The Future of Fitting Shoes
Implementing 3D Scanning Technology in the Online Footwear Industry

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The goal of this research is to explore how 3D scanning technology can be applied to the processes of the online footwear industry. In general, consumers are confronted with confusing sizing systems leading to insecurity among online shoe shoppers. At the same time, online retailers struggle with high return rates due to improper fit. With the advancement of 3D scanning technology, online retailers have the opportunity to offer virtual fitting tools in order to provide the consumer with try-on possibilities prior to the online purchase. This research outlines traditional fitting and sizing methods for footwear, which are then compared with virtual fitting technology and 3D scanning in the second part. The current developments of 3D scanning technology indicate a growing relevance of virtual fitting in the footwear industry. Measurements of the human foot with the help of 3D scanners show greater accuracy and precision in comparison to conventional methods, and are already being utilised in the footwear industry. 3D foot scanning technology in the form of in-store scanners, mobile scanners or photogrammetric scanners are developed to a level which enables the virtual fitting of shoes. These technological developments are explained in the third part of the research, which focuses on the implementation of 3D scanning in the online footwear retail industry. The final part of the research analyses the consumer’s acceptance and attitude towards 3D scanning technology.
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1. INTRODUCTION

Custom-made shoes are the perfect expression of getting what every customer wants: The right fit, the right details, the right style. Until now, perfectly fitting shoes were hard to find, affordable only for a happy few and provided by shoemakers with the highest level of craftsmanship. Today, implementing new technologies into the selection process could provide tools to open this market to everyone at low costs.

The European footwear market is growing constantly. It is forecasted to register about 79.200 million € revenues in 2018 with an expected annual growth rate of 10% until 2022 (Fashion Segment Report, Statista, 2017). The annual average revenue per person amounts to 92,66 € (Fashion Segment Report, Statista, 2017).

There are several factors driving the robust growth in footwear e-commerce, including the millennial’s preference for shopping online and new possibilities of mass customisation enabled through 3D printing and personalisation (Global Industry Analytics, 2017). Online distribution allows retailers to market not only locally but to a world of potential buyers. In Germany, for example, the total number of sales of footwear via online channels made up 12.2% in 2013 and is predicted to increase to 15.7% by 2018 (Online penetration of footwear retail sector in Germany in 2013 and 2018, Statista.com, 2013).

But the online footwear market also involves the risk of high return rates, up to 40% in 2016 (Dennis, 2017) which are caused by three major factors: In a time of increasing globalisation and accessibility of online shoe stores all over the world, consumers are confronted with a confusing system of EU, UK and US shoe sizes, measured in cm or inches. This phenomenon is aggravated by the fact that traditional measuring methods derive from 19th century Europe and therefore, they are not suitable to represent today’s global body shapes and proportions (Innes, 2014). Solely, when it comes to shoes, the average shoe size has increased by two sizes since 1970 (Innes, 2014). Insecurity among customers regarding fit and sizing is considered a major reason for returns (Apparel & Footwear Retail Survey Report, 2016).

The problem of not being able to fit shoes might be solved by 3D scanning technology. Initially, 3D foot scanners were used predominantly for orthopaedic purposes. However, the technology has become more relevant for the customisation of skiing boots, business and sports shoes (Jans, 2017). 3D foot scanners can be an option for the mass market of footwear and enable well-fitted shoes without customers having to physically try them on. Applying this technology to the general online footwear retail
industry could entirely change today’s retail processes and lead to decreased costs with a simultaneous increase in customer satisfaction.

The following research explores the question: How can 3D foot scanning be utilised in the processes of online footwear retail? In the third chapter, traditional shoe sizing and fitting methods will be discussed, followed by an exploration of 3D scanning technology in chapter 4. Chapter 5 examines the possibilities of implementing 3D scanning technologies into the retail process and finally, chapter 6 addresses consumer behaviour and attitudes towards 3D body scanning.

2. METHODOLOGY

The first part of the research provides information on the traditional evaluation of shoe sizing and fitting. Expert interviews with shoe manufacturers and retailers will be conducted, supported by additional online research using Google Scholar, ScienceDirect and the intranet of the Hogeschool van Amsterdam (bib.hva.nl) as search engines with the following word searches: shoe fit, determination of shoe size, sizing system, conversion of shoe sizing systems, foot measurement.

The following part explores the technological background of 3D scanning and virtual fitting through online literature research (3D scanning, 3D body scanning, virtual fitting, virtual fitting shoes, 3D foot scanning, 3D scanning orthopaedic and 3D scan technology). As 3D scanning technology is developing at a fast speed, up-to-date sources written after 2012 will be used as much as possible. The resulting information mainly derives from technology platforms, product information from retailers, research studies, user manuals and consumer reviews. By developing an overview of the most relevant developments, the latest technology and its market applications will be taken into account.

The application possibilities of 3D scanners for the fashion online retail industry and consumer online shopping behaviour will be based on the results of interviews with industry professionals, which will be supported by further online literature research.

