Unlocking Innovation in the Sport Industry through Additive Manufacturing

Abstract

Fast changing customer demands and rising requirements in product performance constantly challenge sports equipment manufacturers to come up with new and improved products to stay competitive. Additive Manufacturing (AM), also referred to as 3D Printing, can enhance the development of new products by providing an efficient approach of rapid prototyping. This research aims to analyse the current adoption of AM technologies in the innovation process of the sports industry i.e. level of awareness; how it is implemented; and it impact on the innovation process. Literature research shows that AM brings many possibilities to enhance the innovation process, and case studies indicated several obstacles that hinder the technology from fully unfolding. AM is still at the early stage of entering the sports equipment industry and its potential benefits have not been fully exploited yet. The findings generated from the research of real life practices show that AM provides several benefits when it comes to the innovation process, such as a faster development process, an optimised output, as well as the possibility to create new designs. However, companies are not yet able to enhance the innovation process in a way that leads to new products and new markets with AM. Limitations, including a small range of process able material and an inefficient mass production, still restrain the technology and lead to unused capability. Nevertheless, future prospects indicate the growing importance of AM in the innovation process and show that its advancement paves the way to new and innovative products.

Keywords: Additive Manufacturing, 3D Printing, Innovation Matrix, Sport Industry,

1. Introduction

1.1 Background

As part of a predicted fourth industrial revolution "Industry 4.0", new technologies, able to produce individual products with a batch size of one as efficiently as mass production, are foreseen to replace conventional production processes (Lasi et al., 2014). One of these new technologies is Additive Manufacturing (AM), more commonly known as "3D printing". The technology allows the manufacturing of one off parts in a faster and less complicated manner than conventional manufacturing processes, and represents a valuable key factor in the implementation of industry 4.0. Therefore, AM technologies gain more and more attention and are currently being implemented in several processes in industries such as aerospace, automotive, health, and others (Schiller, 2015, Lee et al., 2017). Now, the sports equipment industry also starts to implement this new technology (Salles and Gyi, 2012). With a strong focus on the perception of the customer, the benefits of one off parts and mass customisation, enabled by AM, can be crucial in this industry. Every human is anatomically hardwired differently, and every person therefore has different preferences in fit and form. In sports, the equipment used by athletes often significantly impact their performance: A racket that has a better grip, a suit that provides a better aerodynamic, or a cleat that allows better traction. Furthermore, equipment is also a significant factor when it comes to injuries, as wrong fitting equipment can easily lead to accidents. In the fast-moving sports market, companies are constantly challenged to come up with new products that outdo the ones of the competitors and provide a good fit and performance. However, many products in the sports equipment industry have reached maturity, and can hardly be improved by conventional methods. Here, AM as a new technology can bring new possibilities into the innovation process of the sports equipment industry and enhance it to a new level.

1.2 Research Objective and Research Question

This work therefore investigates the use of AM technologies in the innovation process of the sport sector and aims to show the consequences of this usage. Specifically, three research questions will be addressed:

1. How aware is the Sport industry of the potential of AM technologies?
2. How is AM implemented in the innovation process?
3. What impact has this implementation on the innovation process?

For this, the paper will firstly introduce the current literature about this topic, and afterwards develop a framework, based on the literature. The findings, which include results from seven case studies, and the interview with a sports equipment manufacturer to critically evaluate the developed framework are then presented. Subsequently, the discussion comprises reasons for the current use of AM in the innovation process of sports equipment, as well as recommendations for the industry and future prospects. Furthermore, an analysis of the current awareness of AM processes in this industry is conducted. This paper concludes with research limitations and suggestions for further research.

2. Literature Review

The term "innovation" can be defined as developing a new or improved product or process (Damanpour, 1996; Baregheh et al., 2009; Tan et al, 2015; Tan and Zhan, 2017; Tan et al. 2017; Chung and Tan, 2017). Since new products tend to have an increased chance of being flawed, usually prototypes are developed to undergo testing and eradicate those flaws before considerable investment is made (Pham and Gault, 1998). Especially in the sports industry, a flawless product in terms of form, fit and functionality is very important to improve the performance of the athlete on the one hand, and to avoid pain and injuries on the other hand. In the following, an overview over the innovation process in the sports industry is given, and the implementation and impact of AM in this process is explained.

2.1 Innovation in the Sports Industry

The general innovation process can be divided into two different approaches, the *Technological Push* and the *Demand Pull*. In the Technological Push approach, the source for innovation is represented by the producer, for example in the form of the Research and Development department. Science and research play an important role in this approach and an invention has to precede an innovation. This means, that scientific breakthroughs lead to new technological applications, which, in turn, lead to innovations (von Hippel, 2007). The Demand Pull innovation on the other hand, is driven by the consumer. This means the profitability of the innovation in terms of fulfilling the consumers' needs and desires is the main driver of the innovation process (Gerke, 2016). Here, external factors "pull" the innovations into the market. The innovation process in the sports industry is influenced by a combination of those two approaches, with the main sources for innovations being the consumers and firm-internal sources (Tietz et al., 2004, Hyysalo, 2009).

The two distinctions of Technology Push and Demand Pull can be linked to the differentiation of process and product innovation, whereas the technological push represents the process innovation and the demand pull the product innovation. Utterback and Abernathy (1975) argue that the proportion of product and process innovation is depending on the maturity of the related industry in which these occur. Industries evolve similarly over time and thereby pass through three different stages or patterns, called "Fluid Pattern", "Transitional Pattern" and "Specific Pattern". As shown in figure 1, with increasing maturity, the amount of product innovations decreases and process innovation increases (Utterback & Abernathy, 1975, Desbordes, 2001).

