"HOW CAN FASHION COMPANIES IMPLEMENT ADDITIVE MANUFACTURING INTO THEIR BUSINESS ORGANIZATION?"

THERESA SCHEMM / AMFI / 20/01/16
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1. An Introduction of 3D Printing and its relevance for the fashion industry

1.1. Rationale
Additive manufacturing (AM) (see Appendix A.a.), commonly known as 3D (3 Dimensional) Printing (see Appendix A.b.), has been receiving increasing attention in the recent years, as it has come a long way since the first simple 3D printed plastic parts got developed as prototypes by a hobbyist. Today’s 3D printers are able to process various materials, ranging from human tissues, to metals and glass, and can even produce fully operative components, promising a great range of applications across different industries (Mc Kinsey, 2015). Since US president Obama (2013) announced at the State of the Union that “3D Printing has the potential to revolutionize the way we make almost everything”, AM is hailed to be a new business imperative by a diverse range of industries, from aerospace to automotive, and medical to consumer products. But, it is not only industries. End-users are also exploring 3D printing technologies, which progressed into the Maker Movement (see Appendix A.c.) and revolutionized 3D Desktop Printing (see Appendix A.d.). AM with its rapid development and wide ranging applications is being promised as the spark of the next Industrial Revolution (see Appendix A.e.) by many technophiles, as well as industry professionals. Comparing its potential impact to Ford’s introduction of machinery, which enabled mass-production and changed the world from the ground up (see Appendix A.f.) (Barnatt, 2013).

3D printing’s global expansion and distribution is only at its tipping point. Which has been recognized not only by the Harvard Business Review (2013), but also by global research company McKinsey (2013) as one of the 12 disrupting technologies (see Appendix A.g.) that will have a severe impact on manufacturing, product design and the global economy by 2025. It has been estimated that 3D printing will be able to generate an impact ranging from $230B to $550B/year by 2025, while the share of fully printed consumer products will be between $100-200B (Mc Kinsey, 2013). Wohler (2014), which is known as the most relevant consulting firm for additive manufacturing technologies since the ‘80s, expects that the AM industry itself will exceed $21B in worldwide revenue by 2020, with a CAGR (Compound Annual Growth Rate) of 34% (Forbes, 2015). Another McKinsey (2015) study stated that 3D printing is highly relevant to 10% out of 60 manufacturing executives. While, for a further 33% it is not yet highly relevant, though they are seeing a substantial importance for their business in the next three years, with 12% stating that it could be relevant in the future. It can be concluded that these studies give a clear picture on the emerging relevance of AM.

As 3D printing is not a product of the 21th century and rather looks back at a thirty year history, it might be surprising that the technology has only been recently acknowledged by a broader audience. First of all a vast decline in costs enabled the rise of the technology, but also evolving endurance, quality and the stability in the 3D printing industry, as well as the expiration of patents and the spread of information and rising amount of access points through the digital world, triggered its current popularity (Barnatt, 2013) (please see Appendix A.h. for a visualization). Egham (2014) argues that AM keeps on emerging due to the hype in the media, which leads to better visibility and rising demand.

Is it all just a big hype?

Next to 3D printing enthusiasts other observers have a more nuanced view on the potential of the technology due to the low level of adoption and high rates of failure occurred by today’s technical restrictions. This can be confirmed by taking a look at the falling stock prices of the two leading 3D printing software and service providers Stratasys and 3D Systems. It is clearly visible that Wall Street’s interest decreased with a 64% and 58% loss in 2015, after having skyrocketing growth rates of 1000% between 2012 and 2014 (Ho, 2012).

In order to understand the evolution of AM in the past years Gartner’s (2015) Hype Cycle for Emerging Technologies will give deeper insight on the evolution of the innovation (see Appendix A.i.). Hereby, it must be pointed out that the 3D printing market needs to be split in different segments; the consumer-
oriented one and the enterprise one due to different requirements, expectations as well as applications in order to make a clear judgment. Looking at Gartner’s Hype Cycle of 2012 (see Appendix A.j.) it becomes clear that 3D printing has already been at its ‘Peak of inflated expectations’. Which suggests an explanation for Wall Street’s overinvestment in the technology, driven by the unfulfilled promise of a technical wonder machine that enables end consumers to produce almost everything at home with a 3D desktop printer. Basiliere (2014) explains that "hype around home use obfuscates the reality that 3D printing involves a complex ecosystem of software, hardware and materials whose use is not as simple to use as ‘hitting print’ on a paper printer."

However AM offers a broader application spectrum and can therefore not only be judged by the success and failure of 3D printing hobbyists. Analyzing Gartner’s 2015 Hype Cycle for 3D Printing technologies (see Appendix A.k.) it can be said that 3D Printing will keep on gaining momentum as innovation has only just been triggered and AM application like 3D Printing in Supply Chain, Industrial 3D Printing or Retail 3D Printing, will only reach their plateau of productivity in five to ten years.

3D Printing and the fashion industry

Consulting firm Deloitte (2015) conducted a study in order to find out in which industries consumers would like to see AM going forward (see Appendix A.1.). While most participants are looking for the development of more medical applications, the second most important driver at 12% are 3D printed apparel and fashion products.

The fashion industry is known for being innovative, creating and driving trends, but also for its urge to emerge and adapt quickly to constantly evolving market demands, to inspire and make a statement (Stange, 2015). Therefore it is not surprising that some of the first 3D printed products came from this industry sector. For example, Ron Arad’s jewelry series ‘Not Made by Hand, Not made in China’ in 2000 or Janne Kyttanen’s & Jiri Evenhuis’ 3D printed drape dress in 2008. Fashion designer Iris van Herpen is one of the pioneers in 3D printed fashion and introduced the first fully 3D printed conceptual fashion collection ‘Crystallization’ to the broader fashion industry at Amsterdam Fashion Week in 2010 (Perepelkin, 2013). Most approaches towards 3D printing that are coming out of the fashion industry have a more conceptual than commercial background and emerge mostly from smaller artists, like for instance Noa Raviv’s collection ‘Hard Copy’ or Julian Hakes ‘Mojito Shoe’ (Rietveld, 2012). Just recently big fashion houses as well as commercial retailers started to experiment with the technology. Haute Couture label Chanel’s fully 3D printed reinterpretation of their iconic jacket at Paris Fashion Week in July 2015, as well as sporting goods manufacturer Adidas’ 3D printed customizable midsole for their running shoe series ‘Futurecraft’ in October 2015, are only a few examples of the spread of AM in the commercial fashion industry. For a deep dive into the timeline of 3D printing in fashion as well as visualizations of named examples please see Appendix A.m.

UK’s Big Innovation Centre (2012) states that the fashion industry will be facing heavy disruptions by AM, which will be mainly driven by transformations in design, logistics as well as retail processes. It can be argued that the realization of 3D printed clothing on a commercial scale is still a future vision, as it is currently not possible to print commonly used and commercially accepted materials like cotton or leather with a certain quality level (Oeko Institute, 2013). Today’s 3D printed apparel products can be described as an imitation of textile structures rather than actual commercial garments. Though recent developments in Bio Printing, where human blood vessels and organs have been 3D printed, suggest that it is only a matter of time until printed cotton will be a reality (Rietveld, 2012). Another indicator for this development is MIT’s research into the way silk worms construct their cocoons in order to be able to print silk (Rietveld, 2012). Start-up ‘Electroloom’ were the first ones who were able to print wearable seamless garments through an electrospinning process, though the level of quality, look and development is still in its infancy (Electroloom, 2015).
However it might not be possible to print out clothing as we know it right now, 3D printing for
accessories and footwear is already a reality, as they can either be partly or completely 3D printed, or
at least their prototype can be (Raviv, 2015). Furthermore fashion designer Noa Raviv (2015), a 3D
printing enthusiast, states that she is “[…] convinced that it is just a matter of time until 3D printing of
garments will be possible. It is always the same with technology; it takes time to be integrated into an
industry and into people’s lives. For example who would have ever thought what influence the internet
would have on our lives and the way we work?”

Taking all expectations and forecasts from 3D industry experts, professional researching firms,
designers as well as consumers into account, it can be said that fashion companies need to start
contemplating the applications of 3D printing and the potential consequences on their business as "the
3D printing market is continuing its transformation from a niche market to a broad-based, global market
of enterprises and consumers." (Stamford, 2015)

1.2. Research Question
“How can fashion companies implement additive manufacturing into their business organization?”

1.3. Significance of Research
The aim of this research is to provide an overview on 3D printing’s current, as well as future
opportunities, limitations and deeper implications, with the goal in mind to map out potential and to
help make informed decisions to drive performance, growth and innovation goals for a fashion
company. As most other academic publications on this topic have a more technical background and do
not take managerial aspects into consideration.

Organizations should feel stimulated to contemplate on disruptions they could potentially face, consider
the opportunities that are coming along with change, but also feel inspired for further Research and
Development (R&D) into AM.

“Disruption can be dangerous and scary. It can also lead to wondrous new business and ways of life.
Perhaps more importantly, it’s inevitable – so get in front of it while you can.” (Bloomberg, 2013)

1.4. Structure
Chapter 1 / Rationale: What is 3D printing and why is it relevant for a fashion company right now as
well as in the future? This chapter provides a general introduction to 3D printing, while referring to the
appendix for an explanation of (technical) terms. Moreover it dives deeper into AM’s current relevance
and possibilities across various industries and explores market opportunities, while keeping in mind the
goal to provide engaging information towards a fashion company. Furthermore it dives deeper into the
connection of fashion and AM and gives an outlook into a possible future. Finally this chapter
elaborates on the motivation behind this research paper, its structure, limitations as well as
methodology. Due to the complexity of the subject, the guidelines that have been instructed for this
paper and the aim to give a compact overview, definitions and visualizations are provided in the
appendix to avoid superficiality for a reader that is engaged with the subject and provide deeper
insights for the unexperienced one.