In the last chapter, consumer behaviour on online shoe shopping, as well as attitudes towards 3D body scanning technology, will be analysed based on the results of a consumer survey. The results will be brought into a broader context with the help of results from comparable studies and expert opinions on the topic.
The foot consists of “26 bones, 33 joints and over 100 tendons, muscles and ligaments” and supports and balances the whole human body weight (Swierzewski, 1999). The foot is one of the most complex human body structures with deformations, irregularities and asymmetries, varying by gender and age, and changing throughout ones’ lifetime (McGavin, 2014).

With the help of different foot measuring methods, manufacturers and footwear designers are able to create shoes with accurate proportions for the human anatomy. The shoe size is based on the total length of the foot and is traditionally measured with a digital calliper or tape measure (Lee, Lin, and Wang, 2014).

Some of the most common sizing systems are the European (EU, D, F, I), the American (US) and the British (UK) sizes, next to Japanese, Australian and Brazilian shoe sizing systems. The European shoe size is calculated by \((\text{foot length in cm} + 1,5\text{cm gap}) \times 1,5\), while the American and UK sizes are measured in inches by calculating \(3 \times \text{last length} – 23\) (UK) and \(3 \times \text{last length} – 24\) (US) (Blitzrechner.de, n.d.). All of these converting systems are merely focussing on the foot length and do not take into account additional measurements, such as width, ball girth and instep height. With the aim of developing an improved shoe sizing system, the International Organization for Standardization (ISO) introduced a universal system called Mondopoint (ISO 9407), which is directly based on millimetres and considers the foot’s length and width (ISO, 1991). Nevertheless, Mondopoint is not widely established and is primarily used for military and safety shoes.

Globally, size charts and grading systems of shoe manufacturers are not standardised and therefore shoe sizes differ between, and even within, brands, resulting in unreliable and non-transparent conversion systems (Attachment 2).
Well-fitted shoes are crucial for a comfortable wear and healthy feet, as they support the bone structure of the foot. The sole of the shoe should comfortably align with the bottom of the foot while the heel needs to be prevented from slipping out of the back (Miller, Withcome, Lieberman, Norton, Dyer, 2014).

In general, the foot length and width, the ball and calf girth and the instep height are the most relevant measurements to determine shoe size. Especially, for medical purposes, such as orthopaedic insoles or for athletic shoes, the heel angle, Achilles tendon angle and weight distribution on the sole should additionally be considered (Jurca, Kolšek and Vidić, 2010). During the traditional manufacturing process of shoes, manually taken foot measurements provided the basis for the production of the shoe last. But with the development of 3D body scan technologies, there are more sophisticated and precise ways to determine the size of the shoe size using digital technology (Telfer and Woodburn, 2010).
4. **VIRTUAL FITTING TECHNOLOGY**

Virtual fitting, also referred to as a virtual dressing room, virtual fitting room or virtual try-on, gives consumers the opportunity to try on clothing and shoes in a virtual environment, as opposed to in a physical store (Cordero, 2010). There are several techniques on the market which are supposed to help online shoppers with size, fit or styling decisions such as 3D body scanners, size recommendation tools, 3D fitting rooms with 3D models, 3D simulations and augmented reality solutions (Pachoulakis, Kapetanakis, 2012). In the following section, this report focusses on 3D scanning technology and size recommendation tools, as they are the most relevant for online retailing.

4.1 **3D Foot Scanning**

Virtual fitting of shoes is a technique of digitally aligning a 3D model of the 3D-scanned foot with the digital model of a shoe. The 3D data of the shoe measurements are based on internal scans of shoes (Attachment 1). Another possibility is to base virtual fitting on the digital designs of manufacturers and correlate them with the customer’s foot measurements (Apparel & Footwear Retail Survey Report, 2016). Benjamin Rüsing explains that the technology is able to detect fit problems by calculating the distance...
between the inside of the shoe and the foot showing a heat map to give more informed size recommendations (Attachment 1).

The digital model of the foot can be created with the help of different 3D scanning techniques. 3D scanners are ideal for measuring complex shapes which would otherwise require a large number of measurements to accurately describe them. They are able to capture the human body and create a virtual 3D model of it. 3D scanning is especially useful for foot scanning, as it takes irregularities of the bone structure and different foot shapes into account and therefore guarantees a more precise measurement than traditional measuring methods (Lee, Lin, Wang, 2014). 3D scanners can be considered as “intense cameras” (Smith, 2015) which collect information about the surface area of an object. A three-dimensional representation can be created by identifying millions of location points and creating a 3D representation consisting of point clouds (Ebrahim, 2013). Some scanners are additionally able to detect and recreate colours and measurements. 3D scanners are available in the form of full-body scanners with the size of a fitting room, hand-held scanners, desktop scanners, applications for tablets and in scales and smartphones. Scanners differ in terms of range and size, with the most suitable scanners for 3D body scanning being those based on the techniques of laser triangulation, structured light and photogrammetry (The best 3D Body Scanners in 2017, 2017).

