Luminance Guard

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Keywords: 3D printing, 4D printing material, modularity, footwear

Contextual and concept statement. 3D printing (3DP) technology has been widely utilized in the fashion industry for fabricating complex geometries and personalized designs that may be challenged by traditional manufacturing methods (Lee, 2022; Ota et al., 2017). In recent years, 3DP has attracted great attentions in the footwear industry. Several designers and companies started to adopt 3DP in the shoes design for better fit and performance. For example, Aflatoony (2019) developed a customizable shoe sole and footbed with a PolyJet 3D printer. However, 3DP methods used in previous studies have been limited to Polyjet or Selective Laser Sintering, which have limited material options and higher cost associated with. Other designers (e.g., Lee & Li, 2022; Sun, 2018) started to explore the potential use of fused deposition modeling (FDM), an economical way of 3DP, with flexible 3DP filaments such as thermoplastic polyurethane (TPU) when developing 3D printed wearables. For the past several years, the growing needs for rapid prototyping with considering material efficiency have fueled the emergence of 4D printing (4DP) technology. As an extension of 3DP, 4DP was evolved based on the additive manufacturing concept and added the 'time' perspective as a fourth dimension, which allows printed objects to change shapes or properties such as color and luminance over time in response to external stimuli (Becher, 2023). Currently, the application of 4DP materials with abilities to transform shapes or behaviors has been limited in biomedical fields (Momeni et al., 2017).

The pedestrian fatalities in the U.S. have continuously increased since 2009 (Ferenchak & Abadi, 2021), with 76% of pedestrian fatalities occurred at night (Federal Highway Administration, 2023; Hu & Cicchino, 2018). According to the National Highway Traffic Safety Administration's (2020) report, children aged between 10 and 14 years old accounted for the highest percentage of pedestrians injured among various age groups. Improving nighttime visