5-2017

Exploring the Abilities of 3D Printing and its Viability for Consumption in the Fashion Industry

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Abstract

With the ever-evolving state of today's technology, designers and retailers in the apparel industry are seeking out new technological methods that have the capacity to revolutionize and individualize their brand, as well as meet consumer needs and preferences. An emerging technology is 3D printing, which utilizes computer-aided technology and a variety of filaments to construct an object. Though 3D printing technology offers the ability for rapid prototyping, a condensed supply chain, and a sustainable additive manufacturing process, there is question as to whether or not consumers are ready for 3D printed clothing to enter their wardrobes. In this creative study, the authors designed a 3D printed garment in order to test whether 3D printers could be used to make wearable clothing of similar characteristics to clothing typically made of fabric. A survey was then conducted on the University of Arkansas campus to measure consumer response to the project garment. Three primary factors were measured: prior exposure and interest in 3D printing, general fashion interest, and aesthetic appeal of the project 3D printed garment. Overall perceptions of the project garment as well as further use of 3D printing for the apparel industry were positive. The ability of this study to create a fully 3D printed garment as well as understand consumer response to 3D printed clothing provides insight into this emerging technology. The results warrant further research into its capabilities for fashion and that the fashion industry could move towards adopting this technology on a wider scale in coming years. The results indicate that a major transformation in ready-to-wear style is feasible and beneficial to the apparel industry because of 3D printing.

Keywords: 3D printing, fashion, consumer preference, sustainability, apparel, technology

Acknowledgments

This study would not have been possible without funding from the University of Arkansas Honors College and the Bumpers College Honors program. The authors would like to thank and recognize their contribution to this research. With funding from the Honors College, the authors traveled to a Gerber Technology Road Show in San Francisco. This conference allowed the authors to gain greater insight into what new technologies are currently being introduced into the fashion industry. In addition, this conference gave the authors the opportunity to meet a designer who designs exclusively with 3D printing, Danit Peleg. Funding from Bumpers College allowed for investment in 3D printers, which were purchased for the Apparel Merchandising and Product Development program on the University of Arkansas campus where all research was conducted. The Bumpers College grant also funded the purchase of filaments and JB welding glue, products that were necessary for completing the 3D printed top.

The authors would also like to recognize Ms. Stephanie Hubert and Dr. Mahendran Balasubramanian for their assistance and guidance throughout the duration of this research. Ms. Hubert served as the thesis mentor and played a critical role in the development of the research and the production of the 3D printed textile. Dr. Balasubramanian assisted with data analysis by running a factor analysis on the survey questions and explaining how to properly interpret the results from the survey. The authors are very grateful as well to the members of their honors thesis committee –Dr. Kathy Smith, and Mr. Lance Cheramie, and Dr. Laurie Apple. Thank you for your support and guidance with this research.

The authors would like to extend a big thank you to their supporters throughout this research study. The completion of this research would not have been possible without your considerable time and monetary donations.

Exploring the Abilities of 3D Printing and its Viability for Consumption in the Fashion Industry

Introduction

The effective use of three-dimensional (3D) printing for apparel is becoming an increasingly more important topic for the fashion industry to explore. While many industries have already made great use of 3D printing to rapidly prototype objects and create end-user products, the fashion industry looks to utilize the technology for its innovative design qualities and customization possibilities. Consumers show interest in its application for fashion and designers have already begun exploring its capabilities in jewelry, footwear, and clothing (Vanderploeg, Lee, and Mamp, 2016). However, 3D printing technology needs improvement to reach levels of efficiency, speed, and quality that the economies of scale in the apparel industry rely upon in order to be a viable tool for current manufacturing and design processes.

The purpose of this study was to test the abilities and acceptance of 3D printing in the fashion industry by designing and creating a garment that was completely 3D printed. Consumer response was then collected through the means of a pencil-and-paper survey, which measured the participant's prior exposure to and interest in 3D printing, their general fashion interest, and their opinions on the aesthetics of the 3D printed garment that was created. The creative use of 3D printing technology and statistical analysis of survey responses could provide the fashion industry with insight into the capabilities of 3D printing, how 3D printing can apply to this industry, and whether consumers are ready for this dramatic change in clothing.

Literature Review

About 3D Printing

The process of 3D printing involves using computer-aided design (CAD) to build a 3D model that is then coded and sliced into horizontal layers (Vanderploeg et al., 2016). The coded

file is then exported to the 3D printer where it extrudes a plastic resin layer by layer along the x, y, and z-axes until the 3D object is fully formed. The technology was initially introduced in the early 1980's by Charles Hull via a method he called stereolithography (Ventola, 2014). This process of 3D printing is similar to the method mentioned previously, however a liquid resin is cured by an ultraviolet light as opposed to heated filament extruding through an attached nozzle (Vanderploeg et al., 2016). The technology of 3D printing has been improving rapidly since its introduction in the 1980's (The Rise of 3D Printing: Opportunities, 2014). There are currently various types and sizes of 3D printers available on the market that are able to satisfy various consumer needs. Since its invention, 3D printing has been used for prototyping objects in large-scale manufacturing and commercial formats (The Rise of 3D Printing: Opportunities, 2014). The creation of smaller, cheaper printers has made rapid prototyping an option for smaller companies and consumers as well (The Rise of 3D Printing: Opportunities, 2014).

The technology of 3D printing has dramatically altered how several industries, including the automotive and architecture industries, approach manufacturing and prototyping. The dramatic decrease in cost of production allows artists and manufacturers to more easily experiment with customization without the consequence of a heavy bill (The Economist, 2012). Utilizing 3D printing, various industries have revolutionized their approach to product development and subsequent manufacturing by allowing design and creation to occur in the same location with lead times demanding only a few hours.

While the decreased cost of being able to prototype and produce in a single location is attractive to manufacturers, 3D printing also offers a sustainable solution for production. This timesaving mechanism of shorter lead times also decreases travel needed to transport samples and prototypes that are made elsewhere, saving fuel (Gebler, Uiterkamp, and Visser, 2014).

