main focus of this sample was to identify experts on digital technologies in the fashion industry. As such, the initial aim was to contact lecturers and professors specialized on technology and fashion from surrounding fashion schools. The sample was finally selected using snowball sampling, with initial contacts often acting as channels of communication for other actors. The end sample is small as few professors concentrate precisely on 3D printing technologies. The following actors constitute the final sample for this unit category:

(1) Irene Maldini: With a background in industrial design, Irene Maldini is currently a PhD candidate at the Free University of Amsterdam and has a research position at the Amsterdam University of Applied Sciences. Her PhD concentrates on the relationship between the involvement of the user in the process of design and manufacture and sustainability of the fashion industry. She previously conducted research with the Waag Society and the Free University on self-production of digital fabricated objects.

(2) Victor Portes: Founder and Brand Communications Specialist of Dutch Catwalk 3D Printing, he is currently consulting for a number of large fashion firms, evaluating the possibilities to integrate 3D printing or prototyping into their production chain. He is also working on a number of 3D printed design projects, notably 3D printed breasts for breast cancer victims.

(3) Marco Mossinkoff: Currently a lecturer and research fellow in fashion marketing and brand management and Amsterdam Fashion Institute and HKU (Hogeschool voor de Kunsten Utrecht), he has a strong interest for digital technologies. He is also working on publishing a book about cultural entrepreneurship and its indirect effects, all the while continuing to research branding.

3.4. Data Collection

Data has been collected through semi-structured explorative interviews with each unit of the sample. Semi-structured interviews allow for the coverage of a certain number of key topics of themes which are relevant to the research all the while giving the interviewee leeway in his responses (Bryman, 2012). Indeed, in comparison with fixed structured surveys or questionnaires, characteristic of quantitative data collection, qualitative interviewing acts as an interactive, open and unpredictable method which concentrates on the interviewee's perceptions and perspectives (Bryman, 2008).

The use of 3D printing in fashion being a relatively unexplored subject in academia, there exists little research and/or empirical data relating to it. The use of interviews will offer deeper insight of the subject. Interacting with both professionals and theorists will also allow for an all-round understanding of the subject at hand, from theory to practice.

Qualitative semi-structured interviewing is generally defined as an open-conversation between the researcher and the interviewee. Despite this, a number of questions must be prepared in advance to guide the interview. As such, an interview guide sub-divided into general sections has been created (see section 7.4. Appendix 4). The order of questions is subject to variations according to the responses given by the respondents.

The interviews have been structured around the functional framework developed by Bergek et al (2008). The levels and dynamics of each function crucial to the development of the TIS can be assesses by a range of indicators. These indicators have formed the basis for data collection and have thus guided the interview. These indicators consist of:

(1) Knowledge development and diffusion: The level and the dynamics of this function can be measured by bibliometrics which refers to the volume of publications on the subject, the quantity of R&D projects in the given field, the number of patents having been deposed and the range of university courses and size of professorate.

(2) Influence on the direction of search: this function can be measured by the articulation by interviewees of belief in future growth, incentives in terms of factor/product prices as well as external regulatory pressures.

(3) Entrepreneurial experimentation: the dynamics of this function can be assessed by the number, size and impact of experiments taking place. More concrete and detailed indicators include: number of new entrants, different types of existing applications as well as the range of technologies used.

(4) Market formation: market formation is difficult to measure. According to Bergek et al (2008) the analyst must dispose of in-depth knowledge in order to understand what drives or hinders market formation. Overall, the market phase, the nature/type of users, the nature of their consumptions and institutional stimuli for formation need to be identified. This can be done by concentrating "on market size and customer groups as representing what has been achieved, but also qualitative data on e.g. actors' strategies, the role of standards and purchasing processes" (Bergek et al, 2008, p. 416).

(5) Legitimation: legitimization can be measured by studying the level of alignment between the TIS and the legislation, the way in which legitimacy influences demand, supply and firm strategies. The mechanisms which influence the level of legitimacy are also to be looked out for.

(6) Resource mobilization: the mobilization of resources can be assessed by rising volumes of different forms of capital (human, financial, material), the levels of venture capital and investments and the variations in terms of complementary assets.

(7) Development of positive externalities: "external economies in the form of resolution of uncertainties, political power, legitimacy, combinatorial opportunities, pooled labor markets, specialized intermediates, as well as information and knowledge flows" (Bergek et al, 2008, p. 418) must be searched for and acknowledged

Interviews consisted of two parts. The first section focused on the participants' educational and professional background, their first encounter with digital technologies and on specifics projects relating to 3D printing. The second section of the interview concentrated on the use of digital technologies and 3D printing in general with a particular attention brought to its effects on design and manufacturing practices.

Interviews were conducted from March 2017 to May 2017, thus over a period of three months. One was face to face, the other six being over either telephone or skype. The duration of the interviews was not pre-determined and lasted between thirty minutes to one hour and a half. Of the seven interviews conducted only four were able to be recorded. The other three interviews were transcribed manually during the duration of the interview. When the entire sentence were not written down immediately, very clear and precise notes were taken, allowing for the reconstruction of the given sentence. The non-recorded interviews are those conducted with Hoon Chung, BiTs Tailor and Marco Mossinkoff. All interviews were then coded in the same manner. Details about the interview protocol can be found in the appendix section (Section 7. 4: Appendix 4: Interview Protocol).

3.5. Data Analysis

Once, the data is collected, it needs to be analyzed and managed (Bryman, 2012). Interviews were first transcribed and then coded manually using a word processor. Because of the inductive nature of this study, the evaluation objectives of the study provided a focus for conducting the analysis (Thomas, 2006). As the functional analysis developed by Bergek et al (2008) acted here as the analytical framework, codes and categories were inspired by the seven key functions of innovation systems. However, the findings arrive directly from the data analysis not from the a priori developed framework. In order to begin coding, interviews were read and analyzed closely in order to identify text segments containing themes which captured core messages reported by participants. The method of coding used here was descriptive rather than in vivo coding, meaning that the coding method summarized the primary topic of the given excerpt rather than using the participants' own language. Perceived regularities, affinities and similarities otherwise coined patterns, between themes led to the emergence of categories. These categories are as follows: (1) knowledge development, diffusion and experimentation, (2) influences and incentives, (3) market formation and legitimation, (4) resources. These categories were then developed into a functional framework inspired by that advanced by Bergek and al (2008). Details about the coding method can be found in the appendix section (Section 7.5: Appendix 5: Overview Categories and Codes)

3.6. Reliability, Validity, Limitations

The methodology used in this study presents certain limitations, notably interviewing. Indeed, the use of interviews leaves room for a number of limitations notably the risk of subjectivity, the difficulty to replicate the study, the problem of generalization and the risk of lack of transparency. As there is general uneasiness about the application of reliability and validity in qualitative research, the quality of the study shall be guaranteed according to the alternative indicators of quality developed by Guba and Lincoln (Guba and Lincoln, 1994). Through a “thick description” of the data given by the interviews, there will be room to assess the possibility of transferability, for example to other fashion designer or other specialized sub-industries of the fashion apparel industry. Dependability will be assured through kept records of the given interviews, which will take the form of transcripts and which will figure in the study’s annexes. Not only will this empirically back-up the arguments advanced but it will also allow for peer assessment.