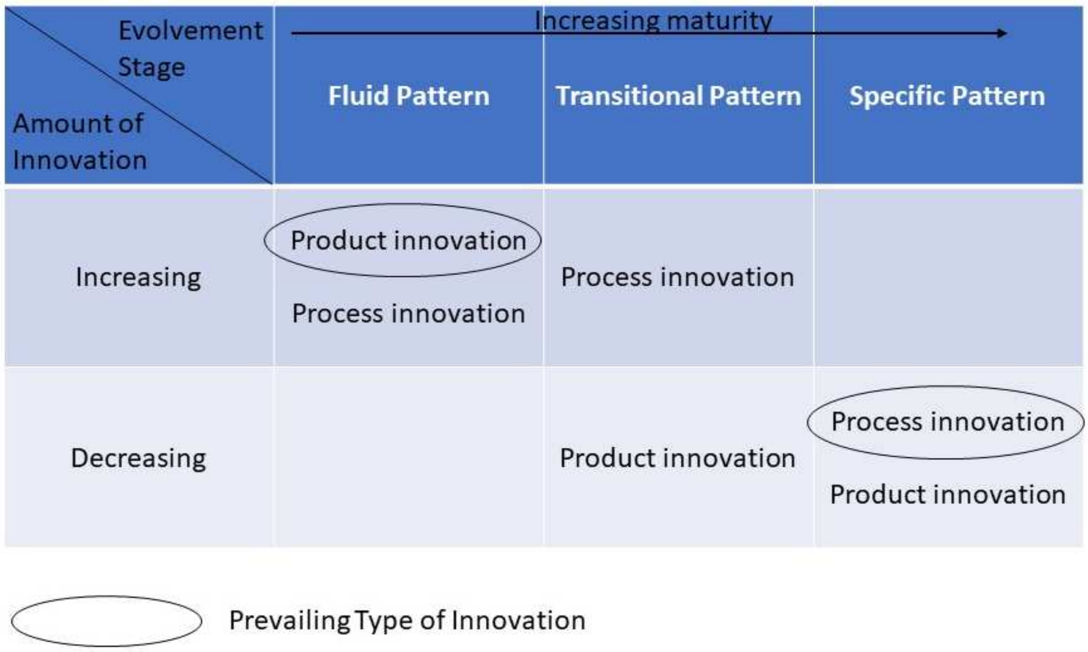

Figure 1 Product and Process Innovation

The determination of the current stage of the sports equipment industry, however, is not that easy. Since this industry encompasses a broad variety of segments, products exist in different forms and complexities and range from clothes over rackets to parts of a race car in the motor sports segment. The fact that not every type of equipment has evolved at the same time and with the same speed, makes it clear that the sport industry with its various goods cannot be assigned to a specific state (Desbordes, 2002). However, it is obvious that many objects of the sports equipment industry have reached their innovative potential. This means, for example, a shoe can hardly be the target of new innovations, at least not by using conventional processes. At this point, process innovations, that lead to advances in technology, are enabling new opportunities for the innovation process (Collins, 2015a). The AM technology represents a new way of producing parts and can be the key to new innovations. The usage of this technology in the innovation process is described in the following.

2.2 Impact of Additive Manufacturing on the Sport Equipment Innovation

As mentioned before, AM is already implemented in different industries and processes. Figure 2 shows an overview of the utilisation of AM in several industries. As illustrated, the sports industry is far behind other industries, such as jewellery or aerospace, and the implementation of AM is still in its infancy. Nevertheless, the sport industry with its high technological nature, frequent product renewals, and high involvement of the customer in the innovation process (Desbordes, 2002), provides several opportunities for the use of AM, which are more and more realised by companies (Gausemeier, 2011).

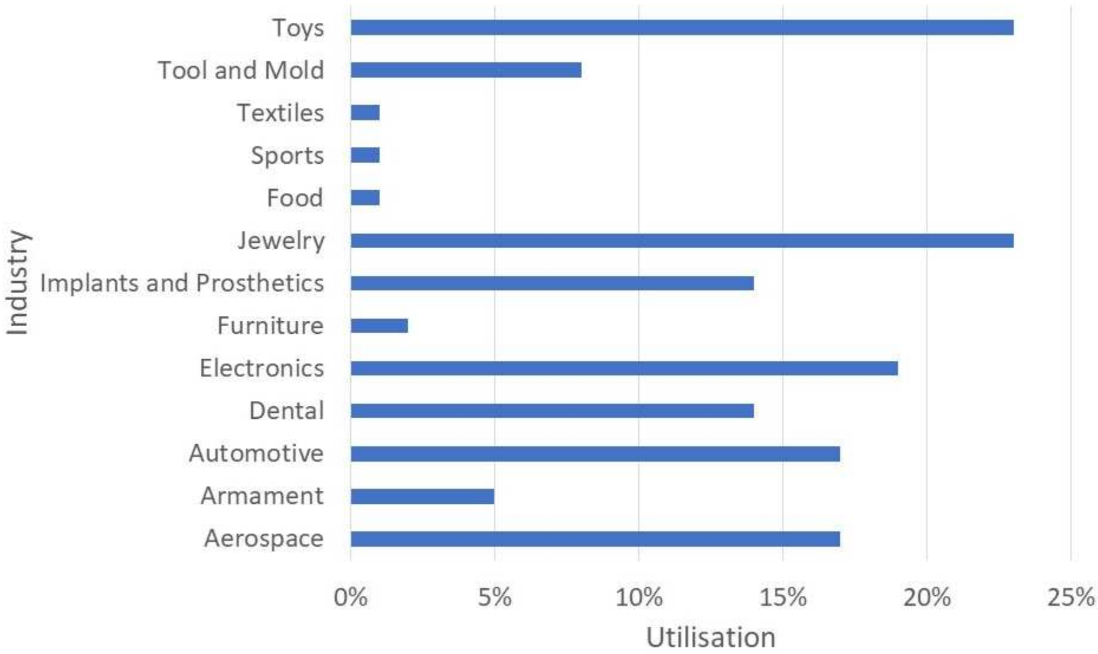

Figure 2 Usage of AM in different Industries

The sport sector is characterised by rapidly evolving customer demands and preferences. The fast-changing market leads to a high competition in making new designs and technologies available as fast as possible (Manoharan et al., 2013). Thus, time to market is critical for companies to be competitive and AM, as an enabler of agile manufacturing, can be crucial in this competition (Gunasekaran et al., 2017). Using AM technologies for the prototyping process can have a significant impact on the duration of the entire cycle of product development, commercialisation and product launch (Manoharan et al., 2013). According to Waterman and Dickens (1994), AM can shorten the time to market by as much as 90% and the tooling lead time by 35% compared to conventional manufacturing, since no moulds, other toolings, or CNC (Computerised Numerical Control) programs are necessary in this technology (Morrow, et al., 2007, Fireman, 2017). Additionally, with the designs being created on the computer, AM enables the opportunity to make design updates within hours instead of months, since adjustments on the digital CAD file can be made and implemented faster (Evans & Spada, 2013). This time reduction can furthermore shorten the gap between small companies and big players, since even smaller companies can alternate designs faster and provide customers with products quickly (Kappius, 2013).

