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3D Printed Wearable Apparel Products and Consumer Perceptions

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Abstract: In this article, consumer requirements for clothes printed on a 3D printer are studied. n this, the philosophies of the clothes created by 3D printers of different designers were compared and the theory of offering them to consumers was developed.

Keywords: 3D printed, functional, consumer, uniqueness, garment, mobility.

Existing 3D printed wearable apparel products have demonstrated improvements in both aesthetics and functionality. Designers have provided demonstrations to indicate how their 3D printed wearable apparel products meet users' needs, in terms of aesthetics, flexibility of their design, comfort, and customization. However, the evaluations of the 3D printed wearable apparel products were mainly from the perspective of designers and news reporters, with a few of them reporting on users' evaluations on how the designs meet users' needs. In addition, it is also necessary to evaluate 3D printed wearable apparel products in a more systematic way with respect to specific user needs that may need to be met. This study will adopt the Functional Expressive Aesthetic consumer needs model to examine whether users' perceptions of 3D printed wearable apparel products influence users' satisfaction [1].

FEA consumer needs model. The FEA consumer needs model was proposed by Lamb and Kallal (1992) to evaluate functional, expressive, and aesthetic considerations to identify the needs consumers have from apparel desig. (Figure 14). In the FEA model, the target consumer or user is in the center of the model. As a user-centered model, it considers the clothing needs from the user's end. Consumers are surrounded by culture, which indicates that culture plays the role of mediator between the user and the needs they have from wearable apparel products (Lamb & Kallal, 1992). A successful wearable apparel product should be in consistent with a user's culture in order to provide corresponding designs. Further, three categories of needs are identified to influence users' perceptions of wearable apparel products; they are functional needs, expressive needs, and aesthetic needs. Functional needs consider utility, i.e., how the wearable apparel product meets the needs of the user to perform specific tasks. Expressive needs concern communicative and symbolic aspects of wearable apparel products, in other words, the wearable apparel product should match users' status and self-image. Aesthetic needs relate to the design and beauty of the wearable apparel products .

Aesthetic perceptions of the 3D printed wearable prototype. By applying Lamb and Kallal's (1992) FEA model, in this study, aesthetic needs depend on user's perceived aesthetics of the 3D printed wearable apparel product. The current study evaluates the aesthetic perceptions for a 3D printed wearable prototype based on perceived novelty and beauty of the 3D printed wearable prototype [2].

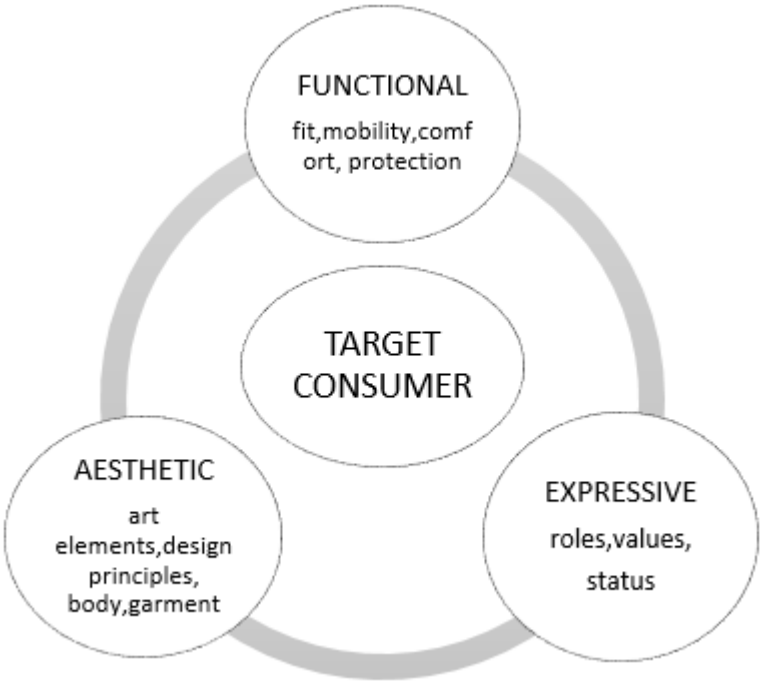

Figure 1. Consumer needs model

Novelty. Novelty refers to "the degree to which a product is seen as different from a prototypical object". Novelty has a significant influence on users' visual perceptions and may further lead to positive aesthetic judgment and product satisfaction. Novelty in the beauty of 3D printed wearable apparel products provides new aesthetic format of textile patterns, which is unusual in traditional fabrics. For example, Nervous System's (2014) kinematics dress is composed of thousands of pieces of 3D printed triangular panels; it was innovative as no traditional garment was. Most current 3D printed wearable apparel products are not as comfortable as traditional ones, however, novelty in new forms of 3D printed structures/patterns may lead to a greater visual impact, and compensate for the weakness in functions. Thus, novelty may enable users to allow future functional improvements, and still positively influence users' satisfaction. Those comments implied that the design was innovative, they were very interested in an novel 3D printed wearable apparel product to be available in the near future. Even though the kinematics dress cannot meet the full functionality of a dress in terms of comfort, the novelty of the new aesthetic forms of garments may still lead to high levels of user satisfaction with 3D printed wearable apparel product. Novelty in 3D printed wearable apparel product increases future expectations of 3D printed wearable apparel products among users and leads to users feeling more satisfied with 3D printed wearable apparel products.