4. Results

4.1. Knowledge Development and Diffusion

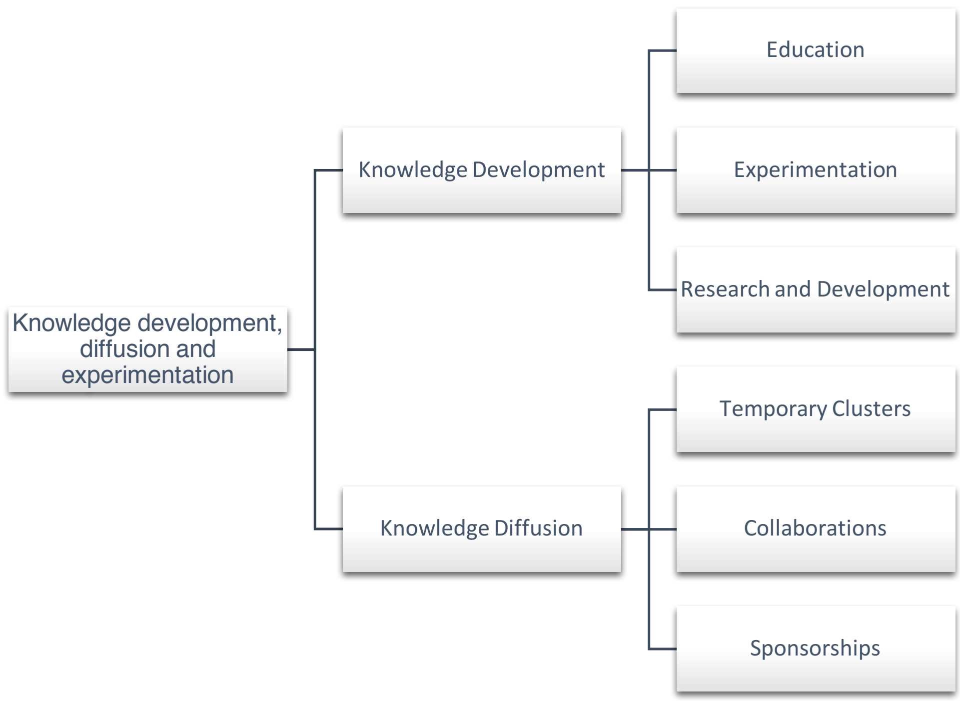

Figure 1: Overview of the factor: Knowledge Development and Diffusion
Source: Own Elaboration

Initially the knowledge existing within the TIS was of technological nature, meaning that actors in the TIS disposed of a general understanding of how 3D printing, tools, resources, softwares and applications functioned. However, the initial knowledge was also said to be design knowledge, understood here as the large body of savoirs used by creators during design processes and problem solving. This available body of knowledge trickled down from the other sectors where 3D printing had already been introduced, such as jewelry for example. The subsequent development of knowledge can be attributed to multiple mechanisms, them being: Education, Experimentation and Research and Development (R&D).

4.1.1. Development: Education, Experimentation, Research and Development

For most creators the first ever contact with 3D printing happened within the academic realm. Most fashion schools have begun offering courses related to digital technologies where students are taught to digitally program, design and fabricate. Universities also offer access to 3D printers, laser cutters and other digital fabrication technologies in what most coin “Digital Labs”. Students can make use of these technologies for a very advantageous price, thus allowing them to experiment and play around with the technologies and thus develop a certain savoir-faire.

However, for most interviewed designers, the discovery of 3D printing was somewhat fortuitous. This is because most of the courses offered remain optional, meaning that students choose to take part depending on their curiosity and interest for digital fabrication. At AMFI for example students can undertake either a minor in textiles or Hypercraft to learn about 3D printing and other technologies. For designer Noa Raviv, from the Shenkar College of Engineering and Design in Tel Aviv, learning about 3D printing was only possible if one took part in the jewelry design classes.

Indeed, within the academic realm of fashion studies, 3D printing remains to a certain extent unexplored and undeveloped. The main stream of education in relation to fashion and technology relates mostly to wearable technology. 3D printing technology is regrouped in courses which concentrate on digital fabrication technologies in general. Attention is brought mostly to digital programming and design, thus leaving students with a rudimentary understanding of the practicalities of 3D printing. As a result, experimentation plays a crucial role in the development of knowledge surrounding 3D printing in fashion.

Experimentation is crucial to most fashion designer’s creative and design process. This is linked to both the lack of knowledge and thus transmission of knowledge in fashionable 3D printing but also to the nature of the technology itself. For most designers, academia was a time to dabble with the technology. As was explained earlier this is the result of the nature of courses offered. However, it is also linked to the time constraints students are faced with and the number of courses they are already required to take.

> Maartje Janse: *“And already when I started there were some new techniques like laser cutting or 3D printing but it came up quite late - I think in my second year. I wasn’t really*

able to apply it in my work back then because you get to know so much stuff and you get a lot of subjects to work on and projects to do"

As such for three out of four designers it was only once they'd graduated that they began truly exploring and experimenting with 3D printing. This allows for the downstream development of the knowledge within the TIS. By experimenting, designers arrive at new design processes, new creation methods, new shapes, new patterns and new forms. As a result, they contribute to the pre-existing body of design and technical knowledge.

The central role of experimentation in 3D printing can be partly explained by the nature of the technology and its related softwares. First of all, like all other technologies, creators must become accustomed to the different softwares, printing techniques and materials available. Secondly, 3D printing softwares allow for the development of novel shapes and forms and offer an infinite variety of possible designs. According to Noa Raviv, experimentation thus allows designers to explore different techniques thus pushing further the realm of possible creations and thus developing the broadness of design knowledge:

> Noa Raviv: "Many times I feel like we are bound by the techniques that we use and what they allow us or don't allow us to do […] Once you know another technique […] you become a better designer because you have more possibilities and it's like it expands your mind in a way"

Experimentation with 3D printing in the fashion industry is particular to a certain kind of designer and firm. As was expressed by Marco Massinkoff one could attempt a typology of firms by distinguishing those that take many social and technological risks, thus turning towards new technologies, and those that attempt to minimize them. This segments the markets into experimental companies which search for novelty and differentiation and highly responsive, fast fashion firms such as Uniqlo or Zara. Experimental companies are often micro-firms or independent designers, as shows the units of analysis of the study. This is linked in part to the contradiction between the responsiveness and fastness of the fashion industry and the lengthiness of experimentation. The fashion industry functions cyclically with a minimum of two collections a year. In parallel, designing 3D printing can take years before arriving at a perfect, wearable design. As a result, most small firms or independent designers, continue designing collections while experimenting or researching 3D printing, thus extending further conceptualization times.

It is important to note that the dynamics of experimentation are strongly interlinked to parallel research on the technology itself and printable productions. Indeed, experimentation is linked to the upstream development of knowledge brought about by research and development. In the 3D printing industry, research and development is conducted by diversified actors. 3D printing services are major actors. Having emerged into the market with the progression of the technology, they work on the development of new 3D printers, technologies and specific algorithms allowing for the printability of a given material or texture. In parallel, a number of designers take on research with given societies or labs to develop a specific printable material. Maartje Janse, for example, first worked with Waag Society and later on with Makerversity, to develop 3D printing on stretch materials.

Research raises crucial questions in terms of patenting. As we have mentioned earlier, IP is crucial to the creative industries, which rely on the production and distribution of novel and original content for economic sustainability. With a technology like 3D printing where design is compressed and shared as files, the question of authorship is extremely important. The issue of authorship will be further discussed in the following sections; however, it is important to note that it can limit the amount of experimentation on the part of a creator. While a traditional experimental garment is physically localizable, a design file which hasn't been patented is not. What is more, it limits experimental collaboration between creators. As was pointed out by Hoon Chung, he was unable to talk too much of his project before having posed the patent, thus forcing him to work independently:

> Hoon Chung: "Before I carried everything myself and I want to show it but I was struggling with IP. But now I have a patent"

4.1.2. Diffusion: Temporary Clusters, Collaborations, Sponsorships

The diffusion of knowledge inside the TIS strongly relies on the organization and attendance of a number of events throughout the world. These events which form what can be coined "temporary clusters" are understood as "a geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities" (Belussi et al, 2006, p.3).

People from the world of 3D printing come together regularly throughout fairs, exhibitions, conventions and conferences worldwide. These events could be divided into two different categories, those that are more oriented towards the technology itself and those more oriented towards fashion. Part of the first category are the 3D Print Fair held in London each year, special conferences dedicated to the launch of new printers (such as the latest launch of the HP Printer Jet), as well as makerfairs. On the more fashion side, the largest event each year are the different Fashiontech Weeks held in Paris, New York or Berlin. A number of other conferences and conventions held on technology in fashion can be adjoined to this category.

According to Maskell et al (2006), these temporary clusters act as "hotspots of intense knowledge exchange, network building and idea generation" (Maskell et al, 2006, p.997). Cedric Magne from BiTs Tailor, a brand and creative content agency specialized in co-creation, attends different events throughout Europe each year and sees it as a chance to meet a wide variety of different people with different skills, making the process fertile.