Next to the benefits of a faster product development, AM provides unlimited freedom of design. By circumventing the necessity of the Design for Manufacturing (Mohr, 2015), a constraint that limits the design for products on those who are efficient to manufacture conventionally, products can be redesigned with a focus on other important aspects, for example enhanced functionality or material savings (Mohr & Khan, 2015). This enhances the product development process by giving opportunities for new design innovations (Huang et al., 2012). Since this can also lead to a design alternation of the product itself, AM can reduce the material consumption by up to 40% by reducing both the weight of the product and the amount of waste produced (Achillas et al., 2015). In doing so, the usage of lattice structures simultaneously increases the strength of a part, leading to an optimal strength to weight ratio (Atzeni & Salmi, 2012). The geometric freedom that allows these lattice structures also leads to the creation of new shapes. Being able to create complex interiors, and to process in non-linear direction, AM overcomes obstacles inherent in conventional processes such as milling or lathing (Jain & Kuthe, 2013, Evans & Spade, 2013). Additional benefits of this geometric freedom are the good dimensional accuracy of AM processes (Manoharan et al., 2013), as well as the use of multiple materials simultaneously (Reinhart & Teufelhart, 2011). All these factors combined can lead to the fabrication of creative new products, and therefore also provide access to new markets and therefore target a broader range of customers (Niaki & Nonino, 2017, Diegel et al, 2010, Dimitrov et al., 2012).

Another important aspect of the innovation process is the cost of developing a new product. Although traditional manufacturing is still more economical when considering mass production, AM is less costly when it comes to producing single pieces, occurrent in the prototyping phase of the innovation process (Gibson et al., 2010, Achillas et al., 2015). In a study, Waterman and Dickens (1994) found that new development costs can be reduced by 60-90 % using AM compared to traditional prototyping. Furthermore, AM processes are less prone to errors in the production, and therefore produce less obsolete products (Jain & Kuthe, 2013). Studies by Waterman and Dickens (1994), Kim and Oh (2008) and Chowdhury et al. (2012) showed, that, due to an accurate 3D model prior to the production, as well as the good dimensional accuracy offered by the machines, AM technologies provide less wastages and errors, leading to a saving of money.

Finally, there is the aspect of convenience. Since AM machines consume less space than most of the traditional manufacturing machines, they usually can be placed near the test site. In fact, the production becomes location independent and can be implemented where it is most efficient. This eliminates a time-consuming and costly transportation and enables a faster adjustment to necessary changes (Manoharan et al., 2013, Mawale et al., 2016). This eases the collaboration with the consumer, which is, as mentioned before, one of the main sources for product innovation in this industry (Niaki & Nonino, 2017). Therefore, consumers are integrated early in the innovation process of sport equipment (Desbordes, 2002) to form so called “prosumers”, people actively involved in the creation of a product, but also being its main customers, and help to enhance the innovation process by guiding the product’s development towards people’s needs (Toffler, 1980, Mohr & Khan, 2015). In fact, 10-38 % of users of consumer products have an impact on the development and modification of products (Franke and Shah, 2003, Lüthje et al., 2005). This shows how important the collaboration with consumers in the innovation process is, and therefore how big the impact of AM is in simplifying this collaboration.

All these factors of using AM can have a positive impact on the innovation process. Nevertheless, as AM is still in its infancy as a technology, it faces certain limits and challenges. One of the main downsides of the technology is the limitation of usable material. Although certain AM technologies have a wide range of materials in theory (any material in powder form) (Waterman & Dickens, 1994), this is not the case in practice due to the complex thermal properties of polymers and a lack of control of current laser systems (Goodridge, Ziegelmeier, 2016). Furthermore, laser based processes require a high level of maintenance and care and their machines are still very expensive (Jain & Kuthe, 2013). This can compensate the savings due to AM technologies mentioned before. Many companies also see themselves confronted with the challenge to handle the high complexity of the CAD tools needed to develop the design transmitted to the printer. Here, experts or further trainings are needed that can increase the cost of the development process further (Gausemeier, 2011). Another financial aspect is the payback time of prototypes made with plastic. Niaki and Nonino (2017) discovered that companies using plastic for prototyping perceive a longer payback time than those using metal. This is due to the difference in the selling price, as the ones made of plastic are sold for less than the same product made out of metal.

Keeping the mentioned limitations in mind, the impact of AM is very dependent on the type of technique that is used. It is therefore important to consider each process' characteristics when implementing AM in the innovation process. There have been several studies evaluating the different AM technologies regarding their capabilities in different categories, including Manoharan et al. (2013), or Waterman and Dickens (1994) which can be used to critically asses the different AM techniques.

Figure 3 visualises the impact of AM on the innovation process with both advantages and disadvantages. The attributes that are increased through manufacturing are shown on the top, the ones decreasing at the bottom of the diagram. As discussed in the previous literature review, there are good opportunities for companies to implement the technology in their process, with only the cost aspect impossible to be assigned to exclusively one side. The following chapter will develop a framework of AM in the innovation process based on the reviewed literature.