Additionally, there are upcoming printer materials created to be recyclable and reusable (Bioinspiration, 2015). And because the essence of 3D printing is additive manufacturing - that is, building material up to create the object rather than shaping the object away from a larger piece of material - there is much less waste involved than with traditional manufacturing techniques which create generally unusable scraps and leftovers (Gebler et al., 2014).

Application for the Fashion Industry

In recent years, designers in the fashion industry have begun to use 3D printing in their collections (Logan, 2015). Designers constantly look for new design media, and this technology offers materials with properties that substantially differ from traditional fabrics. Additionally, 3D printing has the capacity to completely revolutionize the efficiency of the design process by producing prototypes and samples within a matter of hours and minutes, as opposed to weeks and days (Berman, 2012).

There is already 3D technology being researched to explore future retailing and manufacturing possibilities in the way of 3D body scanning and 3D modeling. This 3D body scanning technology scans the entire body and generates its exact measurements (Istook, 2000). Modeling in 3D allows for a computerized visualization of what a garment will look like and how it may drape on various body shapes (Tao and Bruniaux, 2013). The combination of 3D printing, 3D body scanning, and 3D modeling offers the apparel industry a way to achieve perfect fit as a means of customization (Istook, 2000). With such 3D technologies, it is possible that future consumer experiences could include custom-made clothing with quick turnaround from manufacturers (Istook, 2000).

Fashion designers have been experimenting with 3D printing in recent years, primarily in the haute couture sector. Iris van Herpen is a pioneer among these experimental designers and

has created various collections since 2010 utilizing 3D printed materials in playful and abstract ways (Howarth, 2013). Her current collections, however, show a 3D printed application that is more for the fashion runways rather than wearable pieces that could be marketed by a fashion retailer (Appendix A, Figure 1).

Other designers are exploring ways to bring 3D printed fashion into the ready-to-wear sector of the industry. In 2011, the innovative brand Continuum Fashion began production of a 3D printed bikini that appears and behaves very similarly to a traditional fabric swimsuit (Wang and Chen 2014; Appendix A, Figure 2). Danit Peleg is another designer who seeks to design exclusively in the 3D printing medium (About Danit Peleg, n.d.). She has recently completed two collections designed and created solely from 3D printers invented for household use (About Danit Peleg, n.d.; Appendix A, Figure 3). Her designs reflect again the possibility that 3D printed clothing can supplant traditional fabric garments and be created with very little to no waste. Designers' ability to create clothing that behaves similarly to the current applications of regular fabrics offers evidence that this technology can be applied for the common consumer and warrants further research.

Limitations

Limitations in 3D printing come in the form of intellectual property rights issues and current capabilities of the technology. Designers face an issue of compromised intellectual property related to sharing their 3D design files for home use (Sedhom, 2015). Further investigation into the wants and needs of consumers in this regard will be helpful in providing an overall context for the effectiveness of 3D printing in clothing design and manufacturing. However, many enthusiasts and designers recognize that the 3D printing industry can grow from open source file sharing, which may encourage more people to learn the technology and try it out

for themselves at home. This is evidenced through websites like Thingiverse and freeware CAD programs such as 123D-Design and Blender.

In terms of the capabilities of 3D printing, the printing process is still too slow to significantly uproot current manufacturing abilities related to apparel. Depending on the type of filament that is being printed with and the size of the object, a 3D print can take several hours. While the cheaper and more coarse filaments are quicker to print with, the filaments most applicable for fashion industry require longer print times, as the speed of the print must be slowed down to ensure accuracy. In addition, the filaments currently available on the market are all a form of plastic, a material that cannot perfectly replicate the soft hand and drapability of a natural fiber, such as cotton. As 3D printing technology progresses, it is estimated that the process will become much faster and enable the printing of many different kinds of material similar to the current fabrics and fibers known today (Donovan, Gomez, Swann, Niesel, Toth, and Poole, 2016).

Further research in 3D printing technology and intellectual property right issues will need to be conducted to allow proper growth and adoption of 3D printing into the fashion industry.

Materials and Methods

Creating the Textile

In creating a wearable 3D printed garment, the authors were inspired by pioneers in 3D printing for fashion such as Iris van Herpen and Danit Peleg. For this project, creating a wearable garment meant matching commonly recognized properties of fabric garments, such as flexibility and drapability. While van Herpen's collections show the artful applications of 3D printing in haute couture or high fashion, Peleg's collections evidence the possibility that 3D printed clothing can be made to fit close to the body and hang similarly to a traditional fabric

textile.

In designing the textile, the 3D building freeware 123D-Design was used. This program was chosen based on its user-friendly interface and capabilities for creating a unique and repeatable tile. The process began by building a single tile that was then repeated upon itself to create a single sheet of fabric. This first step required extensive prototyping to ensure the tile could be seamlessly repeated and easily printed (Appendix B, Figure 1).

The printers used for this project included the Raise 3D N2 and N2 Plus 3D printers. These printers were chosen for their cost, availability, and utility. The Raise 3D printers are capable of printing with a variety of filaments, including polylactic acid (PLA) and thermoplastic polyurethane (TPU), both of which were used for prototyping and final production of the garment. Initial prototyping was done with PLA, a relatively inexpensive and hard plastic filament that is quick to print (Appendix B, Figure 1). The initial tiles were printed to compare the strength and durability of each design and its ease for being repeated. Once a tile design was settled upon, the prototype went through an additional test print in the TPU filament to gauge the needed thickness or height of the print in order to drape most similarly to a fabric (Appendix B, Figures 2-3). Though an initial millimeter height of 2.4 mm was chosen, the final height of the finished prints was 0.9 mm as further prototyping showed that a thinner height led to a greater drapability with the TPU (Appendix B, Figure 4).

Once the final tile and dimensions were decided upon, the tile was turned into a repeatable fabric that was 206.375 mm long by 206.375 mm wide by 0.9 mm high (Appendix B, Figure 5).