> Cedric Magne: "We usually go to 3D print show in London. It's a very cool event with passionate people from many different fields. We also participate to makerfaire which is dedicated to makers. We participate to different fashiontech events in Paris as well"

To these makerfairs, conventions and techweeks can be added specific exhibitions on the theme of technology in fashion. The largest exhibition to date held on the subject was the Manus x Machina exhibition, organized for the MET's yearly spring expo, a staple in the fashion world. Being featured in such exhibitions is crucial for a creator. Not only does it grant them status and recognition within the fashion industry, it also places them within a specific sub-field of the industry thus categorizing their work and offering it historical relevance

> Noa Raviv: "That was a really big achievement for me as a young designer. I mean I was the youngest designer to be featured in that exhibition […] this is definitely one of the most important exhibitions each year, the exhibition from the Costume Institute. So that was a huge thing for me. And of course, it really defines my work this merge of

hand work and machine work, and these things that the exhibition was about it is really something that I think about a lot and that is part of my work"

Another crucial element to the diffusion of knowledge within the TIS are collaboration between creators, often from very different disciplinary backgrounds. In the 3D printed world of fashion, collaborations are extremely common. Famous examples include Studio Bitonti's collaboration with Michael Schmidt for the creation of an entirely 3D printed dress for Dita von Teese, or Alexander Wang's collaboration with VOJD studios for the creation of a 3D printed umbrella. Because of the technical complexities of 3D printing softwares, it requires a wide variety of skills which can be fulfilled by the participation and contribution of diversely skilled workers. Studio Bitonti's main designer for example is traditionally an architect, thus used to working with complex shapes and forms as well as CAD softwares. Michael Schmidt, as a designer knows the industry, the tastes and disposes of the *savoir-faire* of the haute couturier.

Cedric Magne points out the interdisciplinary nature of the 3D printing field and the way that this fosters and promotes creativity and thus novelty:

"3D printing is a very interesting field as it gathers people from tech, fashion, geek students, designers, engineers etc… I love when something breaks boundaries, it's always a fertile ground for innovation and it helps people to think outside the box"

Collaborations are accentuated by the fact that a great number of designers (fashion, engineering, graphic) and technology start-ups often work in open spaces, fabrication laboratories, or under the aegis of maker communities. The reason for this is mostly economical, as 3D printers and other fabrication technologies are extremely expensive. However, such shared workspaces allow these varied actors to be in constant contact and interaction thus furthering the development and diffusion of varied forms of knowledge. Maartje Janse, who is conducting research at Makerversity explains that not only can designers gain from others designers' experiences and past experimentations thus facilitating the experimentation and research process, they are also presented with new technologies thanks to the presence of IT start-ups.

> Maartje Janse: "Like the guys from 3D printing [3Dprinting.com], if they have a new printer they're going to test it so it will be running in the workspace and you can see. They recently had a printer which was like 2/3 meters high"

Communities such as Makerversity also facilitate collaborations between designers and firms. Being present in different countries, they give access to a large network of designers, companies and institutions. Maartje Janse, for example, was contacted by an English fashion designer in order to develop a 3D printed bra. Not yet accustomed to the technology, Maartje put the designer in contact with another designer working in the Netherlands who had already launched the product.

Partnering with communities such as Makerversity of Waag Society is usual practice for most fashion designers experimenting with technology. As was explained earlier this allows designers to have access to a wide array of fabrication technologies, otherwise too costly. Generally, these communities or societies accept designers on the basis of a research project. Maartje Janse, like Irene Maldini both conducted research with the Waag Society.

Another form of collaboration that takes place is between creators and 3D printing services, or between 3D printing services and firms. However, these partnerships rather take on the form of sponsorship. Because of the costly nature of 3D printing materials, such as nylons or fibers for example, it is difficult for a designer to print out a full-size object independently. As a result, most young creators search for sponsorships by 3D printing services. These partnerships do not only allow them to print out their designs for free, they also give them access to a wider variety of materials and 3D production techniques, as each 3D printing service develops its own range of materials. For both Hoon Chung and Noa Raviv, these sponsorships were crucial to the completion of their first collection.

> Hoon Chung: "I was sponsored. The material is super expensive […] the sponsors offered me the Material, which we called Material X, because it was being patented and is still today not on the market […] So it was a secret material, and I sent my design and they printed it out for me"

Noa Raviv: "I collaborated with Stratasys which is one of the largest 3D printing companies [...] I contacted them five times until they were willing to meet me [..]They were the ones who 3D printed the objects. [...] They got a lot of publicity [...] you know it's like they got really a lot of publicity"

4.2. Influence on the direction of search

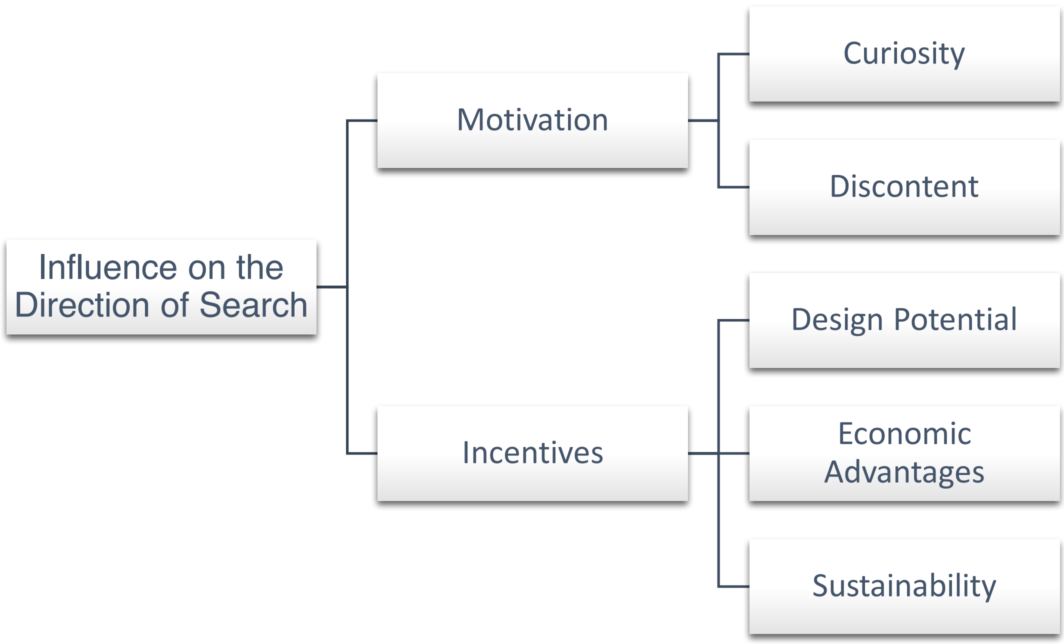

Figure 2: Overview of the factor: Influence on the direction of search

Source: Own Elaboration

4.2.1. Motivation

For most creators, the initial use of 3D printing was prompted by their curiosity in the technology and the possibilities it could and would bring. As such, the direction of search was influenced originally by intrinsic and personal motivations. It is important to note that non-economic values are central for creative workers and often are at the root of their motivation. For most designers, the interest for 3D printing was born out of general interest for new techniques and the way they could change the design process and as such product outcomes. For designer Noa Raviv, 3D printing was first discovered during her jewelry design course at university. She developed a fascination for the technology, and the way it changed one's design thinking process. For fashion designers who were traditionally taught to design in 2D, 3D softwares opened up a new world of possibilities.

> Noa Raviv: “So it was inspiring for me to see how the jewelry designers were thinking. And I started there and thought how can I take these tools and use it as a fashion designer”

Another reason prompting creators towards the use of 3D printing technology is the will to bring change into the fashion industry. Reasons for this include discontent with the way the industry currently functions. Hoon Chung makes clear his dissatisfaction with the existing manufacturing techniques and production models.

> Hoon Chung: “I wanted to develop something further, and I also had a lot of experience with the industry and was not satisfied. I was disappointed. Some people say “oh you know I’m a footwear designer” but in reality they use templates and there is no dramatic change. […] I was interested in efficient and cheap ways to produce. I wanted to develop a new production method. I’m focusing on the question: how to replace traditional manufacturing with new technologies. […] Manufacturing is not changing. This is my passion: jumping into a new era”

For Cedric Magne of BiTs Tailor, dissatisfaction stems from the existing mass production system which is based on the production of standardized goods. According to him, 3D printing offers the possibilities for customization.

> Cedric Magne: “At that time, I wanted to disrupt mass production and bring custom creation accessible to everyone from anywhere”

Cedric Magne’s company, BiTs Tailor, allows customers to co-design products which then perfectly fit their wishes and needs. His website is just one of many specialized in the field of co-creation. Individuals can participate in the end creation of a product by changing certain parameters on the initial 3D file. The then customized product is printed out directly by the firm and sent out to the consumer. Not only does this technique allow for complete personalization it also does not incur any extra production costs.