Chapter 2: How can it be determined if AM is beneficial for a fashion company? Chapter 2
suggests a generic evaluation framework in order to determine when and how AM can be
beneficial for the creation of a product or application from an individual, economic as well as
technological perspective.

Chapter 3 and 4 will form a comprehensive SWOT analysis, which provides and in-depth exploration
of possible AM applications, as well as opportunities and threats that AM implementation could evoke.
Chapter 3: How is 3D printing currently applied in different industries and what are the consequences of these implementations? Chapter 3 gives an overview on a range of possible AM applications and elaborates on their advantages and disadvantages, keeping in mind their potential relevance for the fashion industry.

Chapter 4: What factors are influencing the development of 3D printing right now and in the future? Opportunities and threats of 3D printing applications as described in chapter 3 will be discussed.

Chapter 5: What are the learnings from various industries applying 3D printing into their organization and to which opportunities do they lead for a fashion company? Finally the fifth chapter summarizes key results of the previous ones and elaborates on the actual potential and relevance of AM for the fashion industry.

1.5. Methodology
In order to fulfill this research’s goal to map out various perspectives on 3D printing applications and their potential opportunities and threats for a fashion company, primary as well as secondary research will be employed.

Chapter 1: Literature specialized in the technology of 3D printing and its implications across different industries will give the possibility to establish a theoretical framework of the research topic and underline its relevance. Therefore studies by professional research companies like Wohler’s, whose annual report is commonly known as the groundwork for AM since several decades, McKinsey’s in-depth prognosis reports on AM and disruptive technologies, AM studies by Harvard Business Review, Gartner’s innovation studies, global consulting company Deloitte’s AM studies, as well as the RTHW Aachen (GER) one of the leading research universities for technology and innovation, are going to lay the foundation for this chapter. Statements will be challenged through Wall Street’s current data and opinions from 3D printing and fashion experts will form a base of different viewpoints on the technology in order to provide stimulating information to the reader.

Chapter 2: As there is no comprehensive framework on the evaluation of AM technologies, suggestions from industry experts like Conner et al. who created a map on AM products and services, as well as Buchetti et al. who set up ratios to quantify AM, as well as Senvol’s AM scenarios and AM database, will be taken into account in order build a framework for the determination of the most profitable manufacturing method. Moreover the outcome of expert interviews will underline the problematics of the evaluation of AM’s technologies and build the framework.

Chapter 3 & 4: Chapter 3 and 4 are based on examinations of case studies of different AM applications across a diverse industry spectrum, including the companies Stratasys, NASCAR, Proper Group and Akaishi paired with expert research as well as interviews.

1.6. Limitations
Regardless of the hype around AM, in depth research into the economic effects of 3D printing on businesses is very limited and there is no research about AM in the fashion industry available as this specific market is in its infancy. Only a small number of high quality literatures focused on AM are available, which have in most cases an engineering, material or computer science background. As a result this paper is taking potential key economic implications of different industries and applies it to the fashion industry in order to map out a framework.

Moreover there is only small-scale empirical research available, as the technology has not been tested in large-scale environments. This limits this paper from confirming propositions. Ongoing R&D is driving a fast development of AM technologies, and looking back at Gartner’s Hype Cycle it can be predicted that the technology will have a strong influence across a broad range of industries in 5-10 years. Therefore valid data will be available soon.
As AM technology evolves faster than books or research papers can be published, online articles will also be included into this research, which cannot provide the same reliability as academic publications. Moreover, it should be pointed out that there is almost no academically confirmed terminology for the field of 3D printing and that my personal perception might have influenced the given definitions. Literature that is elaborating on AM’s current state as well as future possibilities is only going to be incorporated, if it is not going back further than 2012 due to the fast evolution of AM technologies.

Another limitation of this paper is the discretion of fashion brands and 3D service providers towards their manufacturing processes, strategies and costs. This research was initially set up with the intention to receive primary data from different companies who are already working with 3D Printing, though this proved difficult as companies were not willing to share due to confidential restrictions.

Taking all this into account, it must be pointed out that the suggested AM implementation strategies and consequences are to a certain extent futuristic.

My current employment at one of the most innovative and the successful sporting goods retailer worldwide could influence my perception of realistic possibilities for an average organization. Finally my personal passion for innovation and technology might influence the method of researching and writing.

1.7. Product
In Oct 2015 sporting goods retailer Adidas, as well as New Balance, released a prototype for a partly 3D printed running shoe, which is aimed to serve the athlete in a personalized way and bring their performance to the next level.

Nike Maxim #9: “We are on the offense – always.” This statement is one of Nike’s company values, which encourages its employees to see it as their first priority to be the leader in their field in order to win and stay ahead in a competitive environment. Therefore a multi-staged business plan, which builds upon the outcome of the research, will present an implementation strategy for 3D printed footwear innovation in NIKE Inc. and represents the next natural step feeding into Nike’s urge to innovate and beat competition.

The paper will be structured as followed

1. EXECUTIVE SUMMARY
2. NIKE AND ITS MARKETPLACE
   Nike will be introduced through an overview on its business practices and product offerings. In order to gain a deeper understanding of Nike’s company culture and practices, a short overview on the history of Nike Inc. will be presented. Moreover, Nike’s current position in the market place will be elaborated.
3. MARKET OPPORTUNITIES – A LOOK INTO THE FUTURE
   This chapter will be focused on overall athletic footwear market and it as a growth driver, to gain an understanding of Nike’s aggressive growth strategies for 2020. Furthermore the unique selling point of the Nike will be highlighted as a growth driver and enabler for the proposed 3D printed footwear initiative.
4. OPPORTUNITIES IN 3D PRINTED FOOTWEAR MARKET
   This chapter is intended to give an overview on the 3D Printing market and Nike’s current position in it. Moreover, a closer look will be taken at the directly competing sporting goods retailer Adidas and New Balance, and at the 3D print startups SOLE and Feetz. Finally the named companies will be evaluated in order to learn from them.
5. CONCEPT & PRODUCT PROPOSAL
The following chapter proposes and elaborates on a new brand initiative and products, which are fueled by AM technology.

6. DESIGN & DEVELOPMENT PLAN
The following chapter will give insight on the N3K insole proposition and chart its product development and elaborate on its relevance.

7. PRODUCTION EVALUATION
A key factor to successfully implement AM technologies into a company is to evaluate strategically if AM will actually be advantageous, either for the production process or product. In order to determine if AM is actually the most suitable manufacturing option, the AM evaluation framework of the research report will be taken as an assessment guideline.

8. MERCHANDISING STRATEGY
This chapter will elaborate on market place management, as well as a product launch strategy.

9. MARKETING PLAN
A comprehensive marketing plan that will energize the market place through several initiatives will be described in this chapter.

10. EVALUATION

2. Evaluation framework for AM

It is already a reality that almost everything can be printed, but does this also imply that it is the best production method (Sevenol, 2015)? Stolberg (2015), merchandiser at Burberry, argues that determining if AM is actually valuable for a company is probably the biggest challenge for everyone interested in AM. Therefore a key factor to successfully implement AM technologies into a company is to evaluate strategically if AM will actually be advantageous, either for the production process or product. Business leaders need to take many determinants into account when analyzing if AM is a profitable proposition for their company. Due to the diversity of AM applications (see chapter 3 and 4) and technologies (see Appendix A.n.) it can be challenging to decide if either AM or TM (Traditional Manufacturing) (see Appendix A.o.) is more beneficial, as each of the applications has its own advantages and limitations towards speed, materials build volume, quality and post processing activities.

The following chapter provides an assessment framework created by the author (please see Appendix A.p. for a comprehensive overview) that aims at covering all factors that a company needs to take into consideration when considering adopting AM as a new business driver.

2.1. Initial Assessment
The first step of the evaluation of AM technologies is to identify at which point the company and its products sits on Conner et al.’s ‘Three axis model of manufactured products’ (2014), which is defined through volume, complexity and customization (see Appendix A.q.). The goal of this evaluation is to analyze which products can be taken into consideration to be efficiently produced by AM technology (Connor, 2014). Moreover, AM service provider Senvol suggests a framework of seven scenarios that help determine if AM is beneficial from an operational perspective (see Appendix A.r.). If a company is not able to answer any of the prosed questions with a ‘Yes’, AM should not be implemented. For a quantitate evaluation it is also advised to investigate further the usability of the evaluated products.
through Bacchetti et al.’s (2015) AM drivers (see Appendix A.s). These three tools cover all aspects that need to be determined from a strategic perspective in the first place.

2.2. Technological Assessment
During the second step of the evaluation the list of products/applications coming out of the initial assessment is being reviewed from a technological standpoint. Hereby it is important to lay out all technological properties of a product/service, like material, physical as well as mechanical aspects etc. A comparison of these aspects with the one of a database, for instance Senvol’s, that includes every possible manufacturing technology, AM as well as TM techniques and their properties and requirements, will result in the identification of the most suitable manufacturing method. In case AM is the most beneficial method Sevenol’s tool will provide a list of 3D printers, going along with a selection of materials for a company’s chosen product or application. Furthermore, this list will be able to give them advice for potential vendors and machinery prices. Therefore, the company will be able to identify which machines and materials they can make use of to fulfill their goal of implementing AM successfully or stick to TM methods.