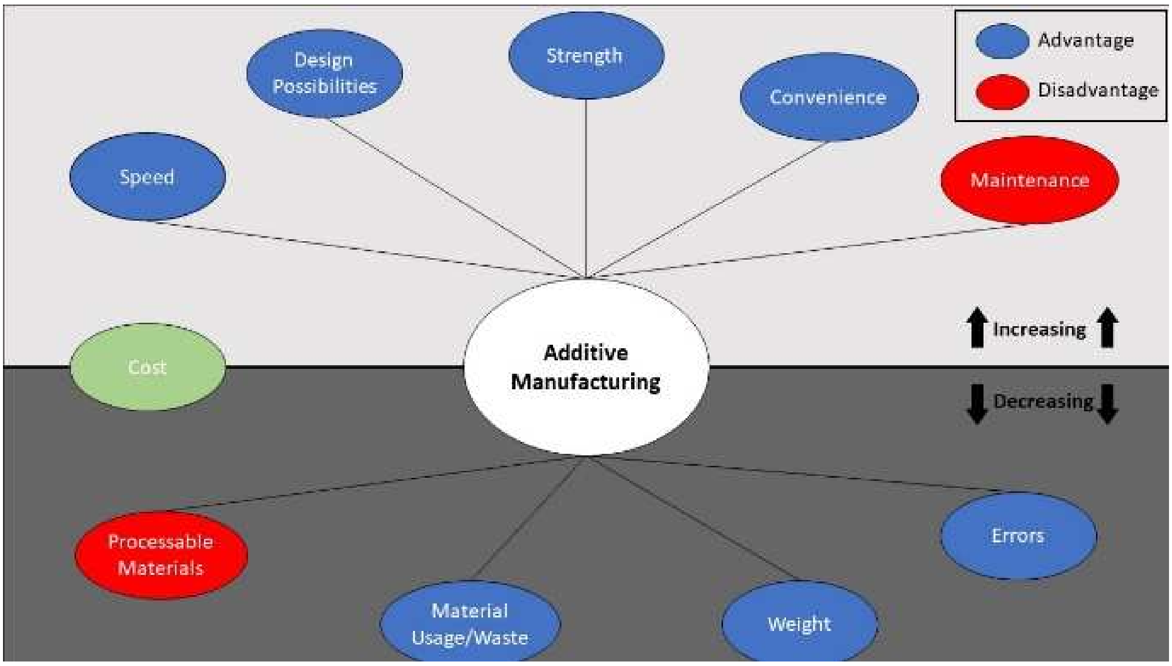

Figure 3 Additive Manufacturing in the Innovation Process

2.3 The Theoretical Place of Additive Manufacturing in the Innovation Process of Sports Equipment

When it comes to determine the place of AM in the overall innovation process of the sports industry, an innovation matrix is a helpful tool to do so. Based on a research by Nagji and Tuff (2012), innovation can be divided into three levels of ambition: Core Innovation, Adjacent Innovation, and Transformational Innovation (Nagji & Tuff, 2012). The core innovation level includes only incremental changes to already existing products, in which company draws on already existing assets. The Adjacent Innovation is a mixture between the Core and Transformational Innovation, and describes the advancement of something the company is familiar with into new space, e.g. new customers or technologies. For this level, the company needs insight in new technology, demand trends and other market variables, for extending existing capabilities to new use. The highest level, the Transformational Innovation, includes the creation of new offers or even businesses to serve new customers and markets. To achieve these "breakthrough" or "disruptive" innovations, companies need to use unfamiliar assets, e.g. new technologies (Nagji & Tuff, 2012).

Figure 4 shows a matrix based on the ambition matrix of Nagji and Tuff (2012). The x-axis represents the novelty of technology and the y-axis represents the novelty of the customer or market respectively. Considering the literature, it can be said that AM technologies have a high potential of enhancing the innovation process of the sports equipment industry. The fact that this new technology, and its process of developing and easily iterating prototypes enables the production of new shapes, leads to a location in the "New" column under technology. As the freedom of design that comes with AM can lead to new products and even markets, as mentioned by Niaki & Nonino (2017), Diegel et al (2010) and Dimitrov et al. (2012), the position of AM in the innovation process can be located in the radical innovation area (white X). This would make the technology the key aspect in overcoming the stagnation in innovation currently inherent in the sports equipment industry.

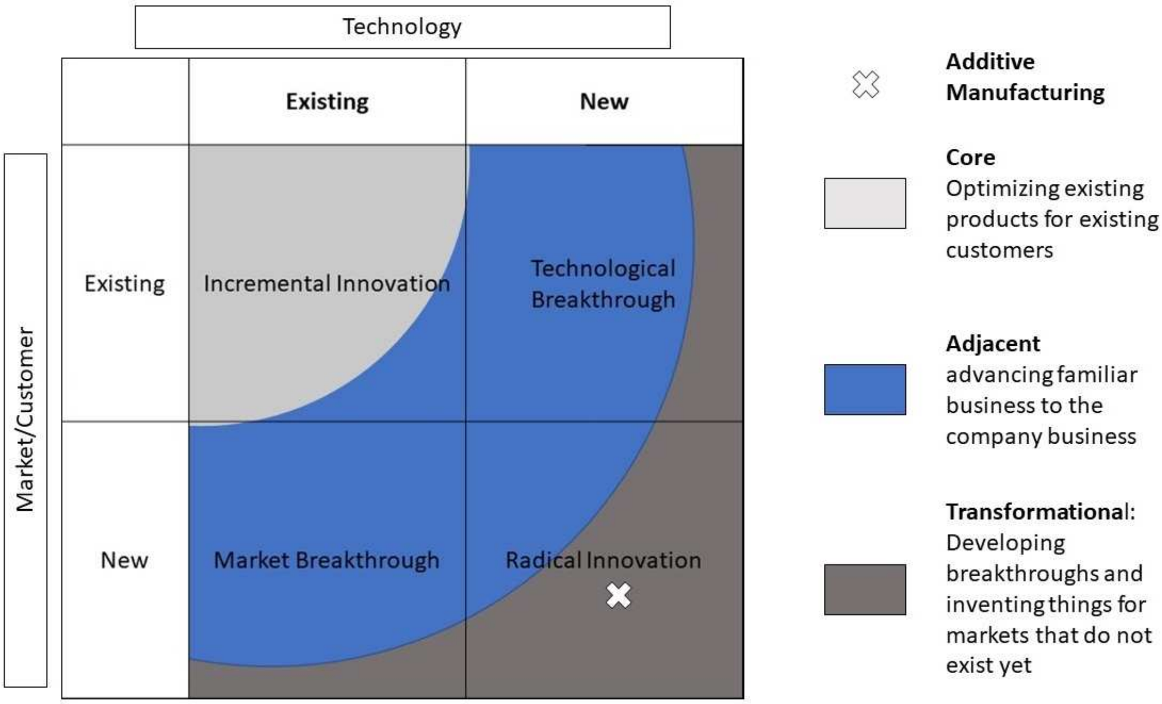

Figure 4 Innovation Matrix

3. Methodology

The aim of this research is to investigate the company's awareness of Additive Manufacturing, its implementation, and its impact on sports equipment innovation. In order to do so, this work followed a qualitative research approach, that includes case studies from different companies, as well as a semi-structured interview with an outdoor manufacturer. The objective of this qualitative research is to obtain a detailed understanding and an in-depth view of the investigated topic, by answering questions concerning the "How" and "Why" (Eisenhardt, 1989, Hennink et al., 2011).

Case studies were found to build an ideal base for this research, as they can give good insights in the practical usage of AM. In view of the fact that AM is an emerging technology with very little literature about its usage in the sports industry, this case study represents a theory generation research (Ketokivi & Choi, 2014). By choosing this kind of research, biases caused by relying on existing theory can be circumvented (Martin and Eisenhardt, 2010)

For this purpose, information was gained from several sources over the period of three months. Websites of different companies, including their own Research and Development Blogs, as well as industry reports and AM magazines have been studied. Furthermore, newspaper articles and articles of companies that either did an interview or a case study with the sports equipment manufacturer themselves contributed to the information used for the case studies. To verify this information from the case studies, a telephone interview with a sport equipment manufacturer was conducted (see Appendix A for the interview questions). Low cooperativeness from other companies to participate limited the number of interviews to one. Among the rejections for interviews, only one company explained its denial with the lack of possibilities of AM for their company.