The issue of mass customization is significantly present in the existing literature on 3D printing. Indeed, it is advanced as one of the technologies key advantages. While the industry is attempting to respond to changing demand patterns, notably the increasing exigence for personalized goods, by offering a large array of variants for one same initial product, customization continues to remain limited. Choosing an initial good and with it its particular design, consumers are able to choose colors, textures and materials. A great example of this is in the shoe sector, where firms like Converse and Nike are allowing clients to personalize classic shoe styles. This phenomenon was clearly pointed out by Hoon Chung:

> Hoon Chung: "In traditional manufacturing there is no real customization. Once it is produced it does not change. You customize before but not after. A good example is Nike iD. My concept goes further. Currently [in current manufacturing] you need different sized soles for every size so there is a lot of processes, a lot of time needed and a lot of labor costs. With 3D printing it can be different"

Weller and al (2015) explain how the technology allows for an infinite variety in product design without any cost penalty in terms of manufacturing. In traditional production technologies, producing customized goods in an efficient way requires modular product architecture. Preassembled modular parts are combined to produce distinct product variants (Weller et al, 2015). As was mentioned by Hoon Chung such a technique leads to a lot of waste in both time and energy because each variant brings with it additional complexity and costs. With 3D printing however, it is possible to flexibly produce customized goods. 3D data is directly transformed into an end-product without any need for molds, tools or assembly activities (Weller et al, 2015). Making use of 3D printing for customizable goods also increases profit. Research has shown that product customization generates an increase in customers' perceived product value which translates as a higher willingness to pay (Weller et al, 2015). In brief, 3D printing allows for what Gibson et al (2010) call an "efficient lot size of one" thus resolving the traditional scale-scope dilemma which argues that efficiency is the results of economies of scale.

If 3D printing is portrayed as a way to change the entrenched industry structure, its usage can also be explained by the potentialities, both economic and design-related, that it brings.

4.2.2. Incentives

4.2.2.1. *Design Potential*

Indeed, if creators make use of 3D printing for personal reasons such as curiosity or discontent, the design potentialities brought about by the technique are also a factor. One of the main potentials cited by creators is that is widens the sphere of design possibilities. As mentioned earlier, 3D design softwares inherently transform the design process. While fashion designers are mostly used to thinking in 2D or what Noa Raviv calls “flat thinking”, 3D softwares such as Rhino or 3D max make it easier for designers to conceptualize and control the design. It’s like seeing the design in live. 3D Max for example makes it possible to sculpt the object like one would sculpt clay. The program even comes with a pad and a special pencil which has arms allowing the designer to feel all the physical tensions that would exist if the object wasn’t being virtually sculpted.

> Hoon Chung: “Like on the program, it’s in free form. The pencil has arms so you can feel all the tensions when drawing. You bring drawings from other programs and then you adapt them. It’s exactly like sculpting with clay”

It also allows them to “imagine wider” according to Cedric Magne. In other words, 3D printing softwares allow for what Weller et al (2015) coin “radical innovation” in that it facilitates if not promotes product innovation. Product design is no longer limited to the designer’s creativity and physical laws. Softwares allow creators to surpass their own cognitive limits thus expanding the boundaries of the imagination. They allow designers to create new shapes which would have been too complicated for a human mind to imagine. As such, designers see these softwares as ways to create innovative and novel products. This is particularly important in an industry where there exist strong market barriers. Using new technologies allows the designers to position themselves as innovative, experimental designers and to integrate the market in this way.

> Noa Raviv: “And I think, since so many things in design and arts has been made already then technology is a really good way to be innovative and to find new ways to express new ideas […] And to tell you today, now, the advantages, I feel like, again, it will allow designers to create new ideas and new shapes and I feel this is something very important in fashion and in design in general, and in art”

Another potentiality brought about by 3D digital softwares and printing is the detail they allow for in terms of production. When a designer wants to create a small object that is very detailed, such as a button for example, he needs to be familiar with a number of different techniques. However, with 3D printing, one solely has to know a single software to have at his fingertips a mosaic of design possibilities.

Another potentiality in terms of design is the rapidity of the process. Rapidity here implies the time with which designers arrive at a marketable and saleable product. With traditional design methods, designers spend a lot of time reiterating a design by hand in order to arrive at the final product. With digital fabrication, designers spend a lot of time conceptualizing and modelling the product on digital softwares. However once the prototype is printed out it is generally very close to perfect. If not, it can be copied and arranged very quickly. Indeed, with 3D printing it becomes possible for a product to be prototyped rapidly, multiple times and for limited costs thus enhancing product quality and fostering product innovation.

> Cedric Magne: “If you are familiar with lean thinking / design thinking, you know that the more you iterate, the better the result. Being able to create 100’s of prototypes in a few days instead of one is a revolution to get better designs”

Another advantage brought about by 3D designing softwares is that it limits production errors. When designing in 2D, there exist a lot of discrepancies and differences between what the designer had imagined and the end-product produced by the factory. Designers must communicate their wishes to the suppliers thus leaving room for interpretation. With a 3D file there is a lot less room for such interpretation and thus for errors. This leads to a reduce in waste in both time, energy and money. When there is no factory involved because the designer can print out the object himself for example in a fabrication laboratory (FabLab) production is immediate. 3D printing thus combines freedom of creativity and immediacy.

> BiTs Tailor makes this clear when he says: “3D printing is the shortest way to go from an idea to an object. It’s like a sketching tool. I think, I create, I print. In a matter of hours, I can bring my ideas to real objects, that is really powerful”

4.2.2.2. Economic Advantages

The design possibilities brought about by 3D design softwares and 3D printing entail a number of economic advantages which act as a major incentive for designers and fashion firms. As we have mentioned earlier, 3D printing and prototyping reduces production errors and renders very cheap customization. For these reasons, product development costs are very much reduced.

Not only does 3D improve communication between suppliers and firms thus limiting discrepancies between wanted product and end product, but it also increases market responsiveness by reducing time to market. In the fashion industry where demand is highly volatile and unpredictable, market responsiveness is key and crucial to a firm’s success. With an information system where designs are shared on 3D files, product development costs are reduced.

> As Marco Mossinkoff explains: “There is less discussion about a product and there is maybe less communication, with the supplies the communication is easier and more formalized. The advantage of systems in general is that it is clearer what you have to do as a supplier […] with a system you can directly see, in that sense, it reduces your product development costs”

For mass-market fashion companies this is crucial. The model they follow is divided into three steps: experimentation, selection and reproduction. Experimentation refers to putting a lot of diversified products on the market in order to test the demand. Selection refers to the consumers’ selection process, and in consequence informs the firm on what is trending and will sell. Finally, reproduction refers to the rapid reproduction of what is selling. With 3D prototyping and information systems, this process is sped up as 3D printing allows for on-direct digital manufacturing of end products at no extra marginal cost.

Market responsiveness is also fostered thanks to the efficient customization that 3D printing allows for. As we have mentioned earlier, such a technology facilitates product personalization as: (1) customization incurs no extra manufacturing costs or time penalties, (2) volume and product variations incur no costs or time penalties in terms of machine setups, (3) no tools or molds are needed (Weller et al, 2015).

> According to Marco Mossinkoff: “Another possible field where it would be useful would be postpone the moment where you adapt the product in market demand [...] So these kind of systems also standardize certain processes and make cheaper and quicker to adapt product to a specific need or specifics needs. So it enhances market responsiveness. So there is a lot of room for it especially in a business where predictability is hard”

4.2.2.3. Sustainability

Another reasons many creators turn towards 3D printing is related to sustainability and eco-friendly initiative. The fashion industry is currently under a lot of mediatic and political attention because of the high levels of waste and pollution that it produces as well as for the terrible labor conditions that it contributes to.

> For designer Hoon Chung, this is one of the main reasons current manufacturing processes need to be transformed: “The environment is the big key word. After the industrial era we’ve damaged all our resources and soils, and we’ve consumed everything. Now the industry is turning towards reusable material and less waste […] These reasons are why I want to change how to make shoes”

Sustainability seems to be a growing trend in the fashion industry. Large fashion firms have begun introducing varied eco-friendly strategies. H&M, for example, has adopted “conscious” lines and promoted recycling. Nike, also, has attempted to reduce textile waste by replacing stitching with lamination, thus allowing for the creation of seamless products. Patagonia, another example, promotes product reparation and thus long product life cycles. Because of the current demand for sustainability and social responsibility, a technology like 3D printing offers great market potential. With a rise in consumer demand for eco-friendly products, promoting environmentally viable products is key. Not only does it fit well into today's zeitgeist which is crucial in the fashion world, but it also allows young designers to emerge into small, niche markets thus enhancing their chances of success. According to Hoon Chung, all manufacturing companies will have to turn to 3D printing in a few years because of changing legislations on production conditions and pollution. In other words, 3D printing could be seen as a necessity.