Beauty. According to Reber, beauty is defined as "a pleasurable subjective experience that is directed toward an object and not mediated by intervening reasoning. Humans have the desire for beauty, thus, beauty is one of the most important aesthetic considerations in designing functional garment. Existing studies of functional garments supported users' needs for beauty in functional garments. For example, Stokes and Black (2012) found that adolescent girls with disabilities had specific aesthetic needs for functional garments in terms of color and style, one of them provided detailed descriptions of her dream coat: "A brown pea coat with two buttons on the left side and the openings on the right." Jin and Black's (2012) study of aesthetic needs of young male tennis players indicated that these tennis players have a 'beautiful tennis garment' in their minds; for

example, 73% of participants preferred T-shirt style shirts, with specific preferences for round necklines, set-in sleeves, and hip length. Through customization, 3D printed wearable apparel products enable beauty in different colors, styles, and textile structures/patterns. For examples, Danit Peleg's 3D printing garment collections provided 3D printing garments in combinations of different colors, styles (shirt, short, and long dresses, etc.), and textiles patterns. Thus, users could select and customize by choosing from these elements to form 3D printing garments that meet their aesthetic needs. Some aesthetic-related evaluations concerning 3D printed wearable apparel products are also revealed in the comments of news reports or YouTube demonstration videos. For example, in reference to the kinematics dress by Nervous System, from Shapeways (2014), there were comments such as: "This is beautiful." and "That's amazing. Dress looks great." The commenters were impressed by the ability of 3D printing technology to provide 3D printed wearable apparel products with beautiful appearance and aesthetic elements[3].

Expressive perceptions of the 3D printed wearable prototype. By applying Lamb and Kallal's (1992) FEA model, in this study, expressive needs depend on user's perceived expressive qualities of the 3D printed wearable apparel product. The current study evaluates the expressive perceptions for a 3D printed wearable prototype based on perceived coolness and uniqueness of the 3D printed wearable prototype. Coolness. Coolness is an abstract concept, and has several dimensions. Coolness is defined as "trendy, hip, appealing, fascinating and attractive," and people may "experience positive emotions ranging from pleasant surprise to excitement" when perceiving a cool product. Holtzblatt (2010) concluded that coolness of a product is a game changer that may disrupt the market since it is beyond aesthetic appeal or surprise, and has a far-reaching influence on our daily life. A cool product is not necessary to be functional, but it is usually novel and trendy when compared to mainstream products. It importantly provides a unique user experience and enables users to express their personalities (Goodman, 2001; Holtzblatt, 2010). Sundar, Tamul and Wu (2014) indicated that a cool product is not only cool itself, but could provide "joy of life" . In other words, the owning and using of a cool product allows users to feel cool and show their identities, leading to users' satisfaction. For example, Apple has several very successful cool devices, the most notable is perhaps the classic iPod. The iPod embodied many properties of cool products: large memory to store more music, color screen interface, unique wheel-shaped touchpad and simple package design. The integration of these features made iPod cool when compared to other products in the mainstream market, allowing it to provide a unique user experience . In terms of 3D printed wearable apparel products, due to the application of the innovative 3D printing technology into apparel design, people perceive them to be cool, innovative, and feel enthusiastic about the difference that 3D printed wearable apparel products can make in the mainstream market. For example, in response to Peleg's (2015) how to 3D print clothes at home, there were some comments such as: "It's fashion for the future. Pretty cool", "That is so cool!", "this is some cool futuristic looking stuff". Some commenters even expressed the idea that owning such 3D printing clothes, would let them feel cool and different from others[4].