Information was sought from different companies, as the information gained from multiple sources is considered more conclusive, which overall results in a more resilient study (Herriott and Firestone, 1983). Targeted companies underlay the condition of having their business area in the sports equipment industry. This can range from clothing equipment over protection material to external equipment like golf clubs or rackets. Right at the beginning, however, the motor sports industry was excluded. Since its nature is far more technical based in comparison to the aforementioned segments, it is not easily comparable to the other sectors of the industry and its investigation could weaken the results of this research. Other than that, the characteristics of the targeted companies did not underlie any further conditions. Following a theoretical replication approach (Yin, 1994), a heterogenous sample with companies from all over the world and of different sizes from under 100 employees to over 70.000 employees enables an even bigger diversity. With regard to the intended diversity, the cases include protection equipment, external equipment from the category “bats, rackets, and other instruments”, outdoor equipment such as surfing and skiing, and clothing equipment such as shoes, with the latter being the most common sector for the use of AM and therefore discussed in more detail than the others. After seven case studies, the data collection was completed, since similarities in the gained information occurred multiple times. This suggests that saturation needed for this approach is reached and the investigated topics have been processed (Glaser and Strauss, 1999).

Getting information from an interview and from this form of case studies, that relies on information presented by the company, always underlie a bias (Kvale, 1994). It needs to be kept in mind that the companies usually want to justify their decision of implementing AM in the innovation process by only showing the positive aspects of the technology and downplay possible disadvantages or obstacles. Therefore, the information needs to be handled with care.

By combining case studies and an interview as described in this chapter, a comprehensive insight about the awareness of AM in the real-life business can be gained and different views about its implementation can be shown. This is needed for the verification of the developed framework and to answer the research questions of awareness, implication and impact of AM on sports equipment innovation.

4. Findings

4.1 Case Studies

The first group of investigated companies are using AM technologies to enhance the innovation process of footwear. The first company, the American sports company Nike, started implementing the technology in 2013 to prototype a plate for a cleat. The benefits in using AM enable Nike to prototype a fully functional plate in a fraction of the usual time that is needed by continuous collaboration with the athlete (Nike, 2013). They continued the utilisation of AM technologies over the years and were able to prototype 30 different versions of the plate for its latest product, the Zoom Superfly Flyknit, reducing sampling time from weeks to days. The possibility to reduce weight, test, and quickly iterate products, enable superior final products. This substantiates the implementation of AM in the innovation process of the company (Nike, 2016a).

Nikes competitor, the German sportwear manufacturer Adidas, implemented AM to reduce the time required to create a prototype to one to two days. Without AM, a prototype shoe consumed the workforce of 12 technicians and took from 4 to 6 weeks to complete (Maxey, 2013). Using AM to create a running shoe midsole, enabled Adidas to reduce weight and increase the flexibility of the product, without reducing its stability (Materialise, 2017). With the aim to use AM in mass production, Adidas is collaborating with the technology firm Carbon to implement a new AM process that can fulfil these requirements (Iglesias, 2017, Collins, 2015b). This collaboration enabled Adidas to produce prototypes the same way the final (mass) product would be produced. Therefore, the prototyping process becomes obsolete and Adidas can perform the testing on the actual end product, which means a shortening of the entire production cycle (Carbon, 2017, Adidas, 2017). In the long run, Adidas plans on producing customised shoes immediately and in store, after a digital measurement of the customers' feet through foot scan technologies, to provide the ultimate personalized experience (Materialise, 2017).

The third company using AM in footwear is the American company New Balance. To create a 3D printed plate for a running shoe, New Balance generates biomechanical data of the athlete to develop a 3D model, entailing a close and continuous collaboration with the athlete. (EOS, 2017; New Balance, 2013). Benefits for the company include a 5% weight reduction (EOS, 2017), unmatched geometry by conventional methods, leading to a highly flexible but durable part (New Balance, 2016). However, the production is rather labour intensive. The sole needs several hours to print, and after completion every sole needs to be removed from the powder, cleaned and processed separately, and then sent to the assembly and finishing department (Grunewald, 2016). Nevertheless, New Balance sees further benefits in using the technology, including the possibility to produce on demand, to make updates without continuous investments, as well as to adjust the process to individual sizes (New Balance, 2016, EOS, 2017).

AM is also used in the innovation process of exterior sport equipment. The American Golf equipment manufacturer Cobra Puma Golf started using the technology in the early 1990s. AM increases the efficiency in the prototyping process in terms of time and money, as conventional methods are time intensive and constant iterations cause high investments. Furthermore, the conventional process usually allows only simple designs, compared to the new possibilities that can be created with AM. However, the outcome of the 3D printing process is only a prototype and since its polymer is weak and brittle, it cannot be used for actual impact testing. Therefore, AM is only used to verify the design in a Computer Aided Design (CAD) programme and to perform non-destructive measurements and test, such as aerodynamic tests, on the golf club (Kennedy, 2013).

The American winter sports equipment manufacturer Burton Snowboards uses AM to develop a new form of binding for snowboards, which allows the snowboarder to mount the snowboard by stepping in the binding instead of strapping it around their shoes. This has always been an insoluble challenge for manufacturers. With the use of AM for the prototyping process, Burton was able to overcome hurdles by circumventing design constraints, and by continuously and immediately test and iterate the product until a functional product was developed (Scott, 2016, Bradstreet, 2016).

The Austrian company Red Bull teamed up with the Canadian 3D printing bureau Proto3000, to 3D print an entire surfboard (Rakic, 2017). The aim was to create an exact duplicate of an already existing board. Since human error, that occurs with the conventional manufacturing of surfboards, makes it hard to shape a board consistently and therefore to produce several boards that are exactly the same, AM is supposed to circumvent this obstacle. The prototyping process took about a month, including the printing of the board in ten different pieces over the time of 100 hours, until an acceptable prototype was created (Scott, 2017, proto3000, 2017). Apart from the weight of the 3D printed board, which was almost three times heavier than the original, the replication was successful in terms of shape, angles and other nuances (Rakic, 2017). To adjust the weight, proto3000 is working on a dissolvable core that serves as a frame or ribbing of the board. After wrapping the fibrous material around it and sealing it, the core will be dissolved away, leading to a seamless wrap and a board, that is as light as the original (Proto3000, 2017). This represents a combination of the new AM technology and the traditional concept of a fiberglass wrapped board, combining complex design possibilities with reduced weight (Rakic, 2017).