2.3. Economical Assessment
Finally, the company will be able to make cost calculations based on the outcome of the technological evaluation. Therefore they will be able to determine if producing by AM or TM will be more cost-effective. Additionally, companies need to take the resources that are being used during AM processes into account in order to evaluate when and where they are being used, to determine a reduction in resource usage. For an in-depth overview on costs, a guideline for reading suggestions is provided in the Appendix A.t..

3. SW(OT) - Strengths & Weaknesses of AM over TM
This chapter will be the first part of a SWOT Analysis and provide an overview on the strengths and weaknesses of AM over TM from a technological and economic perspective. Moreover, it focuses on AM for product development as well as from a greater manufacturing standpoint, which includes the creation of end products, as well as parts and components. For a compact overview of the SWOT please see Appendix A.u..

3.1. Strengths
3.1.1. Rapid Prototyping (see Appendix A.v.) - Acceleration of the Product Development Cycle
3D printing’s initial application purpose, producing prototypes in order to accelerate the product development cycle, is still one of the main drivers of the technology’s popularity for companies. Though, this has been already implemented in many firms across different industries, its strengths compared to traditional prototyping are still far from great importance and should be considered when planning on making use of AM (Piller et al, 2015).

Time & Cost Savings
First of all, the implementation of AM in the product development cycle saves time, because the timeline between the design concept and the prototype diminishes. Traditional prototypes manufactured through an external source ask for custom tooling, which implies a financial investment and a high level of communication, as multiple handovers could lead to the risk of miscommunication and long lead times. Through AM the prototype would be ready sooner for the next step in the design process. Therefore AM shortens the overall go-to-market time. (Michalik et al, 2015).
Furthermore AM is also able to minimize the timeframe in product development through the reduction of work effort, as numerous design alterations and improvements, which require tooling adjustments and often lead to cost penalties, can be done internally. Moreover internal alignment on the design with other functions in the company as well as stakeholders will be speeded up (CSC, 2012). Japanese footwear developer Akaishi implemented AM into their product development process and was able to decrease their lead time by 90%. With the reduction of time, comes the reduction of costs, in this case 73% for Akaishi compared to producing models externally (Stratasys, n.a.). Another example is one of NASCAR’s race team, which was able to reduce 89% of their development costs and 66% of their development time by making use of internal AM models for wind-tunnel testing of their racing cars (Stratasys, n.a.). Also, Burberry uses AM to print buckles for belts in order to see if the size is corresponding with the dimensions of the bag, which speeds up the product development process (Stolberg, 2015).

**Improved Design: Quality, performance, manufacturability**

Next to time and cost savings, AM prototyping is not only able to enhance the product from a quality, performance and design perspective, but also improves its manufacturability. Though it is challenging to quantify this statement, it must be pointed out that through a company’s ability to produce numerous iterated prototypes in-house there is room for more testing, which finally results in a better outcome (Michalik et al., 2015). Moreover the designer feels less restricted due to a larger space for experiments, which leads to a greater progression in design itself. Additionally, the creator is not limited to molds and tooling anymore, which enables him to explore new design possibilities (Lott et al., 2011). In one case a designer that got instructed to accelerate the production flows at an industrial bakery created a new tool, which was triggered by the AM’s solution space, increasing production speed by 40% (3D Systems, 2015).

**Risk reduction**

Another advantage of AM prototypes over traditional ones is the possibility to integrate the end consumer, buyer and investors into an earlier stage of the life cycle process through consulting and co-creation, long before go-to-market timelines. Automotive firm Proper Group International 3D prints small cars in order to show them during focus groups to determine challenges they could face with their customers’ during product launch (Fuges, 2012).

AM used for prototyping is only one possibility for companies to take advantage of 3D printing technologies. What is being hyped and debated around right now is its possibility to replace common manufacturing techniques for rapid manufacturing. Industry experts at Wohler (2015) predict that around 80% of AM products will be part of an end product or one itself by 2019.

**3.1.2. Complexity is free**

As mentioned AM is accelerating design possibilities. This is due to that fact that design complexity with AM does not lead to increased manufacturing costs like with TM (Piller, 2015). Please see Appendix A.w. for a visualization and comprehensive explanation of this statement.

**3.1.3. Inventory and Transport Transformation**

The financial investment for inventory and transportation demonstrates a demanding cost factor for companies. In TM processing various parts of a product are often made in different locations, which ask for inventory storage, as well as additional transportation to the assembly location of the end product. AM is able to transform the traditional supply chain. A CAD (Computer aided design) file does not require physical space, which means that a part of the inventory can be digitalized. Therefore inventory will be reduced and manufacturers will be able to rely on just-in-time production instead of a fully stocked inventory, which at the same time diminishes transportation costs. This also leads to AM’s ability
to replace and reduce some single part production steps for an end product, as various parts can be
easier produced by the same firm, which will be analyzed in depth in the following paragraph.
Shortening the supply chain minimizes its vulnerability and therefore reduces also potential disruptions.
Any additional point in the supply chain adds a potential risk factor, therefore keeping steps in the
supply chain to a few, keeps also the potential of disruption low (Piller, 2015).

3.1.4. Simplifying system set ups
Another advantage of AM over TM is AM’s ability to enhance process efficiency and reduce system
complexity. Transitioning between goods in production will become free of costs, as the process only
includes the upload of another CAD file, instead of creating cost intense new molds and tools (Piller,
2015). Furthermore assembly work will be reduced through one-step production. For example, moving
parts in a product can be directly incorporated and do not need an extra step in manufacturing, which
leads to savings in time, labor and tooling costs. This also enhances the overall flexibility of the
production process as goods can be composed in a random order (Gibson et al., 2015), but also at a
place where they are needed (Sheffi, 2013). For example if a production line goes down, the
component which is needed to solve the issue might have to be delivered from a distant supplier, which
causes high costs through production stop and same day delivery costs. Producing the desired part by
AM directly on site would avoid this issue (Sheffi, 2013).

3.1.5. Sustainability
Moreover companies are able to enhance their sustainability index through the implementation of AM
into their organization (Lipson et al, 2013). This results on the one hand from AM’s design driven
benefits, like its ability to process objects exactly to their measurements instead of carving it out from
another material, which results in more resourceful production as less material is used and wasted, and
finally into products with a lower carbon footprint (Sheffi, 2013). Nike believes that by reducing waste
reduction through AM they will be able to save about $1 billion per year (Low, 2015). Also, the
possibility to run numerous tests before going-to-market, as well as being able to produce on-demand,
causes less unwanted inventory (Sheffi, 2013). But also AM’s ability to shorten the supply chain, as
described in 3.1.3. results in less CO2 emissions, because less energy for transportation and
warehouses is needed (Econolyst, 2012). Moreover comprehensive data on on-demand production is
lacking which is needed to quantify AM’s sustainability aspects, as existing studies only take electricity
power consumption of 3D printers vs. traditional production machines into consideration, leaving
drivers like material and fluid consumption out of their research scope.

3.1.6. Economy of Scale - Scope
AM influences production economics through the reduction of the minimum efficiency scale. Companies
are able to produce an unlimited amount of variations at the same cost as reproducing a single unit.
This enables AM technologies to potentially solve the ‘scale-scope dilemma’ as there are no additional
costs attached to product variety. Furthermore the lead time for individualized items increases as
changeover time and tooling costs are reduced to a minimum, which enables highly efficient small-scale
production runs (Piller, 2015). This is in contrast to TM procedures, which face great costs for small
scale production runs (Cotteler et al, 2014). Please see Appendix A.x. for a deep dive into the
breakeven point of AM compared to TM.

3.2. Weaknesses

Though AM has some clear advantages over TM, there are as well severe limitations that need to be
taken into consideration when contemplating over manufacturing techniques.
3.2.1. **Limited Solution Space**

AM is still limited in its choice for materials, colors as well as finishes (Bermann, 2012). Though it is possible to 3D print multiple materials and colors with certain 3D printers at once, combining materials is still a challenge, as different components have different heat resistances, which are being challenged during the 3D printing process. An example would be the combination of ABS, an in AM commonly used plastic, and titanium. These materials have very different melting points and are therefore incompatible for AM (Piller, 2015). For an overview which materials can be combined during which AM processes, please see Appendix A.y..

3.2.2. **Material Costs**

Another downside of AM is its high material cost compared to TM. A research study by Atzeni et al. (2012) compared the costs for a selected metal part made from aluminum. By producing it through AM the material costs added up to €2.59, while for a production through AM (Selective Laser Sintering) €25.81 had to be invested, almost ten times as much.

3.2.3. **Product Quality**

Due to their sliced build up AM objects are not able to achieve the same levels of resistance towards environmental influences, as well as high stress exposure, as traditional manufactured products (Berman, 2012). Moreover quality issues occur due to a lack in the development of an AM standardization framework. So far, no globally aligned and fully covered set of expectations towards the quality of 3D printed products is being published (Lott et al., 2011) (see 4.2.3.). Furthermore the surface of 3D printed products usually asks for refinement, as the quality that is common in TM does not apply here.

3.2.4. **Production Speed**

The overall manufacturing speed of AM is significantly lower than the one of TM (Gibson et al., 2010). Though AM technologies might become faster in the next decades, it is physically not possible due to friction and viscosity to ever reach the production speed of, for example, plastic injection molding (Barnatt, 2013).

4. **(SW)OT of AM - Strengths & Weaknesses of AM**

This chapter is focusing on the second part of the SWOT Analysis and offers an overview on opportunities in AM technologies and threats that AM might face. For a compact overview of the SWOT please see Appendix A.s..