> Hoon Chung: "Soon in 5 to 10 years all manufacturing will move to 3D printing. And plus, recently there is a big attention brought to environmental issues. Countries are banning manufacturing for pollution reasons"

For most designers interviewed, sustainability played an important role in their creative and design process. All designers mentioned sustainability as one of the core stimulus for their research activities. Hoon Chung for example is attempting to produce 3D printed shoes which are customizable and detachable. This reduces waste not only because assembling and stitching are eliminated from the production process but also because damaged parts can simply be replaced without the entire shoe having to be thrown away. Maartje Janse, is also working on reducing waste through the choice of textiles and materials used. Her current work makes use of stretch filaments which are made of recycled rubber. She is also concentrating on bacteria dyes and zero-waste patterns, all in order to implement sustainable practices into the fashion world.

From the interviews, it was gathered that sustainability comes not from the 3D printer itself but rather from the types of materials used and the designs created by the designers. It was pointed out by most designers that 3D printers are not, in themselves, sustainable. They drain large amounts of electricity, this because of the quantities of energy that need to run on but also because of the times it takes to print out an object. A small sized object, such as a box for example, can take up to twelve hours to print. Despite this, 3D printing has been portrayed in the press and in many research papers as "eco-friendly". As pointed out by Hoon Chung, "most people understand 3D printing as eco-friendly" (Hoon Chung). Because of transaction cost reductions, waste reduction and pollution reduction, 3D printing was presented as the medium for the "next industrial revolution".

4.3. Market formation and legitimation

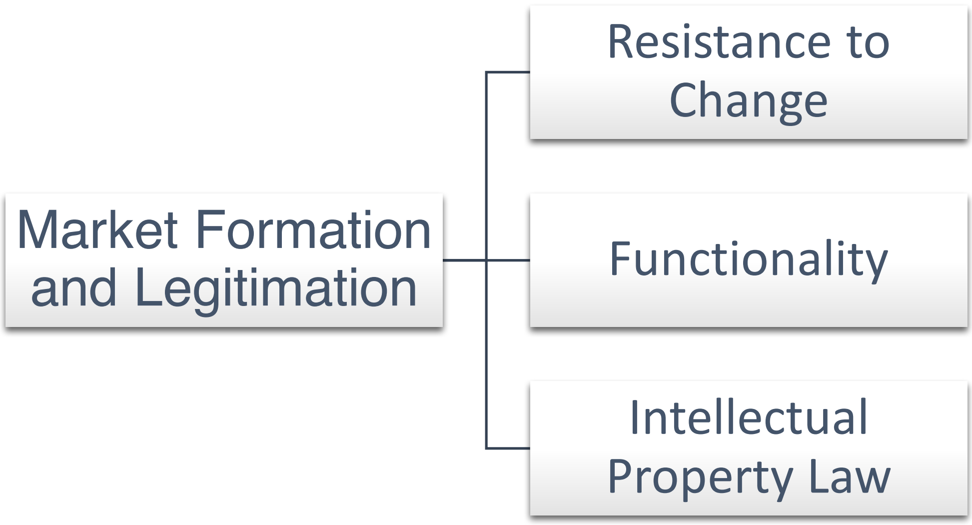

Figure 3: Overview of the factors: Market Formation and Legitimation

Source: Own Elaboration

Research has shown that technological innovation affects firms and market structure. When a radical innovation occurs a new market is normally created. New firms emerge, enter the market and transform the competitive environment (Utterback, 1999). For a given TIS there may or may not be an existing market. Generally, when an innovation is introduced, the market goes through three distinctive phases which are: (1) nursing market, (2) learning space which can become a bridging market, (3) mass market.

4.3.1. Resistance to Change

The existing market for 3D printing has become significant economically. According to the 2016 Wohler's report, the 3D printing industry has surpassed the 5 billion mark, with a growth of 1 billion dollars over the space of one year. However, in fashion, the 3D printing market remains small. As such one could say the market is in a formative phase, which according to Bergek et al (2008) is characterized by uncertainties regarding technologies and market application, undeveloped price/performance relationship, unarticulated/uncertain demand and absence of reinforcing features.

Many reasons can be mobilized in order to explain why market formation is slow. As Hoon Chung points out “3D printing in fashion is still a niche area”. Fashion, traditionally has been portrayed as a conservative industry, slow to adopt new technologies. As such, according to Victor Portes, owner of 3D printing consultancy company, a large part of the resistance stems from fashion firms and designers themselves, with most innovation coming from external entrepreneurs such as himself.

Resistance is linked to knowledge gaps, time constraints and individual preservation strategies. For a firm to integrate 3D printing, 3D printing technologies and 3D imagery into its supply chain entails a number of time-consuming and costly processes. Integrating 3D printing or prototyping processes into the production chain will entail that the entire supply chain will have to change. This is impossible in fashion, where time constraints are very high. In order to integrate the technology into a company’s business plan and supply chain, the technology must be understood, encompassing usable materials, 3D softwares, different 3D printing techniques and so on. However, in an industry like fashion where collection creations are being constantly sped up to answer to increasing consumer demand, time is of the essence. As a consequence, companies cannot take the risk in learning about new technologies, and then in investing and testing them.

> As Victor Portes explains: “I think once the fashion people are allowed to experiment and to get comfortable, meaning the design teams, I think it’s going to take off. Again they just don’t have time. I have a friend, she works for Calvin Klein, she does senior designer for men’s tailor and yeah it’s brutal. They have this collection start and then another collection and they’re just chasing their tails”

What is more, individuals rarely accept change that often they are yet to understand, scared for their position within the firm or the industry as whole. Indeed, there remains a lot of resistance from individuals within the industry who not only are scared for their position but are scared that they will not be able to grasp the newly introduced technology and thus control their environment.

> Victor Portes who is working closely to with large fashion firms to integrate 3D printing technologies into their value chains explains the roots of this resistance: "There's a lot of movement but still a lot of resistance. People are afraid for their jobs. If you're boss of a company, and you've been vice president or director of merchandising or in an executive position and then somebody comes in and says "hey you have to learnt this and this and this. You know the market is going to change". You know there is self-preservation on the personal level, wanting to learn, having the time also because people need to stop and learn. You know it took me a while and I'm a designer […] And the problems that you face is that the technology is a steep learning curve"

Other reasons include the intrinsic nature of fashion. Understanding certain phenomena in the fashion industry also requires grasping the different dimensions and layers of fashion. Fashion can be understood as a social phenomenon of successive incremental innovation. Most money is made not from technological innovation but from small marginal innovations in design. Collections, best-sellers are varied slightly in order to appear new all the while staying recognizable and fitting into the zeitgeist.

> Marco Mossinkoff explains how fashion is all about small, marginal changes: "But fashion is mostly about imitation, not being different. It's about avoiding risk, looking good and different, but not too much. So innovation is always on the margin. So it uses the discourse of innovation because it wants to be contemporary but actually it is the most conservative"

4.3.2. Functionality

Another limitation to market formation comes from the functionality of 3D printed clothing. Creative products interlace functionality and aesthetics. With apparel, functionality is crucial. However, because 3D printed materials are often rigid, printed products often have very futuristic, inflexible forms. Most designers interviewed have thus expressed concern regarding the functionality of 3D printed designs. Indeed, all designers pointed out that they most current designs do not respond to any of the functions that we expect from current clothing, meaning warmth or inversely coolness, softness and comfort.

> As explained by Noa Raviv: “I mean, there is so many limitations that it’s just not like fabric yet. So basically, people want to wear fabric, it’s a very ancient thing […] It’s not just taste, it’s not comfortable […] just the properties. It’s almost like why don’t we wear plastic, or why don’t we wear metal. You know, it doesn’t have the properties that we need, it’s doesn’t make us warm or cold”

Hoon Chung agrees with the non-functional nature of 3D printed garments, all the while advancing that it may be just a question of time, with future generations possibly becoming accustomed to more futuristic styles. While consumers today may not yet have developed taste for 3D printed designs, he believes that society may slowly become accustomed to rigid, futuristic clothing.