Finally, the Austrian body protection company Zweikampf implemented AM to develop a three-part shin guard system, that eliminates issues resulting from bad fitting of mass produced shin guards. The shin guard is designed in a y formed honeycomb structure, which absorbs and diffuses the impact by distributing the force throughout the structure, leading to a tough and durable product (Grunewald, 2017). Next to the complex design, AM enabled the company to reduce weight and thickness and simultaneously increase the strength of the guard. Furthermore, every shin guard is tested inhouse and external regarding its performance (Milsaps, 2016). Similar to Adidas, this company represents an example for the merging of prototyping and final product production.

These case studies represent the implementation of AM technologies in the practical, real-life context. Table 1 shows an overview of these different case studies and their use of AM in the innovation process. The level of innovation indicates how innovative or new the product manufactured with AM is. Since every company apart from Burton did not invent any new products with the implementation of AM, but only improved existing products, the level of innovation is predominantly low.

Company	Sector	Product	Reasons for Implementation	Level of Innovation	Customer Involvement
Nike	Footwear	Spikeplate for cleats	Time savings, continous iteration, weight reduction, possibility of new shapes	low	high
Adidas	Footwear	Midsole for running shoe	Reduce man hours needed, weight; increase flexibility, consistent mechanical properties, high resolution and surface finish, shorten development cycle	low	high
New Balance	Footwear	Plate & Sole for running shoe	reduce weight and turnout time; unmatched geometry; increase flexibility and durability; economical product iterations	low	high
Cobra Puma Golf	Golfclubs	Golfclub	Reduce prototyping time and cost; more iterations possible; more design possibilities	low	low
Burton	Snowboards	Snowboard binding	reduce prototyping time, weight and material; continous iterating and testing; circumvent design constraints	medium	high
Red Bull & Proto3000	Surfboards	Surfboard	eliminate human errors; produce accurate and complex designs	low	high
Zweikampf	Protection Equipment	Shin Guards	savings in time and money; customisation of products; increased durability; reduced weight and thickness	low	high

Table 1 Companies Overview

4.2 Interview

The interviewed company asked for anonymity and is therefore referred to as “company A”. Only selected parts of the interview will be quoted for clarification and illustration of the resulting data.

Company A is a manufacturer of outdoor sports equipment, including ski, trekking and hiking equipment, with their main products being sticks. With less than 50 people working inside the research and development department, and approximately 250 employees in total, the company represents a rather small enterprise. On a yearly basis between two and five new product developments are generated, which, however, are not limited to just one product. If for example a new handle is developed, it is likely to be used on different models and products. This rate of innovation is reflected in the general approach towards new technologies, where the company is located somewhere in the “first follower” role.

> *“I would say we are in the front third. Probably not all the way at the front, because it is known, that the first [companies] invest rather more money or maybe have to pay dearly. But we are in the front third, we are always making an effort to apply or implement new technologies.”*

Therefore, the awareness of AM in the company is high. After joking about implementing AM a few years ago, now the company uses the technology for about three years for prototyping purposes. The company sees the benefits of AM in the rapid production of prototypes, as well as savings in costs, compared to conventional methods such as casting. Furthermore, the possibility to illustrate designs to employees from other departments with an actual tangible product, rather than showing a digital file on a computer, eases the imagination of the final concept, making communications easier. Another benefit compared to conventional method lies in the opportunity to let the production of bigger or multiple parts run over the weekend and therefore use time that is normally idle as well.

Next to the benefits, the company recognised several disadvantages and challenges that come with the use of the AM technology. For one, physical testing on the prototypes often requires an alternation of the product, e.g. a greater wall thickness, since the material used for AM does not represent the attributes of the material used for actual production. For another, since the prototypes look like a final product, it can lead conclusion that the product will be available immediately. However, since it is just a prototype, still time for the real production needs to be considered.

> *"[…] it looks pretty fast like the product would be ready and already available, but this is only the prototype. Back in the days, a prototype looked kind of like a hand carved model and nowadays it looks pretty fast finished with the design and all. But that is simply not the case, because then actually still the injection moulding needs to be done, where up to two month of tool completion needs to be taken into account."*

The information generated from this interview demonstrates, that also a small company is able to implement and use AM in the innovation process. By rapidly and cheaply producing prototypes and easing the presentation of ideas, the technology enhances the innovation process. However, physical testing and misinterpretation in terms of availability of the final product still pose challenges for the company's usage of AM.

5. Discussion

5.1 Reasons for the Implementation of AM in the Innovation Process

After studying the recent literature about the innovation process in sports equipment and the role of AM in this industry, as well as generating real life data from several case studies from different companies and from an interview, the similarities between theory and practice became obvious. Here, three main reasons for the use of AM in the innovation process emerge.

The argument by Manoharan et al. (2013) and Waterman and Dickens (1994), that AM increases the prototyping speed and therefore accelerates the entire development process, is the first main reason why almost every company from the case studies, and also Company A from the interview implemented this technology. The possibility to a faster testing and iterating of the product, and therefore a faster elimination of flaws, enables a better final product, than conventional manufacturing does. Even though the case of Red Bull and Proto3000 indicated that some products cannot exploit the benefit of speed provided by AM, the interview showed, the use of the idle time, e.g. the weekend, can compensate the longer printing time for certain products.

Secondly, the convenience factor was dominant in literature, case studies, and the interview. The enhanced collaboration with stakeholders, i.e. athletes or other departments, has a significant impact on the quality and the performance of the final product. The compact build of most printers and the resulting flexibility of production location enables an efficient work with athletes by prototype, test and iterate location independently. In the sport industry, this collaboration is particularly important, as the athlete's performance, as well as their health, are subject to the performance of the product.

This became clear in the Burton case study, where the numerous testing and iterating of the product led to a binding superior to earlier attempts. Also in Adidas future vision, where the production of shoes will take place right at the store and therefore with close involvement of the customer, this convenience plays an important role.

Thirdly, there is the possibility to create designs and shapes that were not feasible before. As mentioned before by Mohr (2015), Huang et al. (2012), and Evans & Spada (2013), the freedom in design led to more flexible and durable parts in the production of shoe soles and plates, made the exact duplication of a surfboard possible, and improved the quality in protection equipment.

All the benefits of AM lead to the facilitation of the innovation process and therefore to the ease of product development. Being able to prototype hundreds of different iterations in a rapid manner led to the improvement of long established products, such as cleats, as well as to the development of newer products, such as new bindings for the snowboard industry.

An overview over the impacts of AM on the innovation process that compares the findings from the literature to the findings from the case studies is shown in table 2.

