Integrating Three-Dimensional Printing with Shape Memory Material: A Renovation of Mass Customization in the Fashion Industry

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Background and Purpose: Three-dimensional (3D) printing technology has urged the fashion and apparel industry to undergo a fundamental shift from mass-production to mass customization, owed to its characteristics that overcome the conflict between efficiency and flexibility on the configurational dimension in the traditional manufacturing setting (Berman, 2012; Lowson, 2001; Zipkin, 2001). However, the current capabilities of 3D printing remain far behind the expectations for additive manufacturing technology (Tibbits, 2014). Thus, four-dimensional (4D) printing technology has emerged, having gained considerable interest recently due to its emphasis on independent shape transformation, when an object confronts a particular stimulus in the post-printing process. This function is also known as "self-assembling," "self-reconfiguring," and "self-adaptability" (Momeni, M.Mehdi Hassani.N, Liu, & Ni, 2017).

At the core of 4D printing technology are three key components: the smart material, the geometric "programme," and the multi-material printer (Tibbits, 2014). Unfortunately, despite 4D printing showing great potential to disrupt 3D printing technology, it is yet to be accepted at an industrial scale, since the specialized multi-material printer for 4D printing is not commercialized (Headrick, 2015). This paper thus aims to develop an innovative approach for the mass customization business in the fashion accessory industry premised on commercialized technology and accessible materials, considering independent designers and small and medium enterprises (SMEs). By integrating 3D printing technology and a key component of 4D printing, i.e., shape memory material, the product's shape can be change independently; moreover, consumers can be involved in design in the post-production process.

Methods and Results: The core value of 3D and 4D printing technology has inspired researchers to carve an innovative path to access the potential for mass customization in the fashion industry, by embedding shape memory materials into 3D-printed objects. Thus, the customized product can achieve both complex shapes and independent shape changing in the post-production process without investing in a multi-material printer. Depending on different sizes and the properties of the fashion product that designers expect, multiple 3D printing devices and shape memory materials can be applied. The critical advantages of this design concept are feasibility and flexibility.

This paper has selected earring development as an example, using the Lulzbot Mini 3D printer and a heat responsive shape memory alloy (SMA). The process of creating accessory prototypes includes four steps. Since this research aims to explore an innovative design approach instead of developing a particular design, the following steps have been implemented. First, we have downloaded the earring pendant file from Thingiverse (https://www.thingiverse.com) which is licensed for use under creative commons. Second, a user-friendly 3D printing software Cura, maintained by Ultimaker Inc.

(https://ultimaker.com) has been exploited to process the 3D file. Third, the earring pendant has been 3D-printed by the Lulzbot Mini 3D printer using polylactic acid (PLA) plastic as the filament. Lastly, we have combined the pendant and the earring chain, constructed from a pre-trained straight shape SMA. The SMA, obtained via e-commerce for this experiment, starts becoming rigid and returns to being straight when exposed to temperatures above 104°F. The intensity of the deformation can be controlled by manipulating the temperature; thus, the SMA can be customized into different shapes according to the designers' need.

The original hybrid earring prototype had a six-centimeter-long SMA chain. Thereafter, water of temperature 104 °F was used to stimulate the earring chain, which elongated into seven and a half centimeters. Next, we exposed the chain to the candle flame, since it is easily accessible to end-users. The chain became fully straight, reaching approximately 12 centimeters. This approach enables creating customizable products to meet consumers' preferences in the post-printing process. In this process, we found that the more twisted the SMA was, the higher a temperature was needed to trigger the deformation. The process was video recorded.

Conclusion: It was found that the integration of smart materials into 3D printing sets the stage for a profound revision of how designers think about and interact with products using the material and the ease to access facility. The critical advantages of this design concept are feasibility and flexibility, important for customization. Taking the example of earrings, other fashion accessory designs can be created. For example, glasses legs can be made by SMA and attached to a 3D-printed glasses frame. Thereafter, the length of the SMA legs can be adjusted when it is exposed to different temperature stimuli, which provides further implication of customization for the consumers' need.

4D printing suggests a dramatic extension of 3D printing, allowing the fashion industry to create self-assembling objects in the near future. Before 4D printing technology is well developed and moves from the laboratory into the industry, the integration of 3D printing and smart materials is a feasible business strategy for independent designers and SMEs to leverage the value of mass customization. The shape changing property in the post printing process operated by consumers increases product's uniqueness and hedonic value, thus reducing the rate of returned customized items.

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