> Hoon Chung: “Clothing is supposed to be practical and the 3D printed fashion is not practical. But maybe for future generations. They might like the rigid futuristic style. It is also a question of taste”

Because of the non-functional nature of 3D printed clothing, most of the 3D printed fashion projects remain in the art field. The technical limitations brought about by the lack of printable materials, entail that most fashion designers use the technology for art pieces. The designs printed out are impressive, beautiful but unwearable, thus making them non-functional. Often, the designs are used by companies as a wow-effect or a communication stunt. The clothing produced is iconic but hardly wearable. The use of 3D printed dresses at world renowned fashion events such as the MET Gala are proof of this. This year, a number of celebrities were present on the red carpet with costly, 3D printed dress. A stand-out was the sequin dress. While the piece was beautiful and being worn, it was see-through and in no way wearable. Most designers agree that a large quantity of fashion projects involving 3D printing make no sense. The cost of production is often used as a tool for communication.

As a result of this, all of the interviewed designers are working on ways to create wearable designs. However, process is slow as the materials available remain limited and mostly inflexible. Because of this, designers are exploring new fabrics. Maartje Janse for example is experimenting with stretch fabrics and mentioned that many designers at Makerversity are also attempting to introduce new textiles.

In order for an innovation to emerge into a fully formed market, it must gain legitimacy. Bergek et al's (2008) function of legitimation refers to the overall social acceptance and compliance of relevant and related institutions and actors. As we have grasped from the interviews, 3D printing in fashion remains a niche market. Actors within the industry as resistant to change, firms evaluate the introduction of 3D printing techniques as too costly and the functionality of the clothing hinders creation of demand and social acceptance.

4.3.3. Intellectual Property Law

Another concern regarding 3D printing technologies is in regard to patenting and authorship. All interviewees expressed patenting as a challenge be it currently or in the future. Hoon Chung for example explained the lengthy process of patenting his design and the limitations that non-patenting brings. Indeed, he explained that until he had patented his product he could not apply for funding or sponsorships with 3D companies, nor could he communicate his project. As such, the development and production process become longer. Noa Raviva and Maartje Janse also viewed IP as crucial but rather in regard to the future development of co-creation processes.

In the fashion industry, unlike most other creative industries, original content is not protected by intellectual property law. While trademarks are protected, designs are not thus fostering design copying. The standard theory for copyright laws is that in the absence of protection, firms and individuals will be discouraged to innovate. In, the fashion industry however, this is not the case. Quite on the contrary, copying is central to the cyclical functioning of the industry. As such, paradoxically in an industry where the central creative profit-making element goes unprotected, firms continue to invest in product innovation at a very high pace.

However, with the transformations brought about by 3D printing notably in terms of design process, patenting has become necessary. For Irene Maldini, fashion design has become closer to industrial design with the arrival of 3D printing softwares. Garments and patterns are no longer being designed and cut into cloth but are modelled and programmed in 3D. Because of this, the time needed for experimentation and research to produce original content and design is lengthy and requires patenting. Designers need to protect the novel shapes, forms and fabrics that they are working on developing. As was explained in the section about 3D printing, current industrial design rights protect designs' aesthetic appearance and patents protect its technical functionalities. The real problem arises for designers if they decide to share their design files on open-source networks. Because of the lack of protection of authorship in this domain, most of the designers were reticent in doing so. Indeed, out of the four designers interviewed, none believed in participating in open-sourcing because of the major risks it represents in terms of authorship over their work.

4.4. Resource Mobilization

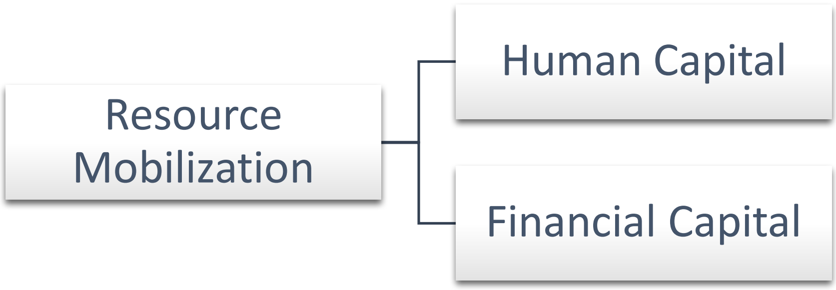

Figure 4: Overview of the factor: Resource Mobilization

Source: Own Elaboration

In order for the TIS to expand, a number of resources need to be mobilized (Bergek et al, 2008), notably human and financial capital as well as complementary assets which encompass compatible products, services and networks. As such it becomes crucial to assess to what extent the TIS is able to mobilize these different resources.

4.4.1. Human Capital

Different views were expressed concerning the mobilization of human capital within the TIS. All however, advanced that the buzz surrounding 3D printing had died down over the last five years. Indeed, in the academic realm the amount of projects and research papers conducted on the subject of 3D printing have decreased. Marco Mossinkoff, fashion branding professor at AMFI, use to have up to 4 or 5 thesis' a year written on 3D technologies. Over time, this number has significantly slumped, with no thesis' currently focusing on the subject. In 2012 there was a major buzz surrounding 3D printing especially in fashion. At the London School of Fashion, conferences were being held and a lot of attention was brought to the potentialities offered by the technology. Hoon Chung, who was a student there at the time explains that since then, little has been done.

According to Victor Portes, fashion consultant, this has a lot to do with the prejudice in academia concerning 3D printing. He explains that introduction to the technology remains concentrated to fashion and design schools thus limiting the amount of human resource mobilization. As such, he advocates for the instigation of 3D modelling courses in marketing, management, entrepreneurship and cultural economic studies. According to him, this will help bring about change in the industry in following years as future employees will understand 3D printing technologies.

Another phenomenon which limits the mobilization of human capital in the fashion field are time constraints. Indeed, both experts, Irene Maldini and Victor Portes, as well as Maartje Janse pointed out that the cyclicality of the fashion industry was a major restraint. Because of the slow design process incurred by 3D modelling and designing, certain designers multitask. They continue researching 3D designing and printing techniques while working on their fashion collection. The cyclicality of fashion obliges designers to continually produce two collections a year. As such, some are obliged to put research aside for certain months of the year when the launch of the collection is approaching. Maartje Janse explains that because of this, research is often slowed down.

Maartje Janse: *"Fashion is short minded. You know you need to have a collection in half a year and that's why I put my 3D printing project aside because in half a year I don't have the output that the fashion industry wants to have. They need to allow you to work on it for a year and that's not what's happening right now so that's why it's more difficult"*

4.4.2. Financial Capital

Money is a major issue for most fashion designers working with new technologies. Not only is the technology very expensive, but time and money constraints impose that fashion designers multitask thus undertaking research and collection design at the same time.

Indeed, 3D printing remains very costly thus making it impossible for an independent designer to invest alone in 3D printers. Because of this all interviewed designers explained that they rely on sponsorships with large 3D printing companies to print out products or partnerships with maker communities and societies such as the aforementioned Waag Society or Makerversity to conduct research. Hoon Chung explains that without sponsoring he would not have been able to print out his first 3D shoes, as the cost of the filaments were too high.

> Hoon Chung: "I was sponsored. The material is super expensive. The nylon which is the white powder (SLS), the hardest material, a lot superior to plastic, is super expensive. Imagine, only the sole of the shoe cost more than 1000 pounds to make, and the total shoe cost 2000 pounds"

Noa Raviv, was also sponsored by a 3D printing company named Stratasys. However, she pointed out that finding sponsors can be difficult and companies are difficult to come into contact with and are often reticent. Indeed, she explains that she was obliged to send multiple emails to different services until she finally got a response.

Another explanation for lack of financial resources is the costs 3D printing represents for fashion brands. Indeed, firms are reticent to invest in 3D printing technologies. This is due to the risks and the high costs incurred by the technology but also to the structure of the fashion market. As Marco Mossinkoff explains, 65% of the market consists of small and medium enterprises who are not interested in investing in technology because their success relies on their "feeling for trends" rather than on advanced and responsive information systems. For these small and medium sized companies investing in 3D printing technologies is too risky.

However, some do attempt 3D printed projects. Maartje Janse explained that she was working with other designers, some of which had been commissioned by fashion brands to design 3D printed objects. One particularly had been asked to design a button, but when the design was finally finished, the firm realized it was costlier to 3D print the button than to design it in a traditional manufacturing way.

5. Conclusion and Discussion

5.1. Summary

Within the existing body of studies conducted on the creative industries, very few have researched and explored the diffusion and adoption processes of digital innovation within the fashion industry. This gap in the literature is what prompted the research. This study aimed to observe and understand the process of diffusion of 3D printing technologies in order to respond to the following question:

"To what extent is 3D printing transforming the design and production processes for independent fashion designers and micro fashion firms?"