4.1.1 Short distance 3D scanners

Short range scanners are most suitable for scanning distances underneath 1 metre and either use the technique of laser triangulation or structured light (Ebrahim, 2013). These scanners are available as portable or desktop scanners and have the ability to perceive detailed surfaces of smaller objects (Ebrahim, 2013). **Laser triangulation** scanners (Image 3) shoot a laser (projector) onto the surface of the object and the sensor (camera) receives the reflection of the laser at a point according to the angle of reflection (Brown, 2012). By using geometry and calculating the angle of the reflected laser, the sensor is able to assemble the structure of the object (Brown, 2012). **Structured light** scanners (Image 4) project (projector) a linear light pattern onto the object’s surface and the sensor (camera) observes how the pattern is reflected around the object (Daanen, Ter Haar, 2013). The advantage of structured light scanners is its scanning speed as it captures several points at the same time (Daanen, Ter Haar, 2013). As a
result of both techniques, millions of points on a XYZ graph are detected and a point cloud or polygon mesh (triangle mesh) is generated, which represents the digital 3D model of the scanned object (Ebrahim, 2013).

4.1.2 Stereo photogrammetry (image-based modelling)

Another possibility to digitise 3D objects is through stereo photogrammetry. It is a technology that generates 3D scans, maps or measurements with the help of photographs by putting the measurements of an unknown object against the known dimensions of another object (Walford, n.d.). The technology requires either multiple cameras from different viewpoints or just one camera taking photos around the object. The software detects location points and is able to recreate a three-dimensional model of the object. The advantage of this technology is that no laser is necessary and the scans can be based on conventional digital or smartphone cameras (Daanen, Ter Haar, 2013).

4.2 Online Size Recommendation Tools

Different size advice tools are based on the manual input of body measurements (Virtusize, Fits.me, Bold Metrics). These programs do not require any 3D scanning technology. According to these measurements, the software is able to create a virtual model of the body on which clothing can be tried on. They are compared to the online shop’s general sizing information or specific product measurements (Polvinen, 2012).

Other concepts ask the consumer to input the sizes from already purchased shoes and clothing. An algorithm is able to give size advice for the desired item based on these experiences (Fit Analytics, My Virtual Model). Online recommendation engines rely on the accuracy of the manual measurements.

4.3 Technological Developments and Market Outlook

4.3.1 The 3D Scanning Market

Virtual fitting and 3D scanning technologies are developing at a fast speed within several different areas which are of relevance to the fashion industry. The application of 3D scanning is widespread across a diverse range of sectors such as entertainment & media, aerospace & defence, medical & healthcare, civil infrastructure, industrial
manufacturing, and others (Person, 2016). Therefore, there are a number of different groups interested in supporting the development of 3D scanning technologies, with the healthcare sector considered as the driving force behind the market growth. Some of the most relevant companies involved in 3D scanning are 3d Systems, Ametek, 3D Digital, FARO Technologies and Autodesk (Person, 2016). The manufacturers are working on new techniques and applications to specialise their product, which adds value to the 3D scanning industry and drives the market (Person, 2016). According to the research of marketsandmarkets.com, “the 3D scanner market is expected to grow from USD 3.76 Billion in 2017 to USD 5.90 Billion by 2023, at a CAGR of 7.8% during the forecast period” (3D Scanner Market by Offering, 2017). Currently, North America and Europe hold the biggest market share, thus a growth of the industry in Asia Pacific will cause a rapid increase of the overall revenues (3D Scanning Market - By Devices, 2017). A range of body scanners in the form of full-body scanners, partial-body scanners, mobile scanners and hand-held scanners is available on the market. Looking at the developments of 3D scanning hardware, it becomes obvious that due to competition, scanners have improved in precision and are simultaneously becoming more affordable (Daanen, Ter Haar, 2013).

4.3.2 Accuracy

Research on 3D foot scanning while performing linear measurements (foot length and width) and during weight bearing shows that the accuracy of 3D foot scanners is sophisticated enough for the application to orthopaedic and medical measurements (Telfer and Woodburn, 2010). Furthermore, the digital reconstruction of the dynamic foot (performing a step) is measurable with a 3D scanner and shows repeatable and accurate results (Thabet, Trucco, Salvi, Wang and Abboud, 2014). In order to ensure the comparability of 3D body scans with traditional measuring methods, the International Organization of Standardization established ISO Standard 20685 (ISO.org, 2010).

4.3.3 Retail Implementation

There are several forms of hardware which contribute to an increase in the relevance of 3D body scanners for the footwear retail industry. The first traces of 3D body scanning can be found in modern retail environments as a tool for customisation. For example, tailors make use of the technology for its exact measurements when customising suits or business shoes (Gayomali, 2014). Another application area is in sportswear. Retailers integrate virtual fitting technology in stores for the fitting of running shoes and skiing boots (Jans, 2017). Among other brands, Adidas started to use 3D scanning to custom-fit shoes. For their limited series Futurecraft (Adidas Int. Trading, 2017), Adidas partnered up with the software developer Materialise to measure customer’s feet with the help of a motion analysis on a treadmill, combined
with 3D foot scanning technology. Afterwards, Adidas 3D-prints a customised midsole in store, according to the measured weight bearing and posture (Koslow, 2015).

4.3.4 Accessibility

The accessibility of 3D scanners has increased by the introduction of different home scanning technologies. The fitness industry launched smart scales, which do not only measure weight but are also able to measure the body proportions and exact volume with the integrated 3D body scanner. It provides the user with their fitness progress by showing changes of several body measurements (Chen, 2017). These scales are likely to be one of the first developments to place 3D scanners into the home environment (Chen, 2017). There is a wide range of 3D scanners available on the market which are targeted at a wider consumer group: Hand-held scanners and add-ons for tablets guarantee the mobility of 3D scanners. Devices such as Oppical’s Structure Sensor and Sense 2 from Cubify make 3D scanning a gadget for hobbyists, which are not only affordable at a price range starting from US $100, but also ensure user-friendliness and precision (Grunewald, 2016). Sony, with its Xperia XZ1 (Sony Mobile Communications, 2011-2018), is the first company to integrate a 3D scanning technology into a smartphone. Making use of photogrammetry, the included 3D Creator processing software enables different entertainment features, such as sending 3D models of items or persons to friends and create avatars from head scans to integrate them into videos and games (Lievendag, 2017).

4.3.5 Virtual Fitting Software

Next to that, virtual fitting software plays a major role for the implementation of 3D scanning into the industry. Companies, such as corpus.e, make virtual shoe fitting with store-integrated 3D scanners possible. The software overlaps the 3D model of the foot with an inside-scan of the shoe and detects fitting problems by calculating the distance between them (Piperi, Galantucci, Kaçani, Shehi, Spahiu, 2014). Applications for smartphones based on stereo photogrammetric measurement of certain body parts already give a sophisticated example for the connection between customer and retailer, by giving size recommendations. The app 3DAbout.me (3Daboutme, 2018) provides the user with foot measurements after only taking three photos of each foot. Afterwards, the app connects the user with cooperating online shops and brands and recommends which shoe to buy in which size. Size recommendation apps give a first indication of how home measurement and virtual fitting could develop in the future.
5. ONLINE RETAIL IMPLEMENTATION

Millennials and the Generation X make up the most important target group for footwear e-commerce, as 67% of this consumer group prefer to shop online rather than in store, with an increasing tendency (Wallace, 2017). This generation grew up with the possibilities of mobile technology and expects the highest means of service and comfort when it comes to online shopping. Especially in terms of payment possibilities, shipment methods and personalised shopping experiences, they have the highest expectations (McGee, 2017). “Whether this is online or in-store, millennials seek customer service professionals who understand their preferences and make recommendations tailored to their specific needs.” (McGee, 2017). For retailers, this means to constantly be aware of current trends and to adapt to the newest technological developments.

An ongoing challenge is the problem of not being able to try on a product when purchasing online (Wallace, 2017). The lack of product information and the fact that the customer is unable to assess and fit the product beforehand, leads to a high product risk for online retailers (Kim, Forsythe, 2008). Even though the exact data on return rates of online footwear retailers are difficult to determine, a study from Body Labs estimates them to be approximately 56% for footwear (Apparel & Footwear Retail Survey Report, 2016). Many of those returns are caused by customers ordering multiple sizes and returning the non-fitting items. This phenomenon is confirmed by Nicole Malucha, a Business Development Manager within Zalando’s sizing team (Attachment 2). She claims that one of the major problems for online customers is to be confronted with a number of confusing sizing systems and non-transparent sizing among footwear brands. The resulting problematic for retailers is to connect the mass market through fitting products with the means of technology.

Implementing virtual fitting into the retail process could be a promising solution, as it provides the opportunity for the customer to determine the fit and acquire more information about the product before the online purchase (Kim, Forsythe, 2008). Depending on the retail concept, virtual fitting tools can be applied in three different ways:

1. The consumer can either install and use a photogrammetry app to generate foot measurements with the smartphone camera. Photogrammetric applications are usually connected to an external provider. For smartphones, there are several apps available, which provide certain foot measurements by taking just a small number of photos of each foot (3Dabout.me, findmeashoe, CA.LA). Photogrammetry apps are available from a range of external providers who offer
the service on a provision basis for the retailer and are free for customers (3Daboutme, 2018).

2. Alternatively, the foot scan can be created with the help of a 3D scanner at a local store. Depending on the technology and the provider, in-store foot scanners consist of a platform and one or more cameras which take photos around the feet within a few seconds. The implementation of physical in-store scanners requires investments, staff, knowledge and the connection to a virtual fitting software.

3. Additionally, the consumer can make use of online size recommendation tools which are based on the manual input of foot measurements. From these data, the software is able to recommend sizes or create a virtual avatar.

In the following step, the acquired measurement data from all kinds of scans are processed through a virtual fitting software, either run by an external provider, via a platform or an app. As a result, the customer receives recommendations from the software. It either connects the user with cooperating online shops and brands and recommends which shoe to buy in which size, or provides information on the right size
for a pre-selected pair of shoes. Some virtual fitting software additionally show possible fit problems of the selected pair of shoes (PR Newswire, 2016). Other business models profit from virtual fitting data for customisation and made-to-measure shoes.

The implementation of these virtual fitting techniques for shoes can be recommended to online footwear retailers who have either high costs for customer service, high return rates and low conversion rates or companies that deal with many customers who are unsure about their sizes and therefore tend to order multiple sizes (Attachment 2). Due to the inconsistent sizing systems among footwear brands, multi-brand retailers would supposedly profit most notably. Another potential target group are kid’s footwear retailers, as children’s feet need to be measured on a regular basis. 3D scanning technology could therefore minimise the risk for parents to select a badly fitted shoe for their children.

Especially, photogrammetry apps and size recommendation tools are most suitable for the e-commerce segment. In comparison to physical in-store scanners which require pricey investments, virtual fitting tools for online shops can be implemented into the retail strategy with the help of a website plugin alone (3D Look LLC, 2017). Due to that, they can be made accessible to 258.1 million smartphone users only in Western Europe (Number of smartphone users in Western Europe from 2014 to 2019, Statista, 2018).

As the application of virtual fitting tools in online shops offers additional information about fit, it leads to more confidence in size decisions for the customer (Kartsounis, Magnenat–Thalmann, Rodrian, 2003). A successful virtual fitting experience would probably promote a higher customer loyalty. It will therefore most likely have a positive effect on online sales, conversion and returns, and thereby on cost reduction and profit margins (Kim, Forsythe, 2008). Even though the exact impact on the return rate cannot be confirmed by independent literature, some providers and users claim it to be between 25% and 37.5% (Volumental, n.d., PR Newswire Association LLC, 2012). Moreover, size guides on websites could supposedly become redundant, as the scans highlight all possible fit problems and recommend the best size. It therefore has the potential to overcome the sizing gap between online retailers and customers (Kim, Forsythe, 2008).

Another major advantage is, that retailers can utilise the complied data for consumer analysis and the optimisation of buying, while manufacturers are able to transfer the knowledge into the prototyping and design stages. Gaining better knowledge about foot proportions with precise 3D scanning measurements could not only help the customer to find better fitting shoes but also support the manufacturer to better adapt to customer needs and specialise on foot proportions (Volumental, n.d.).
6. CONSUMER BEHAVIOUR

As part of this research, a survey was conducted on online shopping behaviour and consumer acceptance towards 3D scanning. The results on online shopping behaviour are compared to the information from an interview with Nicole Malucha, a Business Development Manager in Zalando’s sizing team (Attachment 2) and a study from Body Labs with 1,130 participants in the USA in 2016 (Apparel & Footwear Retail Survey Report, 2016). The consumer attitude towards 3D scanning is supported by research results from Cornell University (Ashdown, Loker, 2011) and Iowa State University “Exploring Consumer Perceptions toward the Use of Me-Ality Body Scanner for Clothing Selection in U.S. Shopping Malls” (Lee, 2013).

The survey was spread via social media platforms on the internet and was accessible to theoretically everyone over a period of four weeks. 129 respondents from the age of 16 to 78 took part, out of which 43% were between 23 and 27 years old and 20% between 50 and 58. Therefore, these two age groups represent the biggest portion of the focus group. The majority (59%) of the respondents were female (41% male). The occupation of the respondents differed as well. 30% are students, while the remaining come from diverse occupational backgrounds, ranging from managing positions, doctors, pharmacists and lawyers, to designers and interns. The great majority of the respondents live in Germany (80%), 11% live in the Netherlands.

A striking number of 83% claim to prefer buying shoes in-store as opposed to online (16%). According to Body Labs, 59% of the shoppers prefer to buy in-store. A possible hurdle for the participants could be the sizing systems: 57% claim fit problems as the major reason for returns.
Regarding sizing systems, only 6% of the respondents never noticed any differences in sizing among different brands, whereas 47% state that “they are all entirely different” and the remaining 47% say that “there are differences but size guides or retail staff help”. The survey shows that 49% decide on their size from former experiences with brands, while 12% order multiple sizes and send the others back. This is confirmed by the study from Body Labs where “57% of consumers only purchase apparel or footwear online from brands or styles they know they fit them” (Apparel & Footwear Retail Survey Report, 2016).

International sizing systems illustrate another problem for online retailers. Almost half of the respondent’s state that they know their EU size but neither know their US (51%) nor UK (49%) shoe size. Malucha explains that Zalando offers items from suppliers in different countries and distributes them again in 15 countries. It causes a logistical difficulty to convert each country’s sizes and offer each item in the corresponding sizing system to customers all over Europe.

The survey shows as well, how little 3D scan technology is used today. Only 3% of the participants have ever been in contact with a 3D scanner before. Malucha describes that Zalando tested 3D body scanning technology based on photogrammetry. Users were supposed to scan themselves in front of their laptop camera wearing just underwear. This lead to discomfort among the users and according to Malucha, the testers were sceptical about the privacy of data and photos. When asking the participants about concerns towards the technology and use of data, 57% claim that they are curious about the technology and would “like to try 3D scanning immediately”. 18% would rather have their feet scanned than the rest of their body, which shows that there is a higher acceptance towards 3D scanning technology for shoes. The remaining participants are sceptical about the user-friendliness (10%) and data privacy (18%) or claim that they do not actually want to know every measurement of their body (10%).

In the research study on 3D body scan technology from Cornell University College of Human Ecology (Ashdown, Loker, 2011), several subjects were scanned with a 3D
body scanner in order to evaluate the fit of a pair of pants. After the scan, the researchers asked the subjects about their experiences in the body scanner and throughout all age and size groups, the participants had a positive experience and were willing to be scanned on a regular basis. Nevertheless, “the participants were less comfortable seeing their scans as a still or moving picture on the computer screen and least comfortable showing their scans to family and friends” (Ashdown, Loker, 2011). As a possible solution, the researchers abstracted the scan “by reducing the number of data points, changing the colour and lighting on the scans, and placing several scans together for context” (Ashdown, Loker, 2011). A different study from Iowa State University “Exploring Consumer Perceptions toward the Use of Me-Ality Body Scanner for Clothing Selection in U.S. Shopping Malls” found that the most common reasons for participants to test the 3D body scanner in a mall were “to check their right clothing size, for fun, and because another person asked them to try the body scanning” (Lee, 2013). Furthermore, it stated that the subjects had a generally positive attitude towards 3D body scanning and “expressed their interest to use this technology in the future, especially obtaining their accurate sizing information in a retail store setting” (Lee, 2013).

7. LIMITATIONS OF THE RESEARCH

This research is limited by the fact that there is no literature by independent sources on the monetary and economic effect of 3D scanning, such as on return rates or on profit. Moreover, there is no information on the accuracy of foot scanning on smartphone applications. As the respondents of the conducted survey were not chosen according to a specific target group and only a relatively small number participated, it is recommended that further research is conducted on these specific topics to better evaluate the efficiency of 3D scanning technology.
Implementing 3D foot scanning into online retail processes is complex and requires a combination of different technologies. The existing 3D body scan technologies, such as store-integrated 3D foot scanners, act as a sophisticated basis for virtual fitting. The development of virtual fitting software shows reliable results in the field of customised and made-to-measure footwear manufacturing. Taking the complexity of the human foot into account, fitting and sizing need to be the major factors for the manufacturing of shoes. Thus, it is a useful solution for the industry to integrate 3D foot scan technology to precisely capture the entire volume and surface of the foot or to get information from dynamic foot scans. Especially, stereo photogrammetry is already able to provide a direct connection between consumer and retailer, and due to its low costs and high user-friendliness, it can be regarded as one of the most promising technologies. Next to that, the integration of 3D scanning software into smartphones opens up a whole new market and increases its accessibility tremendously.

An important step towards realisation of a 3D scanner integration into online retail is to gain the consumer’s trust and confidence in the technology. To most consumers, 3D scanning is still an unknown technology and therefore, scepticism regarding user-friendliness and data privacy exist.

With the installation of virtual fitting tools, retailers have to face certain rearrangements of the selling processes but over the long-term, 3D scanning brings a whole range of advantages: Retailers can minimise costs for customer service and decrease return rates while simultaneously increasing customer loyalty and satisfaction. Additionally, the technology bears the possibility to gather information on the customer’s foot shape, which is valuable for manufacturing and buying.

In summary, an advanced application of 3D scanning into the mass market of footwear e-commerce is still likely to be a future scenario that will require better application possibilities of 3D scanners for consumers and a wider implementation of virtual fitting software in retail.
9. REFERENCES


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Koslow, T. (2015). FUTURECRAFT SHOES FROM ADIDAS STEP INTO THE FUTURE WITH 3D PRINTED SOLES [online] 3D Printing Industry. Available at:


IMAGE REFERENCES


Image 2: 3Dabout.me (2017). Virtual Fitting Software. [img] Screenshot from 3Dabout.me fitting internal software.


All graphs and figures derive from own configuration and are based on own research.
Attachment 1: Expert Interview: Benjamin Rüsing, Salgert Sports

(interview and self-test of 3D scanner in the store, following interview freely reworded from notes, 28 October 2017, 10.30am)

Salgert Sports is a sports store in Bergisch Gladbach, Germany, that uses 3D scan technology and virtual fitting to customise running and skiing shoes.

What do you use the 3D scanner for?
We use the 3D scan technology in our store to custom fit skiing boots to the feet of our customers.

Which 3D scanner do you use?
We use a lightbeam 3D scanner and virtual fitting software from corpus.e.

How does the 3D scan process work?
The 3D scanner is embedded into the floor in a separate room of our store.
1. First of all, the customer needs to put on knee-high socks, which have a structure of squares on them, comparable to a net. This helps the sensor in the scanner’s camera to detect the shape of the feet. It is important that the socks have two different colours, in order to guarantee a differentiation between the two feet.
2. Then the customer is supposed to place his feet on the surface of the scanner. The scanner takes two separate scans, one of each foot, by moving a camera with a flashlight around the foot. The measurement takes around 10 seconds per foot.
3. At the same time, the weight distribution (weight bearing) is measured from the platform underneath, giving additional information for the fitting of the mid soles.

