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Exploring the abilities of 3-D printing and its viability for consumption in the fashion industry

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Abstract

The fashion industry encounters its most general difficulties regarding cost of samples, lead time, sustainability, and fit. An emerging technology that could solve these issues is 3-D printing, which utilizes computer-aided technology and a variety of filaments to construct an object. Though 3-D printing technology offers the ability for rapid prototyping, a condensed supply chain by way of creating samples domestically rather than internationally, and a sustainable additive manufacturing process that results in manufacturing with zero excess material, there is question as to whether consumers are ready for 3-D printed clothing to enter their wardrobes. The purpose of this study was to construct a 3-D-printed garment and measure consumer response to the application of this technology to ready-to-wear clothing. Wearability was achieved with the 3-D-printed garment, meaning it mirrors a traditional ready-to-wear garment. The survey instrument measured three factors: perception of 3-D printing, fashion interest, and opinions of the 3-D-printed project garment. Data were analyzed using a *t*-test for male versus female responses and descriptive statistical methods were utilized to report means and compare responses on the three factors from each age group and ethnicity. Overall the responses for all three factors were positive. The results of this research indicate that a major transformation in ready-to-wear style is feasible and beneficial to the apparel industry because of 3-D printing.

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Meet the Student-Authors

Laura Corral

I was born in Cincinnati, Ohio and moved around quite a bit after that, but have been settled in Fayetteville, Arkansas for the past 14 years. I graduated from Fayetteville High School in 2013. I began my education at the University of Arkansas by taking advanced German classes on campus my senior year of high school. Since then, I have pursued a double major in Apparel Merchandising and Product Development (AMPD) and German, and a minor in International Business. I have been awarded Bumpers Honors College and Honors College grants to fund my research and to help bring 3D printers to the AMPD program. Through this research, I was able to travel to San Francisco to meet fashion technology leaders and learn about the direction in which fashion is going. I am interested in pursuing sustainable fashion in a global market and am thankful for the mentorship of Ms. Stephanie Hubert in encouraging me to pursue a sustainability-linked research topic. I would like to recognize Dr. Mahendran Balasubramanian in contributing to the statistical analysis in my research. I would also like to thank my honors thesis committee for their assistance in this research: Dr. Kathy Smith, Mr. Lance Cheramie, and Dr. Laurie Apple. This research could not have been completed without their guidance and without the support from the Dale Bumpers College and the University of Arkansas.

Kaitlyn Walker

I am from Plano, Texas and graduated with honors from Plano Senior High School in 2013. I chose the University of Arkansas for its well-rounded Apparel Merchandising and Product Development program, studying all facets of the apparel and retail industries along with my Marketing minor. My ultimate dream is to be self-employed and sell my own designs. I graduated with honors in May 2017 and look forward to beginning my career in fashion design or product development. During my time at the U of A, I was a member of Phi Upsilon Omicron honor society, an appointed officer for Kappa Delta sorority, a member of the Association of Apparel Merchandising and Product Development, and participated in the Walmart Mentor Circle through the AMPD program.

I am thankful to Dr. Leslie Edgar for allowing me to join the Bumpers College Honors Program as a junior. During my senior year I was excited to take part in this creative study on 3D printing for a fashion application. This project taught me about design exploration in a rising technology that could have a great impact on my industry and my interests in innovative design and sustainability. I would like to thank my mentor, Stephanie Hubert, for encouraging me to join the Honors Program and bring this exciting field of study to our department and for her hands-on approach in assisting my project partner and me throughout this research. I would also like to recognize Dr. Mahendran Balasubramanian for the considerable time and energy he volunteered to the data collection and interpretation portion of this project. I would like to thank my honors thesis committee for their support and encouragement of this project: Dr. Kathy Smith, Lance Cheramie, and Dr. Laurie Apple. Lastly, a big thank you to my student research partner Laura Corral.