4.1. **Opportunities**

4.1.1. **Customization**

Mass customization (see Appendix A.y.) answers consumers’ rising urge for individualization, on the one hand towards fit, on the other hand towards style, which is especially relevant to a fashion company (Stolberg, 2015). Product Customization has the potential to increase consumers’ perceived product value, resulting in their willingness to pay for the extra value, which gives opportunity to ask for premium price points (Franke, 2004). AM enables companies to deliver mass customized products without cost penalties as complexity and variety is free (Anderson, 2012), which has been examined in chapter 3. A highlight of AM as a mass customization strategy is its ability to actually provide a full customization approach instead of design alterations in a limited framework of designs. For example eyewear brand Protos offers 3D printed glasses tailored to their consumers’ faces or footwear, insole
brand SOLE offer personalized insoles for the perfect fit. An example of a ‘restricted’ mass customization offer would be Nike’s NIKEiD, where consumers can choose between a range of color and material options for certain Nike footwear silhouettes.

4.1.2. Market Opportunities
AM enables a wide range of new business opportunities through the democratization of manufacturing. Set up costs for new manufacturing companies are relatively low compared to TM set ups, which gives new players an opportunity to set foot into the market place.

Furthermore, AM provides also a great opportunity for startups. Like for instance, young fashion designers, as investment costs for small production runs will be kept low and they will not be challenged with minimum volumes and could potentially rely on just on time production, which minimizes financial risks.

Another business opportunity lies in the provision of 3D consulting services and law firms, as the demand for experts is high but the number of 3D printing professionals is low (see 4.2.3.). But also the provision of 3D printable materials will become relevant as the demand for raw AM materials is rising, which is coming along with the expected growth of the overall AM market (see chapter 1).

Through the digitalization of objects, companies could offer their products online as a CAD file as products can also be printed by consumers themselves, for example at home with their own 3D desktop printers or at a 3D printing service bureau.

4.1.3. Research & Development
Ongoing R&D into AM, partially sponsored by the government, suggests upcoming solutions for discussed weaknesses and threats of AM (Piller, 2015). Nations with influential economic power like for example the US, Germany or China have a great interest in the development of AM and allow sponsorships. China for example invested $245 million for a seven year AM research project, as well as the UK who gave $158 million for a new research facility (Zack’s Equity Research, 2015). Research centers like the Oak Ridge National Laboratory in the US is collaborating with industry partners in order to improve AM’s technological capabilities and stimulate adoption by companies. But, also various companies have invested millions of dollars into AM research such as Nike, Adidas, NASA and Boeing (Canalys, 2015). Furthermore, cooperation between businesses are driving 3D printing’s development. Like for instance Stratasys’ and Adobe’s recently announced partnership or Nike’s collaboration with 3D animation company DreamWorks and 3D manufacturing company FLEX (Low, 2015).

4.1.4. Localization
AM’s ability to be efficient with small scale production runs together with the possibility for a localized production close or even at the point of sale (Berman, 2012), results in a reduction of time as well as costs for freight and transportation (Kleer, 2013). This creates new opportunities as companies are able to serve new or distant markets better and can deliver products faster to their consumer (Deloitte, 2015). Sporting Goods retailer Adidas just announced the opening of a fully automated shoe factory near the Adidas headquarter in Germany to achieve exactly these results (Reuters, 2015). Moreover, localization empowers a shift in the market place, where labor is being moving from low wage countries from the East to potentially mostly Western countries, which creates opportunity for high quality jobs (Anderson, 2012).

4.1.5. Accelerate CRM (Customer Relationship Management)
As discussed in 3.1.1. AM gives companies the possibility to engage proactively with their consumers and create consumer-targeted products, which finally results in growing revenues, but also brand loyalty. Through monitoring consumer behavior companies are able to gain valuable consumer insights. If, for example, a 3D jewelry company tracks which design options customers experiment with in a customization tool, they are able to see if their consumers are looking, for example, for a specific kind
of length or shape of an earring. Based on this data they are able to make informed decisions in the future (Stolberg, 2012).

4.2. Threats

4.2.1. Mass Production
As described in 3.1.6. AM represents the most efficient production method if a company wants to produce a small batch of goods, while each unit can even vary. However, mass production is offering the opposite; fast and large volumes production runs of the same single unit. It can be said due to these circumstances, especially triggered by AM’s slow production speed, AM will not be able to replace mass production for standardized parts (Piller, 2015).

4.2.2. Talent Shortage
At the moment companies are being challenged to find skilled candidates for AM related jobs. As AM is a relatively new field, especially when being applied on a big scale, human capacities are low. Wanted Analytics (2014) has monitored an increasing demand for candidates who have AM skills. In September 2014, the number of job advertisements looking for workers with AM expertise had increased by 18% in four years. 35% of all job offerings posted for engineering jobs named AM skills as a criteria (Wanted Analytics, 2014). Due to the great growth of AM, the demand for labor is outpacing its current supply in AM experts. This is due to the fact that AM training usually happens at the work place, rather than in university or school (Snyder, 2014).

4.2.3. Lacking Tools and Standards
Furthermore educational guidelines are lacking, which creates challenges around gaining the needed know-how of the technology. Moreover, design tools specialized on AM, as well as CAD tools with an integrated AM function, which would enable the conversion into a .stl file (see Appendix A.1.), are rare (Lipson et al, 2013). Though as mentioned in 4.1.3 R&D, this field is ongoing.

Furthermore, there is a lack in a fully worked out standardized global framework for AM activities. AM experts at SASAM (Support Action Standardization Tools) extended the existing AM framework that has been worked out by ASTM (Additive Manufacturing Standards), and suggested a roadmap for the work that needs to be done in collaboration with industry partners and stakeholders to achieve the goal of a comprehensive, aligned global AM guideline (Feenstra, 2015). These issues retain a full exploration and research on the topic (Lipson et al, 2013).

As mentioned in 4.1.2., companies could offer their products as CAD files online, like is already being done in digital 3D printing market places, like Thingiverse. It is therefore, not any longer in the hands of the company to set a certain standard for their product, which causes severe quality assurance as well as authenticity issues (Barnatt, 2013).

4.2.4. Unauthorized Reproduction
AM will, especially in combination with 3D scanning technology and reverse-engineering capabilities, challenge IP rights of products (Kurfess, 2014). Reproducing and sharing a physical object through the conversion into 3D file data, will not become more difficult than sharing any other computer file (Wilbanks, 2013). Therefore many industries could potentially face the same disruptions related to IP-rights as the music industry (Wilbanks, 2013). An example of this is the appearance of a CAD file for a belt buckle from the luxury brand Hermes on 3D market place Shapeways, which was open to the public to download for free. 3D Systems (2013) suspects that the markets for automotive parts, toys, IT and consumer products could lose up to $15 billion through AM-related IP issues already by 2016.
5. Conclusion – An Advice

The previous chapters enabled fashion companies to understand AM’s relevance in terms of market potential and what factors are driving its growing importance. Moreover, they were able to develop a critical view on AM’s different application possibilities and gained an insight into opportunities, challenges and limitations of AM technology. Furthermore, they were able to evaluate if AM is a profitable addition to their own business, from a technological as well as economic perspective. Finally, the fifth chapter summarizes key results and elaborates on the potential of AM for the fashion industry.

First of all, it must be pointed out that AM is not to be considered for a fashion company that focuses entirely on apparel (yet), due to the mentioned challenges to print actual textiles. Though R&D in AM technologies is evolving, there is no serious evidence that this will be a possibility in the near future.

AM’s ability for rapid prototyping shows great potential for fashion companies that have footwear and accessories in their design portfolio. Applying AM at the product development stage will enable these companies not only to save costs and time, but also enhance their products in terms of quality, performance and manufacturability. Being able to show prototypes before the actual production stage to consumers and buyers will reduce their risks of failure. This is especially beneficial to fashion companies that are new to the industry as they are lacking historical data, which enables them to make informed decisions, for instance on order quantities and line plans.

But also AM’s ‘Complexity is free’ factor demonstrates an important pillar of the technology. Giving a fashion designer the possibility to create complex designs, regardless of price, will open up innovation space. Which results in surprising new products that feature performance, design and usability benefits that could not be achieved before.

Mass production is dominating the manufacturing market. Being driven by consumerism and keeping costs at a minimum, which results in severe challenges for smaller businesses and retailers, as they are often not able to keep up with prices, options and service opportunities (Petersen, 2014). AM eliminates the reliance on minimum order quantities and enables small production runs and even exactly order production volumes. This gives smaller businesses the chance to enter the market place as their budgets are often limited and it can therefore be a severe risk to be challenged to place a large volume order. Therefore over-estimations for orders will become history, which eliminates unsold stock and therefore financial loss. Designer Kimberly Ovitz, who presented a jewelry collection at NY fashion week in 2015, states that 3D printing transformed her production timeline as customers could purchase product immediately and get it delivered within two weeks (Brooke, 2013).

The fashion industry has been challenged by their consumers to deliver products as fast as possible, resulting in time-to-market timelines of only 6 weeks, which counts for instance for H&M or ZARA (Stange, 2014). But most companies are not able to keep up with this speed, the more common time to market spans over 6 months (Peterson, 2014) or can even take up to 1.5 years, as for example with Nike. Transforming the supply chain, simplifying production system set ups and moving production closer to the point of sale, all achieved through AM, enables fashion companies to serve their consumers faster and respond quicker to market demands and changes. Sporting goods retailer Adidas is setting an example through its announcement of a fully automated footwear factory called ‘Speedfactory’ in Germany, which is being created to be able to respond quicker to the market (Reuters, 2015).