Impact	Literature	Impact on all firms	Specific Impact							
			Nike	Adidas	New Balance	Cobra Puma Golf	Burton	Red Bull & Proto3000	Zweikampf	Company A
Increased speed in prototyping	X		X		X	X	X		X	X
Freedom of Design	X	X								
Improved properties	X		X	X	X		X		X	
Savings in Cost	X				X	X			X	X
Reduced Errors/Waste	X							X		
Increased Convenience	X		X		X					X
Increased Maintenance	X									
Limited Processable Material	x					X				X
Increased labour					X					
Using Idle Time										X

Table 2 Literature Company Comparison

However, with regards to the framework developed in section 2.3, the case studies and the interview showed that the benefit of freedom of design mentioned in the literature can only be verified to some extent. Figure 5 shows the innovation matrix with integration of the cases and the interview. Each black circle represents a company from the case studies and the green circle represents the interviewed company A, all of which are located in the technological breakthrough area. The new technology is mostly used to slightly improve already existing products, such as the sole for cleats, or the shin guards, by using new forms of designs, such as lattice structure. Nevertheless, so far only existing customers and markets can be satisfied with these developments. With the production of a new binding, Burton indicated how the technology could help in the development process and lead to a new product. As this still does not represent a significant new development, the mentioned possibilities for creative new products and therefore new markets, could not have been confirmed by the case studies nor the interview. Considering this, the overall role of AM in the innovation process therefore must be moved from the radical innovation to the edge of the technological breakthrough in the adjacent area (white X).

A further factor from the literature that cannot be verified completely is the savings of cost when using AM, since only one of the cases (Cobra Puma Golf) and the interviewed company mentioned costs as a reason for the implementation. Further interviews would be helpful to see, if the cost aspect plays an important role in the implementation.

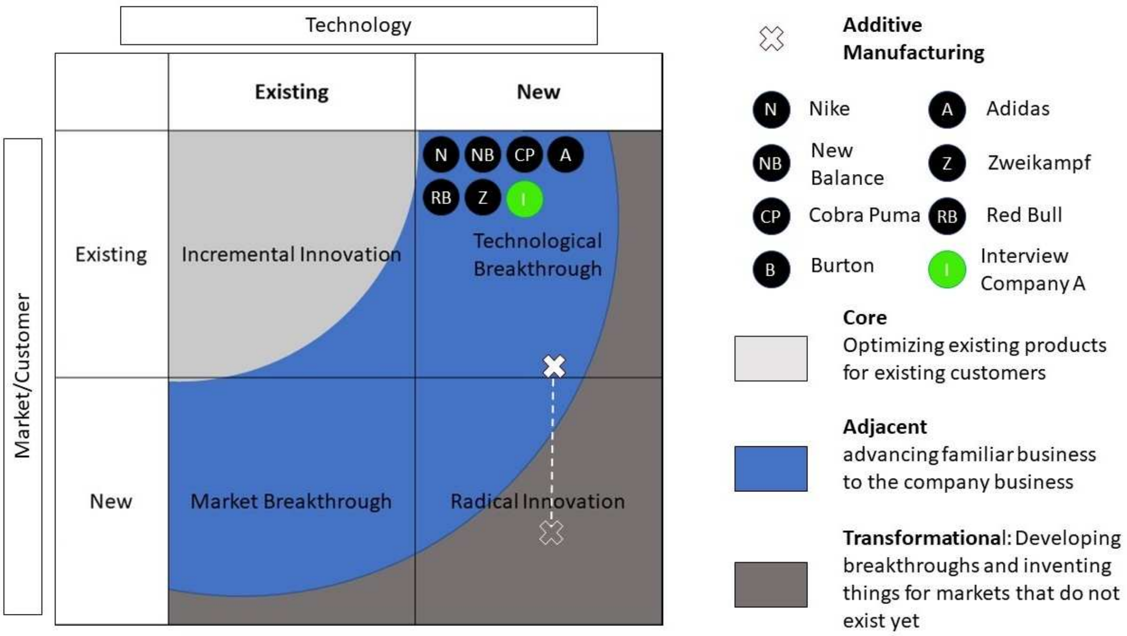

Figure 5 Innovation Matrix II - Cases

5.2 Current Awareness of AM, Recommendations for the Industry

Figure 5 in section 5.1 shows that AM is currently not leading to radical innovations and new markets. This is likely to be due to the early stage of the technology. Considering the fact that AM is still evolving and has room for improvements, the potential to open new markets does exist. For this, two main advancements are necessary. The first one includes the range of processable material. As described in the literature and in the interview, the nowadays useable material for AM processes can introduce certain challenges to the prototyping process. With more and more different materials becoming available to use for AM, the range of properties and product characteristics manifolds, leading to more application possibilities. The second, and more important advancement is the possibility of meeting the demand of a production line. This means that even if AM leads to the invention of a completely new product, it cannot open new markets. For one, AM cannot be used efficiently for mass production yet. For another, conventional mass manufacturing underlies the Design of Manufacturing. As this has most likely been circumvented by AM in the innovation process, the new created product is unlikely to be prototyped with AM and then mass produced with conventional processes, due to a limitation in the production capabilities of the latter.

Showing again an alternated matrix from the framework, figure 6 illustrates the possible future role of AM in the innovation process, given that the two mentioned factors will develop and improve over time. It shows that AM moves into the Radical Innovation field as described in the literature, and really becomes a Transformational Innovation, generating new customers and opening new markets.