Introduction

With the ever-evolving state of today's technology, designers and retailers in the apparel industry are seeking out new technological methods to revolutionize and individualize their brand as well as meet consumer needs and preferences. An emerging technology is 3-D printing, which utilizes computer-aided technology, filaments, and heated extruders to create an object from a computerized vector drawing. The technology of 3-D printing has been referred to as the "third industrial revolution" because of its potential to dramatically shorten the supply chain, utilize sustainable additive manufacturing techniques, and maximize customization possibilities through inexpensive rapid prototyping (Markillie, 2012; Istook, 2000; The United States Congress, 2014).

Designers have already begun exploring the capabilities of 3-D printing for jewelry, footwear, and clothing (Vanderploeg et al., 2016). A pioneer in this area is Iris van Herpen, who has utilized 3-D printing in her haute couture collections since 2010 (Howarth, 2013). While her collections show the artistic and avant-garde expressions of 3-D printing for fashion, designer Danit Peleg has completed collections created solely from household 3-D printers (Peleg, n.d.). Peleg's more wearable garments reflect the possibility that this medium for clothing production could supplant traditional fabric garments and reduce waste. However, there is question as to whether or not consumers are ready for 3-D-printed clothing to enter their wardrobes. Research in this area of consumer preference toward 3-D printing for fashion has not been conducted. This study aims to test the authors' prediction that consumers will have a positive perception of 3-D printing being integrated into ready-to-wear clothing.

Materials and Methods

To create a 3-D-printed textile for garment assembly, several repeatable square tiles were designed using the 3-D building freeware 123D-Design (Fig. 1). To test each tile's strength and repeatability, prototyping was conducted on the Raise 3-D N2 and N2 Plus 3-D printers, first in polylactic acid (PLA) and then in thermoplastic polyurethane (TPU). The PLA was useful for quick prototyping as a low-cost hard plastic filament, and TPU was chosen as the final print material due to its flexibility and rubber-like properties. The final tile was then repeated at a half-step pattern to create a single sheet of textile, and 13 sheets in total were printed measuring 206.375 mm long by 206.375 mm wide by 0.9 mm high (Fig. 2). These sheets were then combined using JB Weld Plastic Bonding Glue to create a full piece of 'fabric', which allowed for cutting out the flat pattern pieces (Fig. 3). The pattern pieces were then assembled into a top using the welding glue, and TPU filament was used to

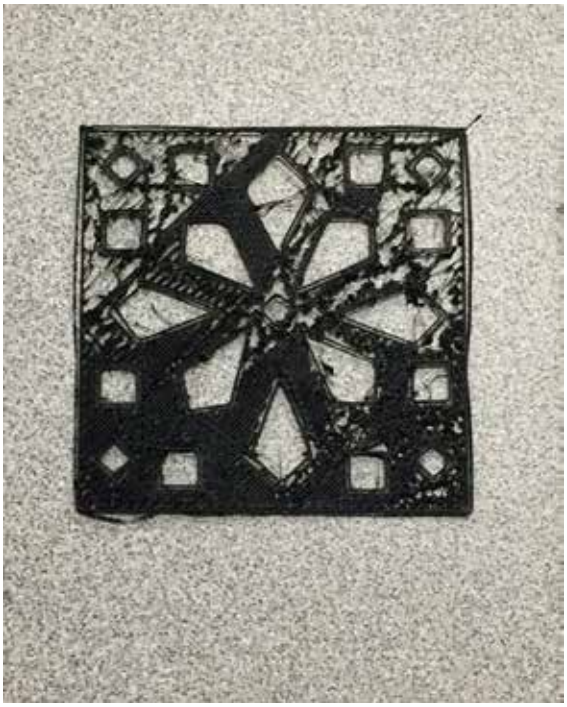

Fig. 1. Final tile designed by the authors, printed in thermoplastic polyurethane (TPU) filament.