Mass Customization can be named as one of the biggest challenges of conventional manufacturing methods, as it does not offer any space for customization (Connor, 2014). As fashion is being driven by people’s individuality, but also by more pragmatic reasons like finding the right size, AM offers a great chance to serve consumers with personalized products (Stolberg, 2015). Furthermore, AM is able to achieve a high level of design complexity (Connor, 2014). This offers a great opportunity for people who are in the need of sizes outside the norm, as it enables them to not only find for example footwear...
in their exact size, but also according to their personal taste, as fashionable options for special sizes are a rare good (Stange, 2015). Though it is possible to purchase individualized products that are made to the consumer measurements, it is combined with high costs. An example of this would be a custom pair of leather shoes by a traditional shoemaker or a custom fit ring.

This does not apply to AM, as it solves the economy of scale issue. Finding the perfect size is inevitable for instance in sportswear. 3D printing will maximize the opportunity to enhance the athlete's performance through providing the optimal gear. This approach can already be seen with professional football players like Cristiano Ronaldo, who has customized Nike soccer shoes. Mark Parker, president and CEO of Nike Inc. (2015) announced that Nike is "inventing new ways to give consumers more choice, more personalized product and faster delivery." With this being said, it can be predicted that it is only a matter of time until 'real' customization reaches a commercial market potential.

Also sustainability has reached a great level of importance for many companies, as the global future depends on it due to climate change, constrained resources as well as population growth. The fashion industry is the second biggest environmental polluter worldwide (Ecowatch, 2015) and is therefore challenged to increase their sustainability index. Though the most critical ecological issues lie in the production of apparel and textiles (Nike, 2015), AM delivers a step into a greener future.

But, in order to maximize the potential of AM, the technology still has to overcome many challenges, as it is still limited to some extent. This especially counts for AM's inability to print textiles that are from commercial value. Moreover the costs for materials that are printable are still a challenge.

Though AM is partly advantageous over Mass Production, it also has a downside. Mass Production is being optimized to deliver large batches of product at a high speed. Being challenged with a very low production speed, AM is not able to keep up to the standards of Mass Production and should therefore only be used for small volume batches, which can on the other hand offer a high level of customization as well as complexity.

A lack in tools and standards are making it difficult for AM to be fully adapted to the market place and to reach its full potential. What is needed is to accelerate collaboration between industry experts. For instance, a partnership of an AM service provider like Stratasys or 3D Systems and a CAD software provider like Lectra, would fuel AM's development. But, in order to actually be able to make projects like this a reality, more AM experts are needed in the market place. Making 3D printing more accessible to (fashion) students would be an enabler. New York's fashion school Parsons already supports this by providing their students with AM classes, as well as access to high quality 3D printers (Parsons, 2015).

AM might enable a possible paradox concerning the role and capabilities of a designer. Though the demand for professional expertise to create AM products is rising, the need for actual design skills are decreasing as digital design comes with automation (Deloitte, 2015). The growing demand for design professionals is resulting from the rising wish for pragmatic design, but also from the implications for product performance and value delivery. Due to the democratization of manufacturing through AM, designers are being stimulated to add more value to design, which results in good design become more important and relevant (Deloitte, 2015).

In the meantime, evolving AM technologies are diminishing the need for expertise as well as educational obligations for designers, which results in a market that is more accessible to amateurs. Due to AM's ability to produce more prototypes to test and alter designs, there is more space for failure. Therefore, designers that get it right in the first place might not be needed anymore. An example of this are two designers without any aeronautical design training that were able to create an operating unmanned aerial vehicle through AM (Wohler, 2014). Self-initiated design and open design opportunities are creating space for design amateurs to add value to product development. By embracing the passion of these hobbyists, companies have the opportunity to access a great source of
inspiration, but also the possibility to gain valuable consumer insights. Though, it must also be pointed out that as more and more design hobbyists enter the market place there is also the possibility of more improper designs flooding the market, which can devalue product design in general (Stolberg, 2015). It could also be possible that as untrained people take part in, for instance, open design contests from a company, products appear that do not meet standards of the company and could therefore have negative impact on the brand (Stolberg, 2015).

Being able to 3D scan and 3D print everything can create a great challenge for the IP rights in fashion (Barnatt, 2013). As soon as objects are being digitized, they can be spread through .pdf or .mp3 files. What the music industry already went through could also be a threat that fashion will have to face soon (Marsh, 2012). This also evokes a discussion around authenticity, which is a crucial factor for the success of any fashion brand. One day it could be possible to purchase a CAD file of any branded product and let it be produced by of a personal 3D desktop printer, as well as 3D printing bureaus or services (Stange, 2015). The question here is where the brand value lies, but also who will be ensuring that the quality standards of the company are met.

As the evaluation of AM’s capability to be profitable and effective for a fashion business is very much dependent on the individual product, giving generic advice towards the implementation of AM can be challenging. But, it can be concluded that the industry has a great opportunity, which is only waiting to be fully explored by ongoing R&D into materials, production speed and sustainability.

6. Suggestions for further research

During the research process it has been discovered that there are more open than answered questions when it comes to AM technologies and applications. Therefore the following questions should be further explored in order to make a clear judgment on additive manufacturing and the fashion industry.

- Consumer perspective: How does the average fashion consumer react to 3D printing and how close does he really want to be to technology? Who is the consumer that appreciates this technology and sees it as an added value? Do consumers really want fully customized fashion, true to their measurements? Does the consumer really want to be a designer himself?

- Retail: For which industry channel is it really relevant to offer customized 3D printed products except for sporting goods? Investing in in-store 3D printers and training for employees will be a challenging investment for many brands. Will this investment be paying off?

- Brands: Do fashion brands want to go so far and offer their products as digital files? Are fashion brands willing to open their design function to their consumers? How can a fashion brand stay authentic and unique when applying AM technologies?
Appendix

A. Terminology

An aligned comprehension of terminology, which has been used throughout this research, is crucial in order to provide a common understanding for the reader. The stated definitions are an outcome of conciliating different interpretations found throughout the research process as well as officially approved definitions aiming at giving an essential and objective explanation of the term.

a. Additive Manufacturing (AM)

AM is colloquially also known as 3D printing (Oeko Institut e.V., 2013) and is defined by ASTM (American Society for Testing and Materials) (ASTM 2792-12) as:

“Additive Manufacturing is a process of joining materials to make objects from three dimensional (3D) model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. As a new tool in the entrepreneurial toolbox, additive manufacturing systems use computer-aided design models (CAD) and 3D scanning systems for production.”

The model below visualizes how a regular AM process is taking place. Starting with a blueprint that has been digitally modeled with a CAD (Computer Aided Design) software, the file is then converted into a .stl file, which is being virtually sliced up into layers as 3D models are also created layer upon layer. Afterwards the file is being sent to an AM system, for example a 3D Desktop printer (see Appendix A.c), which produces the physical object by its operating AM technology. For an overview on different 3D printing techniques see A.n.

Fig. 01: Process of AM

b. 3D Printing

3D Printing is a term that is colloquially known as Additive Manufacturing (see Appendix A.a.)

c. The Maker Movement

3D printing on an end consumer level emerged through the so called ‘Maker Movement’ in the mid-2000s. Before that time the prices of 3D printers were not on a commercial level and belonged therefore mostly to the professional industry. As more and more people started to be interested in AM for home use, the so called ‘Makers’, which describe themselves as innovation, technology, Do-It-Yourself and 3D printing lovers, started sharing their knowledge and ideas on AM technologies and collaborated through online communities and hacker spaces to build 3D desktop printers (see Appendix A.d.) (Anderson, 2012). This open source community enabled the evolution of 3D desktop printers as they made the technology available to everyone at a commercial price point.
d. **3D Desktop Printer**

3D desktop printers are used by the end consumer and are characterized through their compact size, which is around the same one as a regular ink jet printer and their ability to produce small 3D models often made out of plastic. Their most common AM technique is called material extrusion, also known as fused deposition modeling (FDM) (see Appendix A.n.). Before the model can be printed a CAD (computer aided design) file is being created using a 3D modelling program. Popular examples are for instance Tinkercad or MakerWare. Another method to create a CAD file would be to use a 3D scanner, which is able to make a digital copy of any object. When connecting the CAD program to the 3D printer, the CAD file gets sliced in layers by the 3D printer in order to make it printable. MakerBot and the Reprap printer are only two examples among well-known desktop printers. The selection of below objects have been produced with a 3D desktop printer will give a better understanding of their capabilities.

![The Thing-O-Matic 3D desktop printer by MakerBot industries](image)

Fig. 02: The Thing-O-Matic 3D desktop printer by MakerBot industries

![3D printed necklace](image) ![3D printed iPhone cases](image) ![3D printed vases](image)

Fig. 03: 3D printed necklace  Fig. 04: 3D printed iPhone cases  Fig. 05: 3D printed vases

e. **Industrial Revolution**

This term describes the rapid and significant economic, social, demographic and technological development, which took place in Great Britain between in the late 1700s and early 1800s and spread quickly on a global scale. Before that time the world’s society and economy used to be primary based around agriculture. The Industrial Revolution got triggered by the invention of machinery and steam power, which enabled the introduction of factories and mass production (see Appendix A.f.) which finally transformed the world to one that is driven by manufacturing and urbanism.

f. **Mass Production**

Mass production describes the creation of standardized products in high volumes, which are created by machinery usually in an assembly line to assure a high level of productivity. Precise organization of material flows, cautious quality controls and division of labor are distinguishing factors for mass production.
g. **Disruptive technologies**
This term describes ground breaking innovations that replace or significantly improve existing products or services, due to being better and cheaper. Moreover disruptive technologies have the potential to significantly transform the market place and affect life, business and global economy. They force businesses to adapt their way of approaching the market in order to stay relevant and keeping up or maximizing their market share. At the same time they serve as opportunities for new businesses to enter the market. The invention of the smart phone would be an example for a disruptive technology.

h. **Enablers of AM**

- performance improvements (quality, durability)
- technological developments
- public founds
- declining costs
- expiring patents

**ADDITIVE MANUFACTURING**

Fig. 06: Enablers of AM

i. **Gartner’s Hype Cycle – An Explanation**
Gartner’s annual Hype Cycle presents an overview on emerging technologies that offer the highest potential to solve business problems and identify market opportunities for business strategists, R&D managers, entrepreneurs as well as market developers and tech enthusiasts to invest in.