Printing the Textile

After the prototypes had been created and the final textile layout was chosen, the process

of printing full sheets of TPU textile on a continuous basis began. This filament was chosen for the textile because of its high elasticity and drapability characteristics (Huntsman, n.d.; Appendix B, Figure 4). This was the most desirable filament to imitate a fabric textile, as it has more rubber-like properties than stiff plastic properties. In addition, the TPU filament has the ability to be reused and repurposed through the means of melting down the plastic and re-forming it into a filament (Huntsman, n.d.). This was an especially attractive property to the authors, as it offers a viable sustainable option for 3D printing.

In the process of printing the textiles, several conflicts arose from the 3D printer settings and 3D printer functionality. Among the greatest roadblocks was the issue of clogging. Clogs occurred when the filament would stop feeding through the extruder, either due to blockage or due to a grip issue from the gear wheels feeding the filament through the nozzle. Solving this repeated issue required perfecting printer settings as well as attempting to control exogenous factors, such as too much sunlight outside that was causing the room to warm to a higher temperature than that in which the printers best operate.

Another issue that arose was the difficulty of printing with a flexible filament. TPU proved to be much more challenging than PLA to print with, as each printer setting needed to be precise to keep the filament flowing through the duration of a print. In addition, it should be noted that higher-pigmented TPU requires more precise settings (Huntsman, n.d.). Thus, after one week of troubleshooting issues that arose with printing in black TPU, it was decided to switch to clear TPU as it has no added pigmentation.

After a successful print of a full sheet of the designed textile with the clear TPU, the printer began to malfunction mechanically. The source of the malfunction came from a loose bolt in the extruder that was obstructed by filament that had oozed out of the feeding tube. The

consequence of this mechanical error was scorched filament dropping across the surface of the textile. After several attempts to fix the extruder, the clear TPU was abandoned and the authors again attempted printing with the black TPU to stay within the limitations of the timeline.

After working through countless malfunctions and settings errors, the authors were able to successfully print with black TPU for the completion of the textile. A total of 14 sheets were printed, each taking 14 hours to print. Once the sheets were printed, the construction period of the research began.

Constructing the Garment

The 3D printed fabric was cut according to a simple bodice pattern designed utilizing flat pattern techniques. Keeping ease in mind, the bodice was designed with both bodice front darts rotated to the waist. The bodice back darts were rotated to create fullness and additional ease was added to the basic sloper to assist with putting-on and taking-off the garment. Cap sleeves were designed to reach the midpoint of the front and back armscye, allowing ease in getting arms through the holes.

The sheets of 3D printed textile were glued together using JB weld plastic bonder for thermoplastics. The epoxy formula allowed for incredible strength in seaming together the textile to form one large piece of fabric. Once the entire textile was put together, the flat pattern was cut out and then seamed together using the welding glue. The bodice front was attached at the center front seam, the bodice back at the center back seam, and the cap sleeves from the midpoint of the front armscye to the midpoint of the back armscye. The side seams were attached using raw TPU filament that laced between the textiles. The side seam lacing acts as a closure and allows for ease and adjustability of the garment. No traditional sewn seams were used in the construction of the 3D printed garment.

The bodice front darts were originally intended to stay open to allow fullness, but were eventually closed to add shape to the garment. This was done by cutting out the dart space and using the welding glue to seam the triangle space closed. The hem of the top was then scalloped to follow the shape of the design in the textile. A heated modifying pen was used to smooth the scalloping. After minor edits to the scallops, the garment was complete.

Survey

To measure the viability of 3D printing in the fashion industry, a 36 question pencil-and-paper survey was created to measure consumer acceptance of this technology being integrated into clothing. The survey instrument collected data on demographics and three primary factors: Perception of 3D Printing, Fashion Interest, and Aesthetic Opinion of the 3D Printed Garment. To collect this information, IRB approval was obtained from the host institution and each participant signed a consent form (Appendix D). The demographic information collected includes age range, gender, occupation, and ethnicity. The first factor measured the subject's prior exposure to and interest in 3D printing. The second factor measured the subject's consumer purchasing behavior and their willingness to follow or create trends. The third factor measured the subject's appeal to the aesthetics of the 3D printed garment that was designed and constructed in this study.

To conduct the surveys, the 3D printed garment was displayed on a mannequin for the subjects to examine as they completed the survey. Surveys were administered for a total of three days on the University of Arkansas campus, with two days in the Arkansas Union and one day in an introductory apparel course. These survey locations were chosen in an effort to collect data from those who randomly volunteered (indicating their preliminary interest in the 3D printed garment) and those in a classroom who were administered the survey regardless of preliminary

interest. A total of 116 surveys were collected within the course of three days.

To analyze the data, a factor analysis was conducted on the data set and a t-test was used to determine whether there was a significant difference in response between male and female subjects for the three factors. Age and ethnicity results were analyzed descriptively.

Results and Discussion

Garment

The final garment looks very similar to a simple top made of lace fabric. It takes the shape of a regular cropped top with sleeves and darts for shaping around the bust. These similarities to a garment made from typical construction processes in the 3D printed garment seemed to surprise survey respondents. The final appearance of the garment was acceptable given the constraints of material, time, and knowledge of the systems of production with the 3D printer. Still, there were several issues along the way in the creation of the 3D printed garment that we acknowledge as limitations to the design.

The intent of this research was to create a wearable garment from a 3D printer, so from the beginning the goal was to supplant the typical garment construction process with 3D printing processes. Using this method, there are benefits offered by 3D printing that the authors did not take full advantage of: less waste and more inventive construction techniques. It seems that for the potential of 3D printing to truly be recognized, the whole process of designing the garment from textile to construction must be overhauled.

One limitation recognized was the material used to create the garment. TPU was ultimately used due to its flexibility, making it a more comfortable option for clothing, which must move with the wearer. This material also does not absorb any sweat or odor and can simply wipe clean. The survey respondents noted these benefits and suggested applications for

TPU in high-impact sportswear, headwear, and footwear. Yet, this material has many limitations when compared to the fabrics customers recognize today. Most notably, the finished garment in TPU still has a mostly rigid and plastic tactile property, although on average the survey respondents found the texture to be smooth and the garment likely somewhat comfortable to wear. More research is needed to explore alternative materials for creating wearable garments. The usability of these materials depends on the design of the garment and the ability of the 3D printer to work with them, as not all printers can print with all materials. As 3D printing technology improves, print materials will likely be designed to match current fabric and fiber properties more closely.

Perhaps the most efficient techniques were not used in regards to the actual construction of the 3D printed garment. Printed sheets of material were pieced together to create a fabric and flat pattern pieces were cut out of it to form the garment. This is the same process used today with regular fabric garments produced in typical mass production settings. Therefore, the concern of waste from leftover fabric after cutting is not addressed when using the same techniques for the 3D printed project garment. In addition, this study relied upon typical sewing construction techniques, albeit using a powerful bonding glue to assemble the pieces rather than a needle and thread. This process was very time-consuming and poses problems for creating a more complex garment than the simple top created for this project. However, the assembly of the 3D printed project garment without the typical sewing construction techniques is evidence that 3D printed clothing can decrease the costs for much of the current manufacturing process, namely that of thread and costly labor for sewing.

In general, there was a limited amount of time to produce the final project garment. The late arrival of the 3D printers pushed the project timeline from months to weeks so that learning

the printers, software, and materials had to be done quickly. More freedom in the timeline to further explore design and construction processes and materials would be beneficial. Therefore, it is recommended that more creative design research be conducted. Since the start of this project in the spring of 2016, several new materials have been introduced for 3D printers. One such material that would be of interest for designers is WillowFlex, which is a flexible material made from compostable raw products (Bioinspiration, 2015). The sustainability of this material offers a tangible solution to the issue of waste through apparel manufacturing.

Data

The survey data were tested for sample adequacy and significance before conducting a factor analysis. The number of respondents was 116 (sample size, N=116) and the number of survey questions was 36. To test for sample adequacy and significance of the variables, the Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity were used, respectively. The KMO results showed the sampling adequacy as 0.718, which satisfied the criterion of being greater than 0.7. In addition, the Bartlett's test of significance was reported at <0.001, which is less than the alpha of 0.05, thereby meeting the significance. All tests were performed using SPSS 23.0.

The data were then subjected to a factor analysis to determine if they could be categorized into groups that share a commonality in them. Using the Principal Axis factoring and Varimax rotation, the questions were grouped into three factors. Any question with a factor loading less than 0.4 (Ford, MacCallum, and Tait, 1986) was removed from the factor. A total of 25 questions were retained out of the original 36.

Reliability of each factor was tested using Cronbach's Alpha test. The purpose of this test is to indicate the strength of the items in each factor and the reliability of each factor if certain items were removed from the group. For this test, a score greater than 0.7 indicates

reliability (Goforth, 2015). For factor one, Perception of 3D Printing, the final Cronbach's Alpha score came to 0.897 and 11 of 12 items were retained. Factor two, Fashion Interest, scored 0.758 on Cronbach's Alpha test with 4 of 5 items being retained. Factor three, Aesthetic Opinion of the 3D Printed garment, scored 0.794 on Cronbach's Alpha and all 8 items were retained. These factors were reduced to their most reliable items and were analyzed further using averages, t-tests, and charts.

Data were entered into MS-Excel spreadsheets and divided into the three factors of Perception of 3D Printing, Fashion Interest, and Aesthetic Opinion of the 3D Printed Garment. A mean score was calculated for each respondent based on their response to each item within the factors. The data were then organized based on gender, and a t-test with unequal variances was conducted to test whether there was a significant difference in responses from male and female respondents. A p-value of 0.05 or less indicates that there is a significant difference in gender response. Perception of 3D printing proved to not differ significantly between genders. Female respondents (female respondents, N=80) reported an average of 3.81 while male respondents (male respondents, N=36) reported an average of 4, and an average response for both genders was 3.87. A high average (on a scale from 1-5) indicates that the sample population has a high interest and prior exposure to 3D printing. Fashion interest proved to differ significantly between male and female respondents, with a p-value of 0.003 being reported. Female average response was 3.68 and male average response was 3.16. A total average for this factor was 3.52, signifying that there is fashion interest in the sample. Lastly, responses for the aesthetics of the 3D printed garment did not differ significantly between genders. The average female response was 3.56, the average male response was 3.27, and the overall average for this factor was 3.33. Based on the overall average for all the three variables, the subjects showed

1. High interest in and a positive perception of 3D printing,
2. High interest in innovative fashion, and
3. A positive opinion on the aesthetics of the garment created for this study.

Additional demographic data was collected on the respondent's age and ethnicity. The ethnic groups reported were American Indian (0.86%), Asian (3.45%), Black (14.66%), Hispanic (11.21%), White (62.93%), and Other (6.03%). Age ranges reported were 18-20 (52.59%), 21-25 (35.34%), 26-30 (6.03%), 31-35 (3.45%), 36-40 (0.86%), 41-50 (0%), and 51+ (1.72%). Descriptive statistics were used to illustrate the different averages reported by each age range and ethnic group (Appendix C).

The first factor, Perception of 3D Printing, showed a relatively high average among the various age ranges and ethnic groups. The lowest response came from the American Indian ethnic group, with an average of 2.5. Fashion interest among the ethnic groups remained high, with the lowest interest average coming from the white ethnic group, reporting a 3.4 average. Fashion interest among age ranges vary across the board, and ages 26-30 reported the lowest average of 2.4. Aesthetic opinions of the garment were ranked lowest among the white ethnicity, reporting a 2.0 average. There was less variation among the age ranges, as the lowest average was 3.0.

Results from the data collection and analysis indicate that there was an adequate and significant amount of samples for this research, that the survey could be divided into three different factors, and that each of the factors was statistically reliable. The results indicate that there was only a significant difference in gender response for fashion interest (with females showing a higher interest than males), and that among these variables there was a high average rating for all the three factors.

Conclusion and Implications

The results present evidence that 3D printing can be used to create a wearable garment and consumers, on average and overall, are interested in its potential and would like to see further application of this technology in fashion. This indicates that future research is warranted, as it has shown to be a technology that consumers are ready to start seeing regularly.

Time restrictions were a major limitation in this research. Future research should have a larger timeline allotted for the design and creation process. In addition, future research should look into the abilities of creating a garment with zero waste, as this research still applied subtractive manufacturing techniques to a technology that has the capabilities to manufacture additively.

Due to the overall positive response received from the survey respondents, further research about consumer readiness and acceptance of 3D printed fashion is warranted. A smaller number of samples were collected because of the limited timeline for this study, over the course of only three days. Future research should gather a larger pool of responses by having a longer survey time and diversify survey response by expanding the sample population outside of a university campus.

The issue of 3D printing for fashion is very complex. There are many factors to consider when rethinking the whole of the apparel production system, thus this paper is unable to provide a comprehensive overview for the purposes of this creative project. However, there are a few topics which were found to be the most revolutionary to current clothing manufacturing processes and which relate to the current findings of this research: sustainability, dramatically decreased lead times, and mass customization.

Additive manufacturing processes offered by 3D printing allows for a sustainable

solution to the apparel industry. Further research into this area will allow the industry to catch up with other "green" industries and become more sustainable. A dramatically decreased lead time is also an opportunity offered by 3D printing. Studying the effects of a condensed supply chain will allow the industry more insight into how 3D printing could affect jobs and logistics. Lastly, further research is warranted into the abilities of mass customization through 3D technologies and how 3D printing can revolutionize the way consumers shop at retailers.

References

About Danit Peleg, n.d. Retrieved from http://danitpeleg.com/about-danit-peleg/

Berman, B. (2012). 3-D printing: The new industrial revolution. *Business Horizons, 55*, 155-162. Retrieved from http://dx.doi.org/10.1016/j.bushor.2011.11.003

Bioinspiration. (2015). About WillowFlex premium eco-filament. Retrieved from https://bioinspiration.eu/willowflex-faqs/

Donovan, J., Gomez, R., Swann, L., Niesel, C., Toth, B., and Poole, J. (2016, June 30). *Cotton Rapid Customisation Feasibility Study*. Report by Queensland University of Technology for Cotton Research and Development Corporation, Australia. Retrieved from http://www.insidecotton.com/xmlui/handle/1/4409

The Economist. (2012, April 21). A third industrial revolution. Retrieved from http://www.economist.com/node/21552901

Efron, A. (n.d.). *N12 Bikini* [Digital image]. Retrieved from http://www.continuumfashion.com/N12.php

Ford, J. K., MacCallum, R. C., and Tait, M. (1986). The application of exploratory factor analysis in applied psychology: A critical review and analysis. *Personnel Psychology, 39*, 291-314.

Gebler, M., Uiterkamp, A. J., and Visser, C. (2014). A global sustainability perspective on 3D printing technologies. *Energy Policy, 74*, 158-167. Retrieved from https://www.researchgate.net

Goforth, C. (2015, November 16). Using and interpreting cronbach's alpha. Retrieved from http://data.library.virginia.edu/using-and-interpreting-cronbachs-alpha/

Howarth, D. (2013, April 24). Iris van Herpen Print Shift interview. Retrieved from https://www.dezeen.com/2013/04/24/iris-van-herpen-interview/

Huntsman. (n.d.). A guide to thermoplastic polyurethanes (TPU). Retrieved from http://www.huntsman.com/polyurethanes/a/Products/Thermoplastic%20polyurethanes

Istook, B. (2000). 3-D printing: The new industrial revolution. *Journal of Textile and Apparel, Technology and Management, 1*(1). Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.125.598&rep=rep1&type=pdf

Leichman, A. K. (2015, August 13). World's first fashion collection printed at home. Retrieved from https://www.israel21c.org/worlds-first-fashion-collection-printed-at-home/

Logan, L. (2015, November). The dutch designer who is pioneering the use of 3d printing in fashion. *Smithsonian*. Retrieved from http://www.smithsonianmag.com/innovation/dutch-designer-who-pioneering-use-3d-printing-fashion-180957184/?no-ist

Retiner, D. (2015, August 13). *The 3D-printed designs of Danit Peleg*. [Digital image]. Retrieved from https://www.israel21c.org/worlds-first-fashion-collection-printed-at-home/

Sedhom, R. V. (2015). 3D Printing and its effect on the fashion industry: It's more than just about intellectual property. *Santa Clara Law Review, 55*. Retrieved from https://home.heinonline.org/

Tao, Z. and Bruniaux, P. (2013). Toward advanced three-dimensional modeling of garment prototype from draping technique. *International Journal of Clothing and Science Technology, 25*(4), 266-283.

The Rise of 3D Printing: Opportunities for Entrepreneurs: Hearing before the Committee on Small Business, House of Representatives, 113th Cong. 1 (2014). Retrieved from https://www.gpo.gov/fdsys/pkg/CHRG-113hhrg87278/pdf/CHRG-113hhrg87278.pdf

Vanderploeg, A., Lee, S., and Mamp, M. (2016). The application of 3D printing technology in the fashion industry. *International Journal of Fashion Design, Technology and Education*, 1-10. doi:10.1080/17543266.2016.1223355

Ventola, C. L., MS. (2014, October). *Medical applications for 3D-printing: Current and projected uses*. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4189697/

Wang, B. Z., and Chen, Y. (2014). The effect of 3D printing technology on the future fashion design and manufacturing. *Applied Mechanics and Materials, 496-500,* 2687-2691. doi:http://0-dx.doi.org.library.uark.edu/10.4028/www.scientific.net/AMM.496-500.2687

Appendix A

Figure 1. Iris van Herpen dress from Voltage collection, 3D printed by Stratasys (Howarth, 2013).

Figure 2. Continuum 3D printed bikini (Efron, n.d.).

Figure 3. Danit Peleg 3D printed collection (Retiner, 2015).

Appendix B

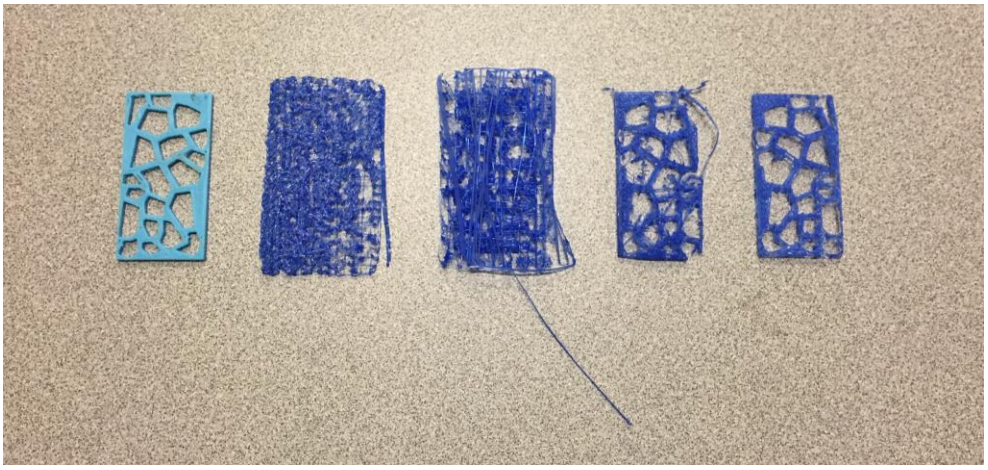

Figure 1. Prototypes of an early tile design in PLA (far left) and various settings on the 3D printer for TPU (right).

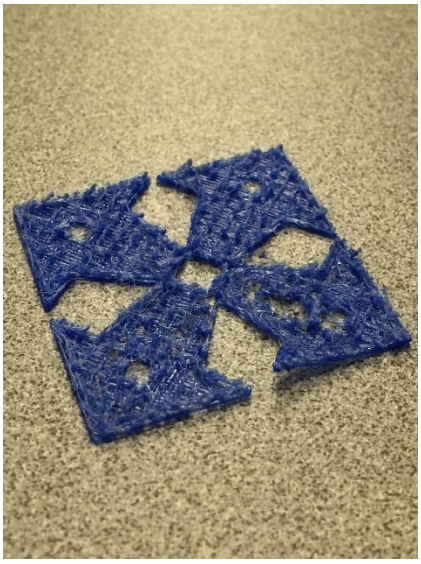

Figure 2. Prototype of design for the single tile that shows direction for final design.

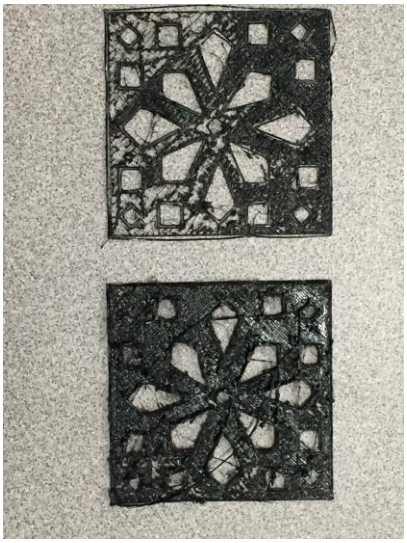

Figure 3. Prototypes of final tile design using different 3D printer settings in black TPU.

Figure 4. Drapability of final 3D printed textile.

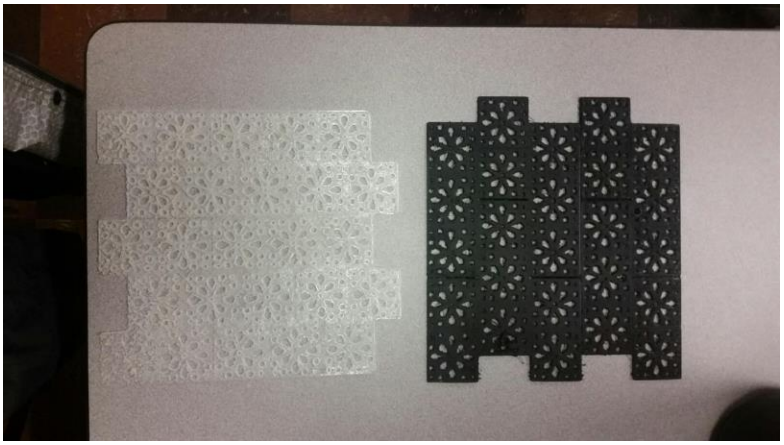

Figure 5. Comparison of initial test sheets printed in clear TPU and black TPU.

Figure 6. Final 3D printed garment.

Appendix C

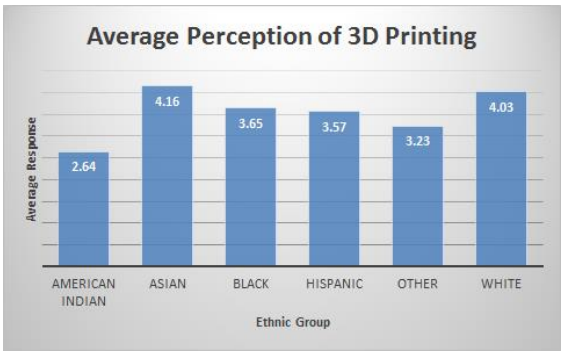

Figure 1. Factor 1 by ethnicity.

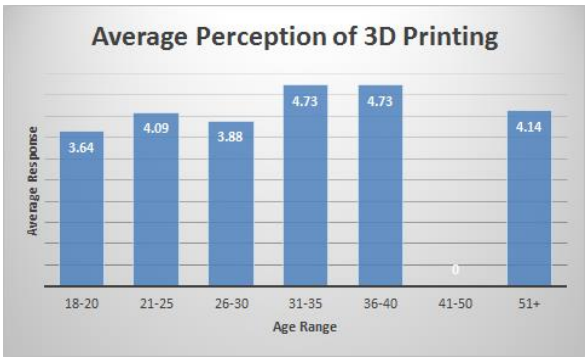

Figure 2. Factor 1 by age.

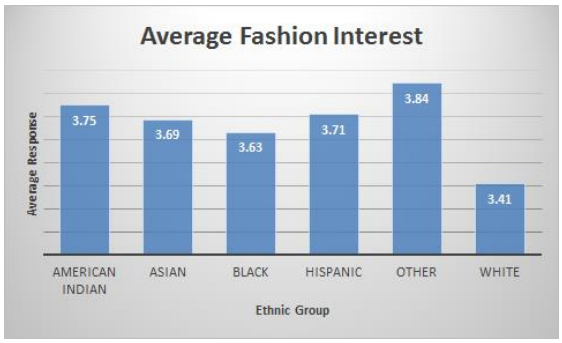

Figure 3. Factor 2 by ethnicity.

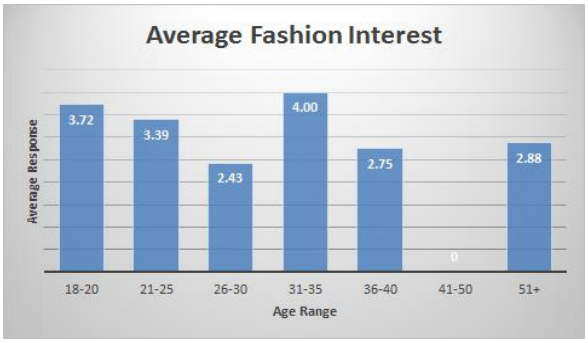

Figure 4. Factor 2 by age.

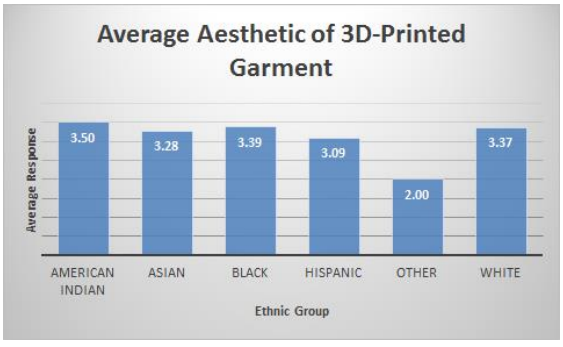

Figure 5. Factor 3 by ethnicity.

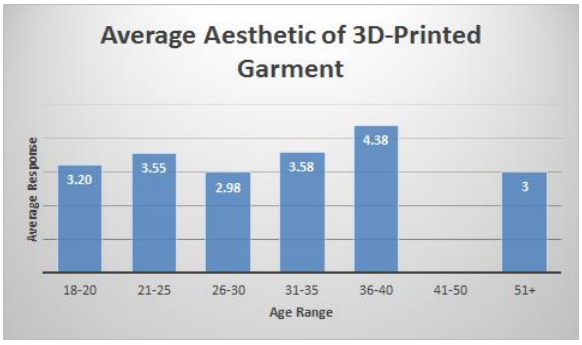

Figure 6. Factor 3 by age.

Appendix D

UNIVERSITY OF ARKANSAS

Office of Research Compliance
Institutional Review Board

February 1, 2017

MEMORANDUM

TO:	Katie Walker Laura Corral Stephanie Hubert
FROM:	Ro Windwalker IRB Coordinator
RE:	New Protocol Approval
IRB Protocol #:	17-01-384
Protocol Title:	*Exploring the Abilities of 3D Printing and its Viability for Consumption in the Fashion Industry*
Review Type:	☒ EXEMPT ☐ EXPEDITED ☐ FULL IRB
Approved Project Period:	Start Date: 01/31/2017 Expiration Date: 01/30/2018

Your protocol has been approved by the IRB. Protocols are approved for a maximum period of one year. If you wish to continue the project past the approved project period (see above), you must submit a request, using the form *Continuing Review for IRB Approved Projects*, prior to the expiration date. This form is available from the IRB Coordinator or on the Research Compliance website (https://vpred.uark.edu/units/rscp/index.php). As a courtesy, you will be sent a reminder two months in advance of that date. However, failure to receive a reminder does not negate your obligation to make the request in sufficient time for review and approval. Federal regulations prohibit retroactive approval of continuation. Failure to receive approval to continue the project prior to the expiration date will result in Termination of the protocol approval. The IRB Coordinator can give you guidance on submission times.

This protocol has been approved for 230 participants. If you wish to make *any* modifications in the approved protocol, including enrolling more than this number, you must seek approval *prior to* implementing those changes. All modifications should be requested in writing (email is acceptable) and must provide sufficient detail to assess the impact of the change.

If you have questions or need any assistance from the IRB, please contact me at 109 MLKG Building, 5-2208, or irb@uark.edu.

Exploring the Abilities of 3D-Printing and its Viability for Consumption in the Fashion Industry
Consent to Participate in a Research Study

Principal Researchers: Katie Walker and Laura Corral
Faculty Advisor: Stephanie Hubert

INVITATION TO PARTICIPATE

You are invited to participate in a research study about the viability of 3D-printed clothing being adopted into the fashion consumer industry. You are being asked to participate in this study because you represent the age range and demographic that may be most open to adopting this wearable technology.

WHAT YOU SHOULD KNOW ABOUT THE RESEARCH STUDY

Who are the Principal Researchers?

Laura Corral lccorral@uark.edu
Katie Walker kjwalker@uark.edu

Who is the Faculty Advisor?

Stephanie Hubert
skhopper@uark.edu

What is the purpose of this research study?

The purpose of this study is to measure consumer response to a 3D-printed garment that is designed and printed by Apparel Merchandising and Product Development students from the University of Arkansas. By collecting and analyzing data on consumer preference for this sustainable solution to clothing production, we will be able to provide significant research to the apparel industry that will fuel the growth for adoption and integration of this form of wearable technology.