Uniqueness. Uniqueness is defined as the degree to which users perceive a product is functional or aesthetic different from similar products (Sundar et al., 2014). Consumers, in some extent, tend to obtain products or services that few others possess. Lynn and Harris (1997) articulated that a unique product should meet one or more of the four features: (1) limited in number, (2) innovative, (3) highly

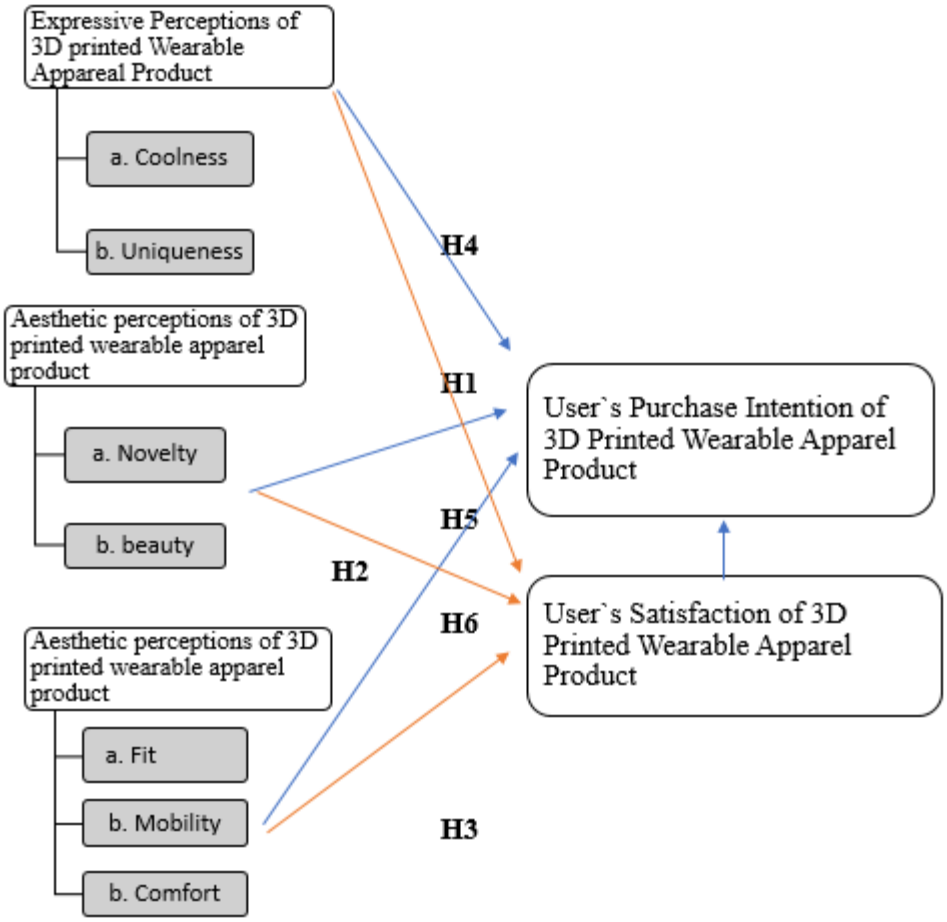

Figure 2. Model of users' perceptions of 3D printed wearable apparel product.

customized, and (4) sold in small/unique stores (limited access). First, in terms of limited in number, 3D printed wearable apparel products are just emerging, and hence only a few people, like models in fashion show, fashion designers own 3D printed apparel. Second, in terms of product innovativeness, 3D printed apparel constitute an innovative product, emerging from the innovative 3D printing technology. Third, in terms of customization, customized products are different from regular mass-manufactured products, and they are relatively unique. 3D printed wearable apparel products can be highly customized to fit specific body size and aesthetic preference (Howarth, 2013). Lastly, in terms of being sold in small/unique stores (limited access), currently most of 3D printed apparel are being sold in a very limited array of stores, such as innovative startups/online stores and individual designers that are able to produce 3D printed wearable apparel products. The desire for the unique 3D printed wearable apparel products enables users to evoke pleasure by being different from others, and allowing them to shape their identity and social status. These affordances have the potential to lead to enhanced satisfaction with 3D printed apparel.

Functional perceptions of the 3D printed wearable prototype. By applying Lamb and Kallal's (1992) FEA model, in this study, functional needs depend on users' perceived functions of the 3D printed wearable apparel product. The functional perceptions of 3D printed wearable prototype can be evaluated based on fit, mobility, comfort, and donning/doffing of the 3D printed wearable prototype. Fit. Generally, garment fit refers to "a harmonious relationship of clothing to the human body". Dickson and Pollack (2000) indicated that fit is one of the two crucial factors (the other one is comfort) to influence user's satisfaction with sports clothing and physical performance. Chen, et al. (2010) further argued that apparel fit could be evaluated by apparel appearance and the user's perceptions of fit. Apparel appearance depends on the apparel designer's perceptions of fit, whereas the current study focuses on user's perceptions to

understand apparel fit from different perspectives. User's perceptions of fit depends on how well a piece of apparel is suited to the body. Several previous studies emphasized the influence of garment fit on user satisfaction. They evaluated users' perceptions of fit based on different functional needs and assessed key body measurement areas. For example, Kidd's (2006) study focused on garment fit needs of four women with disabilities. Dress length was identified as a major fit problem, as it is difficult for users to use assistive tools if a dress is too long. Stokes and Black's study focused on garment fit of adolescent girls with disabilities on several garment types. Their findings suggested that garment fit influences users' satisfaction; concerns are specifically in areas such as shoulder fit of dresses and waist fit of pants. A study from Jin and Black (2012) indicated that 37% of tennis player participants were not satisfied with the fit of tennis clothing because it did not account for the size of their bodies. In terms of 3D printed wearable apparel products, fit is also emphasized by apparel designers. For examples, the kinematics dress from Nervous System (2014) is a custom-fit dress; it used an application called Kinematics Cloth to simulate the size of the 3D printing dress to fit a specific body size. Body fit is one of the important features of designer Danit Peleg's jacket, the first 3D printing garment using FDM printers for sale online. The bomber jacket is customizable by using a special virtual fitting app called Nettelo (Mau, 2017). By taking advantage of customization, designers highlighted body fit as one of the key features of their 3D printed wearable apparel products. However, there is a research gap in that limited study focused on fit satisfaction of 3D printed wearable apparel products from the users' perspective [5].

Mobility. Mobility has a close relationship with fit during body movement, and functional garment design should meet specific mobility requirements for different tasks so that body movements are not hampered). Thus, mobility is another important dimension for evaluating functional garments. Existing studies confirmed the influence of mobility of a functional garment on user's satisfaction. For examples, Wheat and Dickson (1999) indicated that knit fabrics in shoulders and sufficient back length in female golfers' shirts enables female golfers to swing without restrictions. Jin and Black's (2012) study confirmed the influence of mobility on male tennis players' satisfaction with functional garments. Specifically, when serving tennis balls, male tennis players experienced high levels of dissatisfaction with the amount of sleeve fullness and the amount of fabric on the shoulders. A study of rock climbing pants from Michaelson indicated that rock climbing pants should be diverse in order to meet mobility requirements of different techniques and routes, thus leading to positive satisfaction ratings. In terms of 3D printed wearable apparel products, mobility is also emphasized by apparel designers. For example, Nervous System's kinematics dress used interconnected hinges to connect nylon pieces, thus such structures enable flexibility and comfort in body movement. While designer Masaharu Ono designed a 3D printing knitted vest called Amimono, which mimics the flexibility of woven fabrics. Ono indicated that there were limited exhibitions of current 3D printed wearable apparel products, while his Amimono can actually be put on a human body for daily wear, because such 3D printing woven fabrics are elastic in order to accommodate body movement. However, there is a research gap that limited study focused on mobility satisfaction of 3D printed wearable apparel products from users' perspectives.

Comfort. Comfort is a neutral state that exists when an individual does not feel pain or discomfort when wearing a garment. Comfort is considered a quality aspect to evaluate functional garment performance and influences a user's satisfact. Satisfaction in fit and mobility of functional garments do not necessarily lead to satisfaction in comfort, as comfort is subjective and has three main comfort divisions: psychological, physical, and physiological. Psychological comfort is related to an individual's roles, values, and social being. Physical comfort concerns sensorial and tactile comfort when garment fabrics touch the user's body or skin. Physiological comfort considers body thermal regulation and the balance of body heat. This study focused on physical comfort when 3D printed structures interact with the human body/skin. Physical comfort highlights the interaction between garment fabrics and skin. By touching garment fabrics, tactile sensations like warmth, prickliness, stiffness, and roughness are perceived.

Existing studies confirmed the influence of physical comfort of a functional garment on users' satisfaction levels. For example, Stokes and Black's (2012) study found that adolescent girls with disabilities felt discomfort with excess fabric while confined to a wheelchair. In terms of 3D printed wearable apparel products, even though 3D printed structures are not as comfortable as traditional fabrics, apparel designers and researchers are making efforts to explore new properties that would make 3D printed structures more comfortable. For examples, a UCLA-led research team designed a 3D printed lattice by manipulating the internal structure of the material using the SLS method. The new material was soft and porous. Electroloom, a 3D printing technology company, created a textile that is soft and feels like a form of suede. From designers' point of view, the new 3D printed structures were improved to be more comfortable than previous ones, in terms of physical comfort (e.g., softer and smoother). Some physical comfort–related evaluations concerning 3D printed structures could be found in the comments of news reports or YouTube demonstration videos. For example, Shapeways (2014) posted a video on YouTube demonstrated the manufacturing process of the kinematics dress by Nervous System. Some comments below reflected user's concerns with the physical comfort of 3D printed structures.

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