3D printing was first introduced as a new product technology in the 1980's. While 3D machines were first reserved to the R&D departments of large firms, the expiration of patents on a number of initial 3D printing technologies has led, in recent years, to the sophistication and wide-spread availability of the product. Focusing on the application of 3D printed technologies in the fashion sector, this study made use of a technological innovation systems (TIS) approach in order to answer to the aforementioned research question. This approach recognizes the interdependent and non-linear characteristic of innovation and allows for a holistic, multidisciplinary and evolutionary approach to innovation. The development, diffusion and usage of a new technology is the result of the actions and relationships existing between actors, networks and institutions. As such, industry expert opinions or key stakeholders are crucial in understanding the ways in which a technological system functions. In order to explore the functioning of the studied TIS, the functional framework developed by Bergek and al (2008) was used. The latter captures seven key processes which play a fundamental role for the dynamics and development of the TIS.

Interviews with independent designers, micro fashion firms and industry experts offered insight into the levels and dynamics of these stated functions, thus offering a general perspective of the way in which 3D printing technologies are being diffused, adopted and used within the fashion industry. Key processes for the diffusion of the TIS include designers' intrinsic motivations, incentives relating to design, research and development, experimentation and the ability to mobilize financial capital.

Interviews revealed that while 3D printing transformed the product design and development process, 3D printing continues to remain a marginal field in the fashion industry. Most fashion designers turn to 3D printing by curiosity for the design and product potentialities brought about by the new technology. Indeed, all mentioned that 3D printing softwares transformed their product development and design processes. With CAD softwares, design is no longer limited to the creator's cognitive abilities or his/her imagination. The sphere of design possibilities is augmented, allowing designers to create new shapes and new forms, thus leading to radical product innovations. With 3D printing technologies, fashion design also comes closer to industrial design. Creators are required to experiment with softwares, modulations, and different materials and fibers for long periods of time to arrive at a functional end-product, meaning experimentation and research become crucial steps in the design process. Because of the costliness of 3D printers and the materials used, designers often need to collaborate or find forms of sponsorships with maker societies or 3D printing companies and services. These collaborations allow designers to further their design research and print out end-products cheaply all the while benefiting from the knowledge of these organizations.

Despite these aforementioned transformations brought about by the diffusion of 3D printing, 3D printing continues to remain marginal in the fashion sector, especially when it comes to wide-spread production. The TIS is still in a formative phase of development. Indeed, experts and fashion designers have expressed a number of uncertainties regarding the quality of available 3D printing technologies, their existing and future market applications, the price/performance relationship, the formation of demand and the development of positive externalities. First of all, with fashion products combining aesthetic values with functional values, it is crucial that the printed garments be wearable in order to foster consumer demand. Currently, most 3D printed garments remain closer to art pieces than clothing. They are either used as instruments for communication stunts by large fashion firms or are presented as part of haute couture collections. Secondly, costs of production continue to remain very high with 3D printing entailing that fashion firms often do not invest in the technology. Finally, the development of 3D printing for the production of garments and collection is blocked by the cyclical logic of the fashion industry. The quick succession of fashion cycles demands that collections be designed and produced rapidly. This enters into conflict with the experimentation and research times incurred by 3D printing design.

To conclude the SI of 3D printed garments is currently limited to a small number of actors within the fashion industry. However, there exists room for potential development notably in terms of user involvement. The sophistication of 3D printing softwares and machines as well as reductions in their price are opening up doors for individual 3D printing thus leading to a new form of design and production process where consumers would be able to print out designs from their desktop. While such a model of production is not yet applicable, it was often talked about by most interviewees and thus offers an interesting field for future research.

5.2. Research Limitations

There are, despite attempts, numerous limitations to this study. First and foremost are the limitations relating to the research strategy chosen. The use of a qualitative method raises issues such as the risk of subjectivity, the difficulty in replicating the study, the problem of generalization and the risk of lack of transparency.

Secondly, due to the limited time available for the carrying out of this thesis, it was impossible to involve more participants. The limited sample size is also due to the marginal and limited use of 3D printing for the production of garments. While more designers and firms make use of 3D prototyping, few are those that actually 3D print wearable garments. This considerably limited the number of possible of interviewees. What is more, with creators often having little time on their hands, the quantity of interview questions was often limited thus hindering a more profound understanding of 3D printing design and production processes

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7. Appendix

7.1. Appendix 1: Interviewees

RESPONDANT	PROFESSIONAL BACKGROUND	OCCUPATION	PLACE OF RESIDENCE	DATE OF INTERVIEW	LENGTH OF INTERVIEW
HOON CHUNG	Shoe Design	Shoe Designer	London, UK	19/04/2017	1h30
NOA RAVIV	Fashion Design	Fashion Designer	New York, USA	18/05/2017	30 minutes
MAARTJE JANSE	Fashion Design	Fashion Designer Conducting Research Project Makerversity	Amsterdam, NL	23/05/2017	50 minutes
CEDRIC MAGNE	Product Design	Founder of BiTs Tailor (web& brand content agency)	Paris, FRA	28/04/2017	30 minutes
VICTOR PORTES	Experiential Design	Founder and Brand Communications Specialist of Dutch Catwalk 3D Printing	Amsterdam, NL	20/05/2017	1h
MARCO MOSSINKOFF	Economics	Lecturer and research fellow in fashion marketing and brand management and Amsterdam Fashion Institute and HKU (Hogeschool voor	Amsterdam, NL	18/05/2017	40 minutes

		de Kunsten Utrecht)			
IRENE MALDINI	Industrial Design	PhD candidate at the Free University of Amsterdam and has a research position at the Amsterdam University of Applied Sciences	Amsterdam, NL	31/05/2017	1 hour

7.2. Appendix 2: Projects

Noa Raviv: Hard Copy Collection

Source: *Hard Copy*. (2017). *Noa Raviv*. Retrieved 10 June 2017, from: http://www.noaraviv.com/hard-copy-collection/pa0f5hub9byjn4ok4oc1cc5r5q34du

Hoon Chung: Master Project (MA – Footwear)

Source: *Hoon Chung*. (2017). *Showtime.arts.ac.uk*. Retrieved 10 June 2017, from: http://showtime.arts.ac.uk/SHOEMAKER

Maartje Janse: Project conducted during her course at the Textile Academy at Waag Society

Source: Janse, M. (2017). *Maartje Janse / Textileacademy*. *Maartjejanse.nl*. Retrieved 10 June 2017, from http://maartjejanse.nl/?section=textileacademy

Cedric Magne (BiTs Tailor): customizable 3D printed bow-ties

Source: bowtie, W. (2017). *Wireframer Supernova bowtie - Bits Tailor*. *Bits Tailor*. Retrieved 10 June 2017, from https://www.bitstailor.com/collections/bow-ties/products/customize-your-style-unique-custom-shiny-supernova-wireframer-3d-printed-bowtie

7.3. Appendix 3: Draft email for interviewees

Dear [name]

I am writing to you concerning the possibility of a future interview in relation to my thesis.
My name is Chloé Wren. In the context of my master's degree in Cultural Economics at the Erasmus University of Rotterdam, I have chosen to write my thesis on the use of 3D printing in fashion. The study aims to reveal and discuss the current and potential uses of the technology on the design and production process of the fashion industries.

I would be delighted and grateful to be able to interview you through which ever medium fits you best, in order to be able to gain insight into your work as well as your perspectives and opinions on 3D printing.

In the hope of hearing from you soon,

Best regards,
Chloé Wren
T: +33 7 88 22 16 54

Contact details supervisor:
Mariangela Lavanga
T: +31 10 4082459
E: lavanga@eshcc.eur.nl

7.4. Appendix 4: Interview Protocol

(1) For Creators:

a. Background

Can you please tell me about your educational and professional background?

When did you first discover 3D printing?

Can you tell me about your projects using 3D printing?

b. Projects, Activities, Networks

- Knowledge development and diffusion

  Where and how did you first discover 3D printing?

  Is there any room for 3D printing in academia?

  How does the use of 3D printing place you in the industry?

  Do you take part in any events, conferences of awards related to the use of new technologies in design?

- Experimentation

  How important is experimentation and research?

  How do you use the technology? Which specific technology?

  What future projects do you have in mind?

- Influence on Direction of Search/ Incentives

  Why do you use 3D printing?

  What are the advantages of the technology?

  What are the advantages for a young independent designer?