"The Hype Cycle for Emerging Technologies is the broadest aggregate Gartner Hype Cycle, featuring technologies that are the focus of attention because of particularly high levels of interest, and those that Gartner believes have the potential for significant impact" explains Betsy Burton (2015), VP at Gartner.

Fig. 07: Garner’s Hype Cycle – phases
The hype cycle is built up into five phases which ground the life cycle of an innovation:

1. **Phase: Technology Trigger:**
   A new technological concept is being introduced and receives first interest by the media. The innovation is often not connected to functional products and there is no proof of commercial value.

2. **Phase: Peak of Inflated Expectation:**
   Due to rising publicity some companies make successful as well as unsuccessful use of the technology.

3. **Phase: Through of Disillusionment:**
   Rising interest slows down as expected success and delivery of results are missing. Amount of developers decreases and only continue if investors are satisfied through product improvement, which will be accepted by early adopters.

4. **Phase: Slope of Enlightenment:**
   Strengths and opportunities of the technology are becoming clearer to companies and understood on a broader scale. Furthermore the first products are maturing and second and third generations appear in the market place. More and more companies who are willing to take risks are investing, while conservative ones stay behind.

5. **Phase: Plateau of Productivity:**
   The technology is spread through a wide range of industries and becomes main stream. All criteria of the innovation are well-know and applications of the technology are starting to pay off.

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j. **Gartner’s Hype Cycle for Emerging Technologies 2012**

Please see A.i. for an explanation of Gartner’s Hype Cycle.

![Fig. 08: Gartner’s Hype Cycle for Emerging Technologies 2012](image)

k. **Gartner’s Hype Cycle for 3D Printing 2015**

Please see A.i. for an explanation of Gartner’s Hype Cycle.

![Fig. 09: Gartner’s Hype Cycle for Emerging Technologies 2015](image)
I. Consumers’ expectations towards 3D Printing

This graph is based on the own evaluation of a study of Deloitte (2015) for which 507 participants were asked to give their view on their expectations towards the development of additive manufacturing across different industry sectors.

Fig. 10: Consumer’s expectations towards 3D printing
m. Timeline of 3D Printing in the fashion industry


2000

foundation of ‘Freedom of Creation’: first research & design company specialized in 3D printing - development of first textile like structures
- by Janne Kyttanen / Freedom of Creation

first 3D printed jewelry collection
‘Net made by hand - not made in China’
- by Ron Arad

2008

first 3D printed garment ‘Drape Dress’
- by Janne Kyttanen

2010

July:
first 3D printed fashion collection
‘Crystallization’ @Amsterdam Fashion Week
- by Iris van Herpen

2011

January:
first 3D printed haute couture collection
‘Escapism’ @Paris Fashion Week
- by Iris van Herpen
June:
first 3D printed bikini ‘N12 Bikini’
- by Continium Fashion

2012

July:
3D printed fashion collection ‘Hybrid Holism’
@ Amsterdam Fashion Week
- by Iris van Herpen

2013

First 3D printed customizable eyewear collection
- by Protos Eyewear

January
Flexible 3D printed dress ‘Voltage’
- by Iris van Herpen / MIT Media Lab / Julia Koerner, ‘TPU 92A-1’ (see Mar, 2013)

March:
first 3D printed dress on the red carpet worn by Dita van Teese
- by Michael Schmidt Studios / Francis Biltoni Studios / Shapeways
March:
first partly 3D printed football shoes
   — by NIKE

March:
first 3D printed running shoes
   — by NEW BALANCE

March:
Introduction of textile like material ‘TPU 92A-1’, which is cushioning, elastic & lightweight (used already by Iris van Herpen for ‘Voltage’ in Jan, 2013)
   — by Materialise

April:
3D printed eyewear collection
   - by Ron Arad

August:
free downloadable shoes on Cubify
   — by Janne Kytönen
November:
first 3D printed sprayed on underwear
– by Tamicare

November:
3D printed and 3D scanned lingerie set
– by Victoria’s Secret

2014

November:
Fusion of 3D Printing and Knitting
– by Manchester School of Art

2015

May:
first fully printed cotton like T-Shirt
– by Electroloom

May:
first 3D experimental textile like materials
(Polyester / Cotton blend, Silk blend, Acrylic blend)
– by Electroloom
July: worldwide excitement around the ‘Mojito’ shoe
   – by Julian Hakes

July: 3D printed CHANEL jacket @Paris Fashion Week
   – by Karl Lagerfeld, Chanel

July: first fully printed fashion collection with a commercial approach towards design
   - by Danit Peleg

October: ‘Futurecraft’ running shoes series
   - by Adidas

October: Nike’s COO thinks we could soon 3D print Nike sneakers at home
   - NIKE

Fig. 11: Timeline of 3D Printing in the fashion industry (own research)
**n. Most common AM processes and their methods**

The below graph by Hopkinson and Dickens provides a generic overview on the most common AM processes. Moreover an in-depth explanation into the most commonly used AM methods can be found.

![Diagram of AM processes](image)

1. **SLS – Selective Laser Sintering; Method: Powder Bed**
   In order to manufacture a 3D shaped object SLS printer’s laser ‘draws’ layer by layer on a powder bed that is located on the build platform. During this process the laser melts the powder and therefore every layer is being fused into the desired shape. After each layer the build platform together with the created layer moves down, therefore ‘fresh’ powder is deposited on the layer, which is being drawn on again for the next layer. SLS generates no waste material as it only uses what it needs to create the object as the powder that was not needed during the printing process can be recycled. Another advantage of SLS is to be able to produce objects with a high level of complexity as there is no building structure needed. So far SLS is being commonly used for the creation of prototypes, but it is becoming more popular for small actual production runs for end products.

2. **DMLW - Direct metal laser sintering; Method: Powder Bed**
   DMLW is an AM technique that is very similar to SLS (see 1.). Hereby a carbon dioxide laser ‘draws’ into a melted metal powder, which defines layer by layer a 3D model.

3. **FDM - Fused deposition modeling / Material Extrusion, Method: Solid Based**
   FDM describes the creation of a 3D object by extruding heated small beads of material, often plastic or wax, which become immediately solid, in order to structure layers on top of each other, regulated from a computer-controlled print head nozzle. In case a supporting structure is required, FDM is making use of a second heat nozzle which creates it with an easily removable material such as polyvinyl alcohol.
This AM technology is next to SLS commonly used for prototyping, but also for low-volume production runs.

(4) **SLA – Stereolithography / VAT Polymerization; Method: Liquid Based**
During SLA printing a laser or another UV light source ‘draws’ a layer of an object on to a liquid photo-reactive resin. This sort of material is extremely sensitive to light and changes its structure as soon as it is exposed to it. SLA is popular for rapid prototyping, but also for the creation of complex shapes that require high-quality finishes.

(5) **LOM – Laminated Object Manufacturing / Sheet Lamination; Method: Solid Based**
During LOM a sheet of material, for instance plastic or paper, is being fed over the build platform of the 3D printer and bonded through heat to the layer below that has been created previously through a roller system. LOM creates a flame and a severe amount of smoke, which results in the need for a chimney system or similar. LOM is commonly used for rapid tooling pattern and the production of less detailed parts, but mostly for fit and form testing.

**o. Traditional manufacturing**

This general term describes all commonly used manufacturing methods like casting, cutting, reforming, molding or stamping. It is also often connected to the term ‘Subtractive Manufacturing’, which is the most common method used in traditional manufacturing and describes the creation of an object by removing raw material by turning, boring, drilling, milling, broaching, sawing, shaping, reaming and tapping. As it is subtracting material it is the opposite of additive manufacturing, which adds on material.
p. Evaluation framework for AM
For further explanation please see chapter 4.

Fig. 13: AM evaluation framework
q. Conner et al.’s ‘Three axis model of manufactured products’ (Conner, 2014)

In order to build a reference system and map, which enables companies to make informed decisions regarding product development as well as manufacturing, Complexity, Customization and Volume have been identified as the key drivers by Conner.

a. Volume = production order quantity created in a defined timeframe.
b. Complexity = amount and localization of features, form and shape of a product
c. Customization = uniqueness
d. These three aspects put into a matrix define eight areas, which are able to characterize any manufactured object however it might have been produced.

Fig. 14: Connor et al.’s Three axis model of manufactured products

1. Mass Manufacturing

Today Mass Manufacturing is the most commonly used production method and is defined by the simplicity of its manufactured part and/or assembling numerous simple parts. Hereby all products are standardized and therefore there no approach towards customization, which is driven by the goal to keep costs low and achieve in order to be able to support large volumes. Simple parts that are being produced by mass manufacturing might be part of a more complex system that asks for an extensive assembling process, but the focus of this manufacturing model lies on the single parts.