Who will participate in this study?

Voluntary participants found on the University of Arkansas campus will be involved in this study. Volunteers must be at least 18 years old to participate, and may be students, faculty, or other. Our goal is to get at least 200 respondents.

What am I being asked to do?

Your participation will require the following:
Answer a Likert scale survey based on questions related to this 3D-printed garment and your previous exposure to 3D-printing technology.

What are the possible risks or discomforts?

There will be no risks or discomforts in this study.

What are the possible benefits of this study?

There are no possible benefits of participating in this study.

How long will the study last?

The duration of this survey should take less than 15 minutes.

Will I receive compensation for my time and inconvenience if I choose to participate in this study?

Yes, the first 50 volunteers will receive a 3D-printed souvenir for their time.

Will I have to pay for anything?

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Expires: 01/30/2018

No, there will be no costs associated with volunteer's participation.

What are the options if I do not want to be in the study?
If you do not want to be in this study, you may refuse to participate. Also, you may refuse to participate at any time during the study. Your job, grade, relationship with the University will not be affected in any way if you refuse to participate.

How will my confidentiality be protected?
All information will be kept confidential to the extent allowed by applicable State and Federal law. All signed consent forms will remain in a locked box and data will only be run on the anonymous survey response.

Will I know the results of the study?
At the conclusion of the study you will have the right to request feedback about the results. You may contact the faculty advisor, Stephanie Hubert at skhopper@uark.edu or the Principal Researchers, Laura Corral at lccorral@uark.edu or Katie Walker at kjwalker@uark.edu. You will receive a copy of this form for your files.

What do I do if I have questions about the research study?
You have the right to contact the Principal Researcher or Faculty Advisor as listed below for any concerns that you may have.

Laura Corral
lccorral@uark.edu

Katie Walker
kjwalker@uark.edu

Stephanie Hubert
skhopper@uark.edu

You may also contact the University of Arkansas Research Compliance office listed below if you have questions about your rights as a participant, or to discuss any concerns about, or problems with, the research.

Ro Windwalker, CIP
Institutional Review Board Coordinator
Research Compliance
University of Arkansas
109 MLKG Building
Fayetteville, AR 72701
479-575-2208
irb@uark.edu

I have read the above statement and have been able to ask questions and express concerns, which have been satisfactorily responded to by the investigator. I understand the purpose of the study as well as the potential benefits and risks that are involved. I understand that participation is voluntary. I understand that significant new findings developed during this research will be shared with the participant. I understand that no rights have been waived by signing the consent form. I have been given a copy of the consent form. I verify that I am at least 18 years old.

Signature _____ Date _____

IRB #17-01-384
Approved: 01/31/2017
Expires: 01/30/2018

University of Arkansas 3D-Printed Clothing Research Survey

Researching the topic, "Exploring the Abilities of 3D-Printing and its Viability for Consumption in the Fashion Industry"

The following questions pertain to demographics. Please check the box that best describes you for the following categories:

Select your age:
___18-20 ___21-25 ___26-30 ___31-35 ___36-40 ___41-50 ___50+

Gender:
___Male
___Female

Occupation:
___Student (Please specify your class standing and field of study: _____)
___U of A Faculty (Please specify your department: _____)
___Other (Please specify your occupation: _____)

Ethnicity:
___American Indian or Alaska Native
___Asian
___Black or African American
___Native Hawaiian or Pacific Islander
___White
___Hispanic or Latino
___Other (Please specify: _____)

The following questions aim to determine your exposure and willingness to adopt 3D-printed technology. Please indicate on the scale the degree to which you agree or disagree with each statement.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
1. I have been exposed to 3D-printed items in the past.					
2. I have a positive perception of 3D-printing and its capabilities.					
3. I find 3D-printing to be a technological fad.					
4. I find 3D-printing to be a generally useful technology.					
5. I would like to own a 3D-printer.					
6. I consider myself to be concerned with environmental sustainability.					
7. I believe that 3D-printing is environmentally sustainable.					
8. I believe that 3D-printing has a positive environmental impact.					
9. I believe that 3D-printing can be useful in clothing manufacturing and production.					
10. I consider myself to be innovative with my fashion choices.					
11. I like to follow fashion trends in my own clothing.					
12. I prefer to purchase clothing from boutiques.					
13. I prefer to purchase clothing from mass retailers.					

14. Generally speaking, I do not mind spending a significant portion of my income on clothing.					

15. I am more likely to spend a large sum of money on clothing if it is a unique item.					
16. I would purchase a 3D-printed garment.					
17. I would be more likely to purchase a 3D-printed garment if the 3D-printed elements were minimal, such as buttons.					
18. I find this garment visually appealing.					
19. I find this garment to be unique.					
20. I would wear this garment as it is presented on the model.					
21. I find the texture of this garment to be smooth.					
22. I find the texture of this garment to be rough/coarse.					
23. I find this garment to have a sharp texture, particularly around points and edges.					
24. I find this garment to have a soft texture.					
25. I would wear this garment if it had a different texture.					
26. I like the color of this garment.					
27. I would wear this garment if it were in a different color.					
28. I think this garment would be comfortable.					

29. I would be concerned with how to care for this garment.					
30. I would be more likely to purchase 3D-printed garments from a boutique than a mass retailer.					

31. I would be more likely to purchase 3D-printed garments from mass retailers than a boutique.					
32. I would be willing to pay more for a 3D-printed garment than a fabric garment.					
33. I would *only* be willing to purchase a 3D-printed garment if it cost less than a fabric garment.					
34. I would like to see more 3D-printed application in the fashion industry.					
35. I can imagine seeing 3D-printed clothing in my favorite fashion retailers.					
36. I would like to see 3D-printed clothing in my favorite fashion retailers.					

If you have any additional comments regarding the garment or your answers to the questions above, please use the space below.

_____

_____

_____

_____

_____

Your survey is complete. Thank you for your participation.