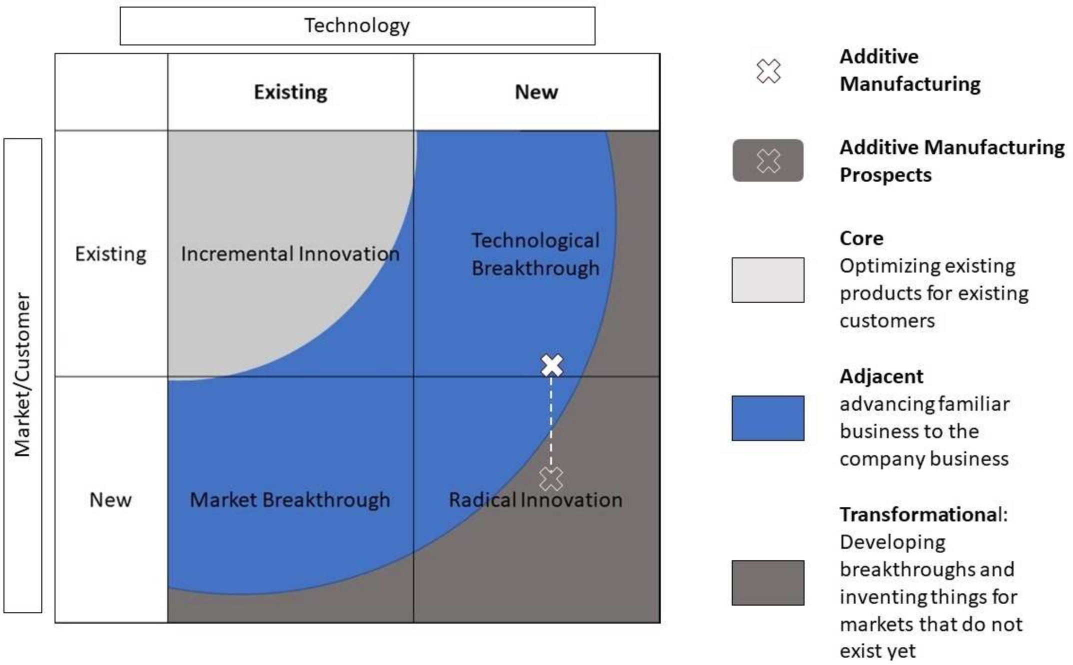

Figure 6 Innovation Matrix III Future Prospects

Next to the reasons for the implementation of AM, the investigation showed that the awareness of the new technology in the sports equipment innovation process is still very low. Figure 2 by Gausemeier (2011) illustrated that the sports industry is significantly lacking behind in implementing AM technologies. Considering the number of companies that have been contacted for this work and did not reply, as well as the fact that 18 companies denied help because of not using this technology or not being familiar with it, it is likely to say this industry is indeed not very aware of the potentials of AM.

This unawareness, however, seems neither to be due to too high investment cost, nor to be in any relation to the size of a company. Small companies such as the interviewed company, as well as Burton (aprox. 400 employees worldwide and a revenue of approx. 40 million US Dollar), and especially Zweikampf as part of Bernstein Innovation only having 10 employees, also the smallest companies managed to implement AM technologies in their innovation process. Compared to these firms, the big, established companies such as Nike, New Balance, and Adidas can draw on much more resources, and still did not achieve more significant process improvements. The fact that size and revenue are not in relation to the possibility of implementing AM, supports the argument made by Kappius (2013) that small companies could equal disadvantages and become more competitive to the bigger companies.

Finally, it is not possible to say AM technologies are definitely enhancing the innovation process of every company. Appropriate material that represents the final product's material as accurate as possible, and the dimensions of the prototype must be considered by companies before the decision of implementing AM is made.

6. Conclusion

The purpose of this research project was to investigate the industry's awareness of AM, its implementation, and its impact on the innovation process of the sports equipment industry. The results of this research show that the use of AM technologies in the innovation process of sports equipment can have a significant impact on both innovation speed and output. By using AM for the creation of prototypes, the possibilities of fast iteration and testing, combined with the creation of shapes that are not possible with conventional manufacturing, lead to optimised final prototypes in a shorter timeframe than with traditional prototyping processes. The fact that the prototyping process can take place where it is most efficient, enhances the collaboration with the consumers, or "prosumers", which is key in the sport industry. This enables the production of equipment that provides a superior performance. Although the literature states that AM leads to entirely new products and therefore can open new markets, this could not be confirmed by the information generated from real-life companies. The sports industry's current awareness of AM technologies is still very low and not even close to the level of industries such as the aerospace industry or the jewellery industry. In addition, the technology itself is still evolving, meaning there is still room for improvement. Especially the low range of processable material and the slow speed for mass production withhold the technology from making the major changes in the innovation process of sports equipment, that can lead to new products, customers, and markets.

6.1 Implications for Theory

This work contributes to the existing literature in the fields Innovation and Additive Manufacturing, and with the latter to the theory of agile manufacturing. By showing how AM is used in a real-life context, the results represent a counter view to the existing literature and put the many theoretical benefits of the technology into perspective. Therefore a broader picture is generated. Furthermore, the work is relevant for the literature in the fields of Industry 4.0 and Internet of Things, by showing a digital and connected way of the innovation process.

6.2 Implications for PracticeThis paper shows that AM technology can be implemented by companies of all sizes. Furthermore it gives good examples on how AM can be used in the innovation process and what the outcome of this usage is. Companies that have not implemented AM or are completely unfamiliar with this technology can use this paper as a guideline and aid in their decision process of implementing the new technology in their innovation process or not.

6.3 Limitations

Limitations exist in the qualitative approach of this study. Especially in this case, with only one source for primary data, there was no possibility to verify the generated information. Although several companies were contacted as potential interview partners, the unwillingness for cooperation made it impossible to avoid this limitation.Additionally, every company underlies a certain bias of justifying the investment in AM for the innovation process, and therefore is likely to understate downsides of these technologies. Independent observers could circumvent this bias and put focus on the downsides as well.

As mentioned before, the sport industry and its equipment are very customer focussed and builds around the perception of the consumer. Therefore, the generated theory in this paper is very context specific and represents a theory in use (Voss et al., 2015).Further research is therefore needed to quantitively review and verify the findings generated in this study and to expand the findings on other industries. Furthermore, only western companies were investigated, which leaves China, as one of the biggest player in the industry, to the subject of further research. Finally, since this work only focussed on the innovation process, it is important to see, how AM can be implemented in the manufacturing of end products, to determine the progress that has been made and to see, how realistic Adidas' vision of mass customisation is.

Appendix

Appendix A: Semi-structured Interview Guideline

Background

1. What is the main business area of your company?
2. How many workers are employed in the development department?
3. How much money is annually invested in the innovation process?
4. How many new products are developed (e.g. per year)

AM Focus

1. How would you asses the attitude of the company towards new technologies on a scale from 1 (early adopter) to 10 (forced adopter)?
2. How high is the level of awareness for AM technologies in your company from 1 (not heard from it) to 10 (implemented in the company)?
3. Since when are you using that technology?
4. What technologies specifically are used? How many machines are currently in use?
5. Why? What was the trigger for the implementation and what benefits are you gaining from the use of AM technologies?
6. Have you noticed any disadvantages and challenges with this technology?
7. What is going to happen in the future for your company in this area?
8. What needs to be changed/improved on current AM technologies?
9. Can you name an example development you made with using AM technologies?

After a short introduction about the topic, information about the background of the company was gained. The main part started with a broader opening question, followed by the key questions. At the end, again a broader closing question was asked to finish the questioning (Hennink et al., 2015)

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