Though costs are kept low during the actual production of the parts, when it comes to building production facilities within assembly lines the investment capital increases. In order to be able to crate the unique products that are needed for the end product tools and fixtures need to be created, which result in longer lead times up to several months, depending on their complexity. Though these costs might be high, the concept of mass manufacturing is built on its large volumes, which make up for the investment costs in the end.
e. **AM & Mass Manufacturing**

f. Mass manufacturing is a well-established manufacturing strategy worldwide due to its cost structure and therefore it can be said that products within this sector should not be considered using AM due to their restricted complexity and individualization option.

g. Nevertheless one option could be to make use of AM as a production method for tooling, for example for the creation of a cast which is needed for example for injection molding, a very common mass manufacturing method, which results in an increasing lead time, one of the main challenge of mass manufacturing.

h. **2: Manufacturing of the Few**

i. Manufacturing of the Few is defined by products that have limited complexity and customization as well as low production volumes.

j. It cannot be quantified generally what a high or low production volume is, as there are different maxims in every industry. Therefore it must be said that each individual company needs to determine if their production volume is either low or high depending on its industry position.

k. The volume of <10,000 parts per year is being used as an example to define the matrix. Costs for tooling and fixturing play an important role for low volume manufacturing as their lead times are often longer than the time to produce the product itself. An example for this are prototypes that are being mass manufactured afterwards, which are defined by low volumes, but high value, like for instance satellites.

m. **AM & Manufacturing of the Few**

a. AM is playing a role in ‘Manufacturing of the Few’ with its ability to create prototypes, which gives the possibility for functional prototypes that can also be integrated into working mechanic structures.

p. As there is neither tooling nor fixturing needed for these prototypes, they have a great advantage over commonly manufactured prototypes as they are cost and time savvy. This results in a decreasing time-to-market, but also making sure that the desired object is able to function properly.

q. Hopkinson (2003) et al. compared the costs for a small plastic lever using SLS (AM) and injection molding (TM). The outcome showed that in case the units are <10,000 parts AM is the more productive method.

3: **Complexity Advantage**

s. The complexity of products in this area of the model is driven by their functionality and aesthetics. In traditional manufacturing methods complexity comes with high costs as the assembly line is getting extended, tooling and fixturing is being added, lead times are getting longer and therefore the overall production rate decreases.

t. However it is also possible to create complex products through welding or fastening with TM, which results in rising costs as before assembling, tracking and inventory becomes necessary. For example a company must invest in qualified welders or fastening equipment. Moreover it must be pointed out that joined parts can be less robust than a single one. Due to cost and restrictions for the production of complex parts, examples for this area can first of all be found in medical or aerospace applications as their performance enhancement quantifies the extra costs.

u. **AM & Complexity Advantage**
v. Generally designers and engineers are trained to create products that are being manufactured and assembled. Those designs are restricted in their complexity due to the costs and capabilities of tools.

w. In AM complexity is free, due to its layer-on-layer production, which enables a highly complex part to essentially have the same costs as a simple plain part.

x. Through AM the following complexity enhancements are possible:
   - Features: undercuts, variable wall thickness, deep channels
   - Geometries: crooked and contorted shapes, blind holes, high strength-to-weight ratio
   - High surface area-to-volume ratio designs, lattices, topologically optimized organic
   - Parts consolidation: integrants that would otherwise be welded or joined together into a single printed part
   - Fabrication step consolidation: moving parts can be integrated in one step

y. Therefore it can be advised that when creating products through an AM technique their level of complexity is enhanced to drive performance as well as aesthetic.

4: Mass Complexity

In this area of the matrix products are not being customized, but from high complexity and the volumes are larger than the ones in ‘Complexity Advantage’. This can be explained best with the following example. There are about 440,000 total hip replacements in the USA every year. One integral part of a hip replacement is the so called acetabular cup, which holds the ball socket into the hip bone. In order to produce this cup a net shaped part made out of titanium needs to be created, which is being machined into the final cup and coated with a special surface finishing. Producing a net structure by any traditional manufacturing method is a highly complex and therefore also expensive process. With an additive manufacturing method and its possibility to create objects layer by layer and complexity advantage, a porosity structure can be integrated into the printed bone which matches the needed net shaped parts, which finally enhances the quality of the replacement part and lowers the overall costs (Conner, 2014).

5: Customized for the Individual

‘Customized for the Individual’ describes products that are being manufactured with a low volume and complexity, but with a high level of customization. Products that have been produced by TM are for example engraved jewelry pieces. The jewelry has been mass produced, though the engrainment asks for customization through for instance a laser. Products made by AM technologies like for instance customized prosthetics, implants or a simple key chain fall into this area. It can be said that almost everything that has been created with a desktop 3D printer is ‘Customized for the Individual’.

6: Mass Customization

bb. Mass customization can be a challenging strategy for conventional manufacturing as it is characterized by standardization, which is opposite to customization. On the contrary AM is able to fulfill mass customization’s driver towards a high level of customization, but also complexity. An example for this are the 17.2 million customized braces, which are being produced from molds of x-ray scans, annually. Many examples for mass customization can be found in the fashion industry. For instance New Balance gives their customers the possibility to have customized spikes for their running shoes 3D printed in order to enhance its wearer’ performance. Many other footwear retailers, such as
Prada, Nike or Adidas offer customizable shoes that can be delivered to their consumer’s house in a matter of two weeks.

7: Artisan Products

Making use of TM methods to produce unique artwork is not only pricy, but also labor and time intensive. Tying back to the value of artistic freedom to manufacture artwork that has a high complexity factor is beneficial for society. However AM gives designers the freedom to create artwork for highly complex and customized items in a short matter of time and cost. Next to art, products in this area would also contain for example complex articulating prosthetics or parts for a F1 race car.

8: Complete Manufacturing Freedom

The most desirable goal of any manufacturing method lies in the combination of high complexity and customization, while being not restricted to the volume ratio. Until today there is no product that would fall into this category. As described in chapter 2 and 3 AM is still limited in its capabilities in terms of production rate and solution space. Due to ongoing R&D into this issue which aims at making the technology more accurate, repeatable and faster it can be predicted that there will be a solution towards the achievement of complete manufacturing freedom.

r. Senvol’s seven scenarios to determine AM’s value from a supply chain standpoint

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Scenario Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expensive to Manufacture</td>
<td>Do you have parts that are high cost because they have complex geometries, high fixed costs (e.g. tooling), or are produced in low volumes? AM may be more cost-efficient.</td>
</tr>
<tr>
<td>Long Lead-Times</td>
<td>Does it take too long to obtain certain parts? Are your downtime costs extremely high? Do you want to increase speed-to-market? Through AM, you can often get parts more quickly.</td>
</tr>
<tr>
<td>High Inventory Costs</td>
<td>Do you overstock or understock? Do you struggle with long-tail or obsolete parts? AM can allow for on-demand production, thus reducing the need for inventory.</td>
</tr>
<tr>
<td>Sole-Sourced from Suppliers</td>
<td>Are any of your critical parts sole-sourced? This poses a supply chain risk. By qualifying a part for AM, you will no longer be completely reliant on your current supplier.</td>
</tr>
<tr>
<td>Remote Locations</td>
<td>Do you operate in remote locations where it is difficult, time consuming, or expensive to ship parts to? AM may allow you to manufacture certain parts on-site.</td>
</tr>
<tr>
<td>High Import / Export Costs</td>
<td>Do you pay substantial import/export costs on parts simply because of the location of your business unit and/or your supplier? On-site production via AM can eliminate these costs.</td>
</tr>
<tr>
<td>Improved Functionality</td>
<td>AM can enable a part to be redesigned such that its performance is improved beyond what was previously possible.</td>
</tr>
</tbody>
</table>

Fig. 15: Senvol’s seven scenarios to determine AM’s value from a supply chain standpoint

s. Bochetti et al.’ drivers to quantify products AM value.

With the goal in mind to find out if AM is a valuable production proposition, Bochetti et al defined four drivers that can be a first indicator.

- The higher the ratio, the more likable a product is to be manufactured using AM technologies.

(1) Cost weight intensity = Product overall cost ($) / product weight (kg)
Cost weight intensity: measure of resources (material, water, energy)

(2) **Buy to fly** = total material consumption (kg) / product weight
*Buy to fly:* ratio between raw material and weight of component

(3) **Mold cost intensity** = cost of the mold allocated to the product ($) / product weight (kg)
*Mold cost intensity:* ratio between actual costs for a mold and the overall price

(4) **CNC time intensity** = CNC time consumption (h) / product volume (dm3)
*CNC (computer numerical control) time intensity:* labor intensity
Below table gives the reader an overview on different cost studies of 3D printing by the combinations of AM processes and corresponding materials. The black cells indicate where a combination of materials is not possible further explained in 3.2.1. The crosses where combinations might be possible, but there is no further literature existing. The grey column on the right side gives an overview of studies where the scope of research was on AM but also on TM and show therefore a comparison of costing.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Material Extrusion</th>
<th>Material Jetting</th>
<th>Binder Jetting</th>
<th>VAT Photopolymerisation</th>
<th>Sheet Lamination</th>
<th>Powder Bed Fusion</th>
<th>Directed Energy Deposition</th>
<th>Additive Manufacturing Research that Includes Traditional Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>blends, and composites</td>
<td>Hopkinson and Dickens (2003); Hopkinson (2006); Baumanns (2012)</td>
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<td></td>
<td>Hopkinson (2005); Ruffo, Tuck, and Hague (2006a); Ruffo and Hague (2007); Hopkinson and Dickens (2003); Atzoni et al. (2010)</td>
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<tr>
<td>Metals</td>
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<td>Allen (2006)</td>
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<td>Graded/hybrid metals</td>
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</tbody>
</table>
Build time and energy consumption are two major cost drivers of AM. The following tables give the reader information on further reading options for those topics.