How does the use of 3D printing affect your design process? Compared to other technologies?
How does it affect your manufacturing or production process?

- Market Formation
  How would you characterize the role and place of 3D printing in the fashion industry?
  How big is the market for 3D printing?
  Is there a demand for 3D printed garments?
  What are the main limitations of 3D printing? And why?
  What is the future for 3D printing?

- Legitimation
  The media depicts a certain portrait of 3D printing, what do you think of it?
  Are they any problems legally with 3D printing? Copyright or Patenting for example?

- Mobilization of resources
  Which actors in the fashion field mostly use 3D printing?
  Do you work only with designers or individuals from other fields?
  How costly is it for you to use 3D printing? How do you finance it?

- Development of positive Externalities
  Are there new actors using 3D printing in fashion?
  If yes, what positive effects does this bring?

c. Any additional comments …

(2) For experts, consultants and researchers

a. Background

Can you please tell me about your educational and professional background?
Can you tell me about what you are currently working on?

b. Projects, Activities, Networks

- Knowledge development and diffusion

When did you first discover 3D printing? Where and how?
Is there any focus on 3D printing in academia?
What role do events, conferences or awards play for the diffusion of the technology?

- Experimentation
  How important is experimentation and research?
  What technologies exist? How are they diffused?

- Influence on Direction of Search/ Incentives
  What are the advantages of the technology?
  What are the advantages for a young independent designer?
  How does the use of 3D printing affect the design process? Compared to other technologies?
  How does it affect the manufacturing or production process?

- Market Formation
  How would you characterize the role and place of 3D printing in the fashion industry?
  How big is the market for 3D printing?
  Is there a demand for 3D printed garments?
  What are the main limitations of 3D printing? And why?
  What is the future for 3D printing?

- Legitimation
  The media depicts a certain portrait of 3D printing, what do you think of it?
  Are they any problems legally with 3D printing? Copyright or Patenting for example?

- Mobilization of resources
  Which actors in the fashion field mostly use 3D printing?
  How costly is it to use 3D printing? How do most designers finance it?

- Development of positive Externalities
  Are there new actors using 3D printing in fashion?
  Is there market growth?
  If yes, what positive effects does this bring?

c. Any additional comments …

7.5. Appendix 5: Coding Method

7.5.1. Overview Categories and Codes

CATEGORIES	CODES	
KNOWLEDGE DIFFUSION & DEVELOPMENT & EXPERIMENTATION	DEVELOPMENT	ACADEMIA / EDUCATION / UNIVERSITY RESEARCH EXPERIMENTATION, PROTOTYPING
	DIFFUSION	EVENTS, CONFERENCES, WORKSHOPS COLLABORATIONS SPONSORSHIP
INFLUENCE ON THE DIRECTION OF SEARCH	MOTIVATION	CURIOSITY, QUESTIONNING,INSPIRATION, INTEREST UNHAPPY, DISCONTENT, DIFFERENT
	INCENTIVES	ADVANTAGES, INNOVATION POTENTIALS, EVOLUTION, POSSIBILITIES ECO-FRIENDLY, SUSTAINABLE
MARKET FORMATION & LEGITIMATION	RESISTANCE TO CHANGE	CHANGE, TIME CONSTRAINTS, WANT
	FUNCTIONAL	MATERIALS, TASTE, WEARABILITY
	PATENTING	PATENT, COPYRIGHT, AUTHOR, FILE SHARING
RESOURCES	HUMAN RESOURCES	TIME CONSTRAINTS RESEARCH, PHD, THESIS
	FINANCIAL RESOURCES	COSTS CONSTRAINTS, INVESTMENT SPONSORSHIPS

7.5.2. Overview Manual Coding Method: Excerpt from the interview with Maartje Janse

Chloé: I was wondering if you could present yourself quickly as in your educational and professional background?

Hoon: So I studied footwear as a major, which is basically making shoes. I did this at the London College of Fashion. I also studied fine arts before. It was based on a traditional way of making shoes, on a traditional methodology. After this traditional bachelor I did an MA. I wanted to develop something further, and I also had a lot of experience with the industry and was not satisfied. I was disappointed. Some people say "oh you know I'm a footwear designer" but in reality they use templates and there is no dramatic change. They only change little things. That was a consideration for me. Also, I was interested in efficient and cheap ways to produce wanted to develop a new production method. So I contacted factories but prices are high, like the induction made costs are high and too high for the individual. So I wanted to look for other ways, and I jumped to 3D printing, a new methodology. And I achieved it. My good relationship to the digital studio [at London college of Fashion] helped. I contacted 3D printing material manufacturers and they sponsored me.

Chloé: And what have you been working on since then?

Hoon: I'm still developing new types of shoes. I'm focusing on the question: how to replace traditional manufacturing with new technologies. I'm creating my first prototype the shoe could be variable. Shoes means that they should be wearable. A lot of people use 3D printing but they make objects. They don't understand the key points of 3D printing. My shoes are the first 3D printed shoes. They are tricky, and the concept is not really mentioned. They are not only made out to be ecofriendly. People understand 3D printing in relation to ecofriendly. The shoes are jointed with a special structure so there is no glue The manufacturing makes a lot of waste and shoes too. There is a lot of glue used in the traditional way. Manufacturing is not changing. This is my passion: jumping into a new era. At the time of my first shoe, the question was combining the upper and lower sole. At that time, I needed a jointed system, that was the first stage. All the experimental phases succeeded. I am still developing and furthering, trying to find a better way.

Chloé: Do you work closely with people from other disciplines and backgrounds like engineers and programmers?

Hoon: No not really. 3D modelling or engineering is not really developed. Now most designers use programs such as Rhino. I use 3D Max which is more mathematical. It is a more specific program where you can sculpt the object on the program like you sculpt clay. I am not an expert but I use it anyway so I can see the actual output. Most draw in 2D and then imagine as much as they can. And then with the first prototype there is a lot of differences and discrepancies between what the designer imagined and what the factory actually produced. This is waste in time and in energy. That's why I just want to see the final product in live. It is easier to design and control and there is a lot of benefits to imagining wider. That is why now I am really focused on 3D technology. Also, I am interested in how people, how human sense will be evolved. Now all our senses are realistic but future generations may be able to feel through the virtual space. Like on the program, it's in free form. The pencil has arms so you can feel all the tensions when drawing. You bring drawings from other programs and then you adapt them. It's exactly like sculpting with clay.

Chloé: Are they many different 3D printing techniques? And which do you use and why?

Hoon: The actual 3D printing technology is not important. There is not enough material to reach mass production. Some 3D printing companies print products but only small, rigid objects. Soon in 5 to 10 years all manufacturing will move to 3D printing. And plus, recently there is a big attention brought to environmental issues. Countries are banning manufacturing for pollution reasons. But for shoes and clothing there is no proper materials, it is still a problem to make them.

Chloé: What do you believe are the greatest advantages of 3D printing?

Hoon: The advantages are time, customization and the environment is the big key word. After the industrial era we've damaged all our resources and soils, and we've consumed everything. Now the industry is turning towards reusable material and less waste. For example, Nike is a leading company in that. 15-20 years ago they tried to reduce waste by introduction lamination, which means seamless products, and wielding. It's also a more modern aesthetic as well. There is no stitching needed. Stitching produces a lot of waste. When a company makes a product there is a lot of wasted thread. Nylon which is a plastic is in the thread and is really painful to nature. Nike change factory wastage. Now many companies are following and its much better. These reasons are why I want to change how to make shoes. I cannot tell you too much detail about the shoe I'm making. I'm getting the IP, preparing the patent.

Chloé: Do you work entirely by yourself or in a team? Or, are you part of a community?

Hoon: Yes, at the moment I work by myself. I've recently applied to patent and now I've started searching for fundraising. I look for funding but not for 3D printing the shoe at the moment.

Chloé: Where did you go to print your first shoes?

Hoon: I was sponsored. The material is super expensive. The nylon which is the white powder (SLS), the hardest material, a lot superior to plastic, is super expensive. Imagine, only the sole of the shoe cost more than 1000 pounds to make, and the total shoe cost 2000 pounds. Now there is more material available like rubber material. Shapeways created it and print it. But it is tearable. But no other companies are releasing material. So anyway, at that time the sponsors offered me the Material, which we called Material X, because it was being patented and is still today not on the market. There aren't many 3D manufacturers releasing materials but we will see in a few years. So it was a secret material, and I sent my design and they printed it out for me. London has 3D printing so the company also gave powder to the school and I printed stuff there for free.