What are the requirements for a good scan?
1. The socks need to be very tight because otherwise sticking out material is measured as part of the foot. Additionally, it is important that the seams and the net structure on the sock are placed neatly around the foot and the leg.
2. The customer needs to stand straight and still during the scan (for skiing boots the legs should be slightly bent).
3. There need to be good lighting conditions, which are guaranteed by the integrated light source on the head of the sensor.

What information do you get from the scan and which measurements are most important?
Within a few seconds, the scanner is able to precisely measure all points the feet’s surface and automatically creates 9 different measurements about the customers feet and legs which are relevant for the fitting of skiing boots:

1. Recommended shoe size
2. Foot length in cm
3. Foot width in cm
4. Instep height in cm
5. Ball girth in cm
6. Calf girth on 15cm height and 25cm height in cm
7. Heel angle in cm
8. Achilles tendon angle in cm
9. Weight distribution on the sole

How do you get from the foot to the shoe?
After scanning the foot and analysing the measurements, the next step is to choose the best fitting pair of shoes. Therefore, we work together with the Munich skiing boot producer Ertlrenz. The boots are scanned from the inside and the corpus.e software is able to access these information and match them with the 3D model of the foot. It automatically gives the information which boot in which size would be the best fit for the customer. The level of skiing experience and the individual preferences are included in the size selection as well.
The scan of the foot and the shoe are layered and you can see on the screen with the help of a heat map, where the shoe fits well and where it fits less, meaning where is needs to be adjusted. Afterwards, the customer is able to try on the boot in the store and give feedback on the fit.

How are the shoes fitted afterwards?
At Ertlrenz, the ski boot is customised. The hard shell of the shoe is heated and adjusted. Afterwards, the customer puts on the inner shoe, which is foamed. The last step is to adjust the insole with the help of a mouldable vacuum pillow and the information from the weight distribution.

How much is a customised ski boot?
A complete package is around 1.100€
Attachment 2: Expert Interview: Nicole Malucha, Zalando

(Free translation from notes from German interview, 25 October 2017, 6.30pm)

Zalando is an internationally operating online retailer offering a range of 2.000 brands in 15 European countries.

What is your position at Zalando?
Business Development Manager within the sizing team

Is Zalando interested in 3D body scanning and virtual fitting technology?
Yes, in fact, we researched and looked into several 3D scanning companies 1.5 years ago

How did the proposed technology work? Did you have to measure the garments yourself or did the scanning company take over that part?
The scanning company took that part over. Zalando has over 100,000 items live online and therefore, it is impossible to ensure that ourselves.

Why did you decide against the technology?
- Scanning companies scan the customer’s body with the help of the laptop camera (photos in underwear or without clothing) plus manual information about height and weight, software gives size advice based on those information
- Problem: software did not include any information about the material composition, whereby stretch or wanted fit were not taken into account
- Example: H&M has a way more body near and smaller sizing system than s.Oliver

Do you think your customer is willing to use 3D scanning technology?
- The software we looked at was too time consuming and too difficult to use. Especially taking into account, that most of our customers are people who are very busy and don’t have a lot of time to go shopping. Will those customers be willing to go through the procedure of body scanning?
- Besides, customers are sceptical about their data privacy (what happens with the photo and the measurements? Who sees them?)

Do you recognise difficulties with the traditional size guides?
- Zalando has very many different brands from different countries with different sizing systems
- Zalando sells in 15 countries, where the customer needs to be able to buy his size in the particular sizing system
- What makes it even more difficult is, that Zalando needs the information already before the item goes online, therefore the sizing team is in close contact with the buyers and producers
- Difference between fitting (how does the item fit: loose, body near) and sizing (actual measurements of the item)
- Loyal customers often know their sizes from experiences with brands, whereas new customers or people with less understanding of fashion are often unable to cope with sizing systems
- In order to give customers a good size advice, Zalando has its own fitting station where we do fittings on live models who have body measurements representing our customer’s sizing. We start off by fitting items with a high return rate to check their fit. After the fitting,
we make our advice available in the web shop (e.g. if you are a 34 we’d recommend you buying a 36 because the fit is smaller than usually)

- It is even more difficult when it comes to shoes because there are very many brand-specific grading systems.
- Example: Nike has different product lines such as Nike Performance and Nike SB with again different fit. If a customer orders in our German online shop from both lines in 39, he once gets a UK 6 and once a UK 6.5. This leads to a lot of confusion and increases the return rate.
- We help out with our Customer Care where experts help out by asking shoe sizes from other brands or exact measurements
- We are a team of 13 people only responsible for the sizing, so it becomes obvious how time-consuming and labour-intensive it is.
- Especially fast fashion companies often have less experiences with fitting and cause extra work for Zalando.
**Attachment 3:** 3D scanning technologies which are targeted to the mass market and would have the potential to be used for virtual fitting