### Literature on the Build Time of AM

**Fig. 17: Literature on the build time of AM**

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Material Extrusion</th>
<th>Material Jetting</th>
<th>Binder Jetting</th>
<th>Vat Photopolymerization</th>
<th>Sheet Lamination</th>
<th>Powder Bed Fusion</th>
<th>Directed Energy Deposition</th>
<th>Undesignated Process</th>
<th>Additive Manufacturing Research that Includes Traditional Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymer, Polymer Blend, and Composites</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td>Metals</td>
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<td>Graded/hybrid metals</td>
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<td>Ceramics</td>
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<tr>
<td>Investment casting patterns</td>
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<td>Sand molds and cores</td>
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<tr>
<td>Undesignated Material</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td>Di Angelo and Di Stefano (2021)</td>
</tr>
</tbody>
</table>
### Literature on the Energy Consumption of AM

<table>
<thead>
<tr>
<th>Material Extrusion</th>
<th>Material Jetting</th>
<th>Binder Jetting</th>
<th>Vat Photopolymerization</th>
<th>Sheet Lamination</th>
<th>Powder Bed Fusion</th>
<th>Directed Energy Deposition</th>
<th>Undesignated Process</th>
<th>Additive Manufacturing Research that Includes Traditional Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymers, polymer blends, and composites</td>
<td>Mogno et al. (2006); Bauners (2011); Luo et al. (1999)</td>
<td>x</td>
<td>x</td>
<td>Mogno et al. (2006); Luo et al. (1999)</td>
<td>x</td>
<td>Sreenivasan et al. (2009); ATKINS (2007); Telenko and Seepersad (2010); Telenko and Seepersad (2012); Paul and Anand (2012); Kellens et al. (2011); Verma and Rai; Bauners (2011); Sreenivasan and Bourell (2009); Bauners et al. (2010); Luo et al. (1999); Kellens et al. (2010); Sreenivasan et al. (2010)</td>
<td>ATKINS (2007); Telenko and Seepersad (2012)</td>
<td></td>
</tr>
<tr>
<td>Metals</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Bauners et al. (2017); Bauners et al. (2013); Mogno et al. (2006); Bauners (2013); Sreenivasan et al. (2010)</td>
<td>Morrow et al. (2007); ATKINS Project (2007)</td>
<td>ATKINS Project (2007); Morrow et al. (2007)</td>
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<tr>
<td>Graded/hybrid metals</td>
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<tr>
<td>Ceramics</td>
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<tr>
<td>Investment casting patterns</td>
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<td>x</td>
<td>x</td>
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<td></td>
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<tr>
<td>Sand molds and cores</td>
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<td>Paper</td>
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</tbody>
</table>

Fig. 18: Literature on the Energy Consumption of AM
u. **SWOT-Analysis**

<table>
<thead>
<tr>
<th>STRENGTHS</th>
<th>WEAKNESSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Rapid Prototyping - Accelerated Product Development Cycle</td>
<td>• Limited Solution Space (materials, colors, finishes, material combinations</td>
</tr>
<tr>
<td>o saving time</td>
<td>• Material Costs</td>
</tr>
<tr>
<td>o reducing costs</td>
<td>• Product Quality</td>
</tr>
<tr>
<td>o reducing work effort</td>
<td>• Production Speed</td>
</tr>
<tr>
<td>o maximize internal &amp; external alignment</td>
<td></td>
</tr>
<tr>
<td>o enhance design &amp; quality</td>
<td></td>
</tr>
<tr>
<td>o risk reduction</td>
<td></td>
</tr>
<tr>
<td>• ‘Complexity is free’</td>
<td></td>
</tr>
<tr>
<td>• Supply chain transformation (digital inventory, just in time production,</td>
<td></td>
</tr>
<tr>
<td>reduced transport</td>
<td></td>
</tr>
<tr>
<td>• Simplification of production system</td>
<td></td>
</tr>
<tr>
<td>• Sustainability</td>
<td></td>
</tr>
<tr>
<td>• Economy of Scale - Scope</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OPPORTUNITIES</th>
<th>THREATS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Customization</td>
<td>• Mass Production</td>
</tr>
<tr>
<td>• Market Opportunities</td>
<td>• Talent Shortage</td>
</tr>
<tr>
<td>• Ongoing R&amp;D</td>
<td>• Lacking tools &amp; standards</td>
</tr>
<tr>
<td>• Localization</td>
<td>• Unauthorized Reproduction</td>
</tr>
<tr>
<td>• Accelerate CRM (Customer Relationship Management)</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 19: SWOT-Analysis (own research)

v. **Rapid Prototyping**

Rapid Prototyping describes a model that has been created through AM, which serves as a prototype for product development.

w. **Complexity is free**

The graph demonstrates the price evolution of a product on a scale of complexity. The red curve shows that in conventional manufacturing the price of a product rises with increasing complexity and that at one point if reaches as limit, as it does not have the same design possibilities as a product manufactured with AM technologies. At this point the cost advantage of AM becomes clearly visible (green space), as complexity is endless.
**Breakeven analysis: AM vs. TM**

Below figure visualizes a standardized set of costs for additive manufacturing and traditional manufacturing processes. The cost curve (green) demonstrates the flow of average costs for each unit during production. When those two production methods cross break even comes into place. Where the cost curve is flat, the production methods are at their most efficient point. For AM this means that efficiency is high when the number of units is low. Therefore it can be figured that marginal costs do not change with volume. For TM counts the opposite, producing low volumes is costly, while mass producing evokes a decline in costs per unit.
y. **AM process and material combination**

Certain 3D printers are made for certain materials. Below Table by the Wohler provides an overview of possible combinations of AM processes and the corresponding materials and are marked with a cross. The empty cells indicate where a combination is so far technically not possible.

<table>
<thead>
<tr>
<th>Material Extrusion</th>
<th>Material jetting</th>
<th>Binder jetting</th>
<th>Vat photopolymerization</th>
<th>Sheet lamination</th>
<th>Powder bed fusion</th>
<th>Directed energy deposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymers and polymer blends</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Composites</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Metals</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td>x</td>
</tr>
<tr>
<td>Graded/hybrid metals</td>
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<tr>
<td>Ceramics</td>
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<tr>
<td>Investment casting patterns</td>
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<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand molds and cores</td>
<td>x</td>
<td>x</td>
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<td>Paper</td>
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</tbody>
</table>

Fig. 22: AM process and material combination

z. **Mass Customization**

Davis defined Mass Customization in his book Future Perfect as the “the ability to provide individually designed products and services to every customer through high process agility, flexibility and integration without sacrificing scale economies”. (1987)

This definition is confirmed by Kotha (1995) who described mass customization as a system by which companies apply technology and management methods to provide product variety and customization through flexibility and quick responsiveness.

The development of a mass customization strategy is based on three main changes (Silveira et al., 2001):

1. New flexible manufacturing and information technologies enable production systems to deliver higher variety at lower costs
2. Increasing demand for product variety and customization

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B. Bibliography

Books


Journals


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**Research / Company Reports**


**Interviews**

RAVIV N. (2015) Interviewed by: Schemm T., 18th October, Amsterdam

NOA RAVIV - fashion designer, specialized on 3D printing

- How did you come up with the idea to 3D print your graduation collection?
- How did you manage to master CAD? (as a regular fashion design course often doesn't feature CAD classes)
- Do you think that this is something that could be mastered by a ‘regular’ person who wants to have e.g. a new pair of shoes?
- What programs and printers did you use for your collection?
• What materials did you use for your prints?
• Could you imagine that it will be possible to print with real fabrics at one point?
• How did the 3D printing community and the fashion industry respond to your collection?
• Do you think 3D printing in fashion can be commercialized? Or will this stay a conceptual approach?
• How do you see the future of 3D printing in fashion? (future vision/impact)
• How do you see the future of 3D printing across all industries? (future vision/impact)
• Are you planning to do more 3D printed clothing in the future?

Antonia Stolberg, Merchandiser/Product Developer at Burberry

Larissa Stange, Buyer at Net-A-Porter

Interview Questions (same for both)
• What do you know about 3D printing?
• Are you making use of 3D printing at Burberry?
• If yes, how and how does it benefit you?
• How does this technology affect the way you think and design?
• What possibilities are brought by additive manufacturing in terms of form, creation, material selection, design process, manufacturing?
• How do you see the future of 3D printing?
• Do you think 3D Printing could affect the global manufacturing industry?
• How do you think 3D printing will affect the fashion industry?
• What are the threats that the industry could face from 3D Printing?
• Do you think 3D printing in fashion can be commercialized? Or will this stay a conceptual approach?

Online Articles


Images, Figures and Tables

Fig. 01: Process of AM (own research)

Fig. 02: MAKER BOT INDUSTRIES (2010), The Thing-O-Matic 3D desktop printer; Image source: [Online] https://upload.wikimedia.org/wikipedia/commons/8/87/Makerbot_Thing-O-Matic_Assembled_Printing_Blue_Rabbit.jpg [Accessed: 12th October 2015]

Fig. 03: Fig.3: WU J. (2014) , 3D printed necklace; Image source: [Online] http://3dprint.com/26034/lace-by-jenny-wu-3d-jewelry/ [Accessed: 12th October 2015]

Fig. 04: KYTTANEN J. (2012) 3D printed iPhone case; Image source: [Online] Available from: http://www.google.de/imgres?imgurl=http%3A%2F%2Fmedia02.hongkiat.com%2F3d-
Fig. 20: Complexity is free; WOHLERS (2012) Additive Manufacturing and 3D Printing State of the Industry. WOHLER’S ASSOCIATE INC.

Fig. 21: Breakeven analysis AM – TM, (2015) Image source: own research

Fig. 22: AM process and material combination. WOHLERS (2012) Additive Manufacturing and 3D Printing State of the Industry. WOHLER’S ASSOCIATE INC.