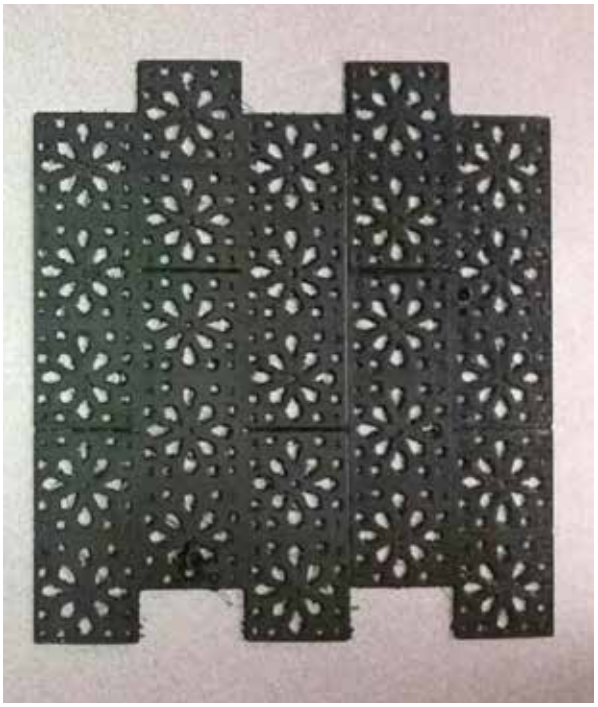

Fig. 2. Sheet of 3-D printed textile in thermoplastic polyurethane (TPU) filament.

lace up the side seams, which served as the closure for the garment. No traditional stitches were used in creating the garment.

To test the viability of 3-D-printed clothing in the apparel marketplace, a 36-question 5-point Likert scale survey was created to measure consumer response to the project garment and was administered on the University of Arkansas campus (with two days in the Student Union and one day in an introductory apparel course). The 3-D-printed garment was displayed on a mannequin for the subjects to examine as they completed the survey.

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 and therefore met sample adequacy. In addition, the Bartlett's test of sphericity was reported at <0.001, which is less than the alpha of 0.05, thereby meeting significance. All tests were performed using SPSS 23.0 (SPSS Inc., Chicago, Ill.).

A factor analysis was run to divide the 36 survey questions into groups to assist with the data analysis. The factor analysis divided the questions into three groups: prior exposure to 3-D printing, innovative fashion interest, and opinions of the aesthetics of the 3-D-printed project garment. Each factor was then tested for reliability using Cronbach's Alpha test and a total of 25 out of 36 questions were retained within the factors to ensure the strength of each group of questions. Data were entered into MS-Excel spreadsheets and divided into the three factors, and 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 between male and female respondents for each factor. In conducting the *t*-test, a *P*-value of 0.05 or less was used to indicate a significant difference in gender response. Additional descriptive statistics were utilized from the data means to illustrate the range in responses received from various ethnic and age groups. These demographic questions sought to understand what ethnic groups and age ranges were participating in the survey. The ethnic groups reported were American Indian (0.86%), Asian (3.45%), Black (14.66%), Hispanic

Fig. 3. The authors assemble 3-D printed top with welding glue.

(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%). These ranges were chosen based on the authors' general understanding of the youthful demographic makeup of the University of Arkansas campus.

Results and Discussion

3-D Printed Top

The final 3-D-printed garment achieved the project goal of wearability (Fig. 4). The design allows it to look very similar to a traditional fabric top made of lace, and some respondents even likened the TPU to leather when given the opportunity to leave additional comments on the survey. Additionally, the flexibility of the TPU allowed for the garment to have slight drape and it fit the body well with dart shaping.

The intent of this research was to create a wearable garment from a 3-D printer, so from the beginning the goal was to supplant the typical garment construction process with 3-D printing processes. Using the 3-D printing method, there are benefits offered by the technology of which the authors did not take full advantage: reduced waste and more inventive construction techniques. It seems that for the potential of 3-D printing to truly be recognized, the whole process of designing the garment from textile to construction must be overhauled. In addition, though TPU provided several tactile benefits during construction of the garment, 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. Further 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 3-D printer to work with them, as not all printers can print with all materials. As 3-D printing technology improves, print materials could be designed to match current fabric and fiber properties more closely.