<table>
<thead>
<tr>
<th>Company</th>
<th>Product</th>
<th>Type</th>
<th>Application for virtual fitting</th>
<th>Accessibility</th>
<th>Price</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Styku</td>
<td>Styku</td>
<td>3D scanning scale, home use 3D scanner to measure body and fitness progress</td>
<td>No integrated software to enable virtual fitting</td>
<td>Home use possible, targeted for mass market, user friendly</td>
<td>Request quote</td>
<td><a href="http://www.styku.com">http://www.styku.com</a></td>
</tr>
<tr>
<td>Shape Scale</td>
<td>Shape Scale</td>
<td>3D scanning scale, home use 3D scanner to measure body and fitness progress</td>
<td>No integrated software to enable virtual fitting</td>
<td>Home use possible, targeted for mass market, user friendly</td>
<td>299 USD</td>
<td><a href="http://www.Shapescale.com">www.Shapescale.com</a></td>
</tr>
<tr>
<td>Eora 3D</td>
<td>Eora 3D</td>
<td>Hand-held 3D scanner, small scale mobile scanning device</td>
<td>No integrated software to enable virtual fitting</td>
<td>Not on the market yet but targeted to home use</td>
<td>319 USD</td>
<td><a href="https://eora3d.com">https://eora3d.com</a></td>
</tr>
<tr>
<td>Oppical</td>
<td>Structure Sensor</td>
<td>3D scanning iPad add-on, able to capture small objects and full rooms</td>
<td>No integrated software to enable virtual fitting</td>
<td>Small device for mass market</td>
<td>379 USD</td>
<td><a href="https://structure.io">https://structure.io</a></td>
</tr>
<tr>
<td>3D systems</td>
<td>Sense 2</td>
<td>Hand-held 3D Scanner to capture small scale objects</td>
<td>No integrated software to enable virtual fitting</td>
<td>Small device available for the mass market</td>
<td>349 EURO</td>
<td><a href="https://www.3dsystems.com/shop/sense/order">https://www.3dsystems.com/shop/sense/order</a></td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Model</td>
<td>Type</td>
<td>Features</td>
<td>Price</td>
<td>Website</td>
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<tr>
<td>3D systems</td>
<td>Geomagic Capture</td>
<td>Desktop 3D scanner for small-scale objects</td>
<td>No integrated software to enable virtual fitting</td>
<td>Precision on industrial level, high priced</td>
<td>20,000 USD</td>
<td><a href="https://www.3dsystems.com/3d-scanners/geomagic-capture">https://www.3dsystems.com/3d-scanners/geomagic-capture</a></td>
</tr>
<tr>
<td>Sony</td>
<td>Xperia XZ1</td>
<td>Smartphone with integrated ‘3D Creator’ scan camera and software</td>
<td>No integrated software to enable virtual fitting</td>
<td>First smartphone with 3D scan technology</td>
<td>699 EURO</td>
<td><a href="https://estore.sonymobile.com/de/sony-xperia-xz1-warm-silver-de-302569/">https://estore.sonymobile.com/de/sony-xperia-xz1-warm-silver-de-302569/</a></td>
</tr>
<tr>
<td>Ametek Creaform</td>
<td>HandySCAN 300 and HandySCAN N 700</td>
<td>Portable 3D scanner</td>
<td>No integrated software to enable virtual fitting</td>
<td>High accuracy, measures objects of all sizes but too expensive to be interesting for mass market</td>
<td>50,000 - 100,000 USD</td>
<td><a href="https://www.creaform3d.com/en/metrology-solutions/portable-3d-scanner-handyscan-3d">https://www.creaform3d.com/en/metrology-solutions/portable-3d-scanner-handyscan-3d</a></td>
</tr>
<tr>
<td>Ametek Creaform</td>
<td>Go!SCAN 50 Creaform</td>
<td>Hand-held 3D scanner for Medium and big-scale objects</td>
<td>No integrated software to enable virtual fitting</td>
<td>High accuracy but too expensive to be interesting for mass market</td>
<td>20,000 – 50,000 USD</td>
<td><a href="https://www.creaform3d.com/de/messtechnik/tragbare-3d-scanner-goscan-3d">https://www.creaform3d.com/de/messtechnik/tragbare-3d-scanner-goscan-3d</a></td>
</tr>
<tr>
<td>Shining 3D</td>
<td>EinScan Pro</td>
<td>Hand-held 3D scanner, weighs only 0.8kg, high scanning speed</td>
<td>No integrated software to enable virtual fitting</td>
<td>Small device available for the mass market</td>
<td>4,999 USD</td>
<td><a href="https://www.einscan.com/einscan-pro-plus?gclid=EAIaIQobChMIIm_2Kn-Wn1wlVVeAZCh3L9QfpEAAYAyAAEgKrvrD_BwE">https://www.einscan.com/einscan-pro-plus?gclid=EAIaIQobChMIIm_2Kn-Wn1wlVVeAZCh3L9QfpEAAYAyAAEgKrvrD_BwE</a></td>
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