There are also some important considerations that the apparel industry should take in adopting 3-D technologies. For one, 3-D printing offers a sustainable solution to waste in the apparel industry by being an additive manufacturing process. Designers and manufacturers should research the abilities of 3-D printing to create a garment with zero waste; whereas this study applied subtractive manufacturing clothing production techniques in cutting out pattern pieces from a larger textile and, therefore, created waste from the scrap pieces of material. In addition, 3-D printing also offers the opportunity for a dramatically decreased lead time. Studying the effects of a condensed supply chain with minimal to no sample lead time will provide the industry more insight into how 3-D printing could affect jobs

Fig. 4. Final 3-D printed top.

and logistics. Lastly, further research is warranted into the possibility of mass customization through the adoption of 3-D printers for manufacturing and home use, and how that can revolutionize the way consumers shop at retailers.

Survey

The authors' prediction that consumers will have a positive perception of 3-D printing being integrated into ready-to-wear clothing was supported by the data. Based on the overall average for all the three variables, the subjects showed:

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

The sample size for this project allowed for a *t*-test assuming unequal variances on the gender demographic. The results of the *t*-test between male (31% of sample) and female (69% of sample) respondents showed a significant difference (*P*-value = 0.003) in the responses for the second factor: innovative fashion interest. On a scale of 1–5, female average response was 3.68 and male average response was 3.16. A total average for innovative fashion interest was 3.52, signifying that there is fashion interest in the sample. Since the data from this study show that women reported a higher interest in innovative fashions than did men, the authors suggest further integration of 3-D printing into women's apparel first as this segment may be more willing to try new technologies and innovations in their clothing, according to the results from the survey data. In comparing means, there was not a significant difference in response between the ethnic groups nor between age ranges. This could be due to the homogenous nature of the age demographic data reported: 87.93% of the respondents were in the 18–25 age range. No meaningful data can be reported based on those demographics. Averages for each factor are shown in Fig. 5.

Conclusions

The results present evidence that 3-D 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. Because the results of this study show 3-D printing to be a technology that consumers are ready to start seeing regularly, future research should be conducted to measure consumer preference and design wearable garments. Future research, however, 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. Additionally, with the large positive impact that this technology could have on sustainability, dramatically decreased lead times, and mass customization, future research should explore the total effects and integrations of utilizing new 3-D processes to test fully the viability of the apparel industry adopting this technology on a wider scale.

Acknowledgments

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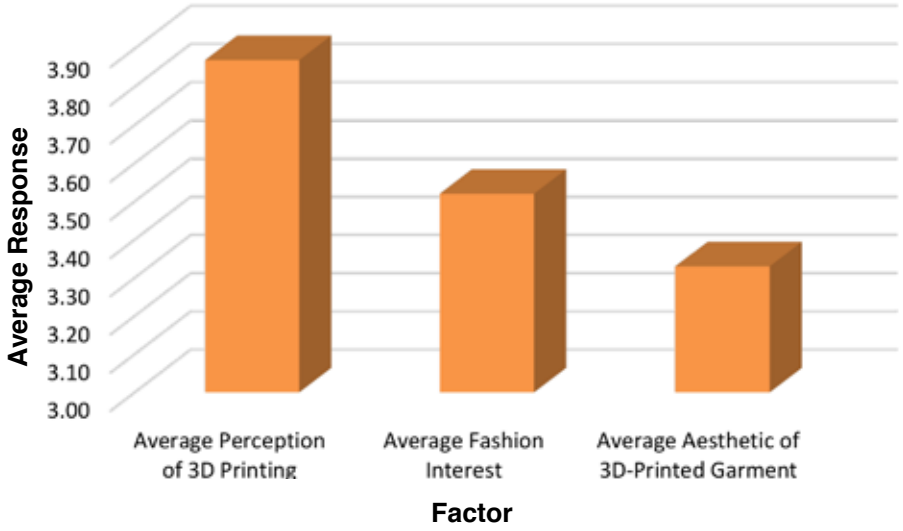

Fig. 5. Graph depicting average survey responses based on 5-point Likert scale (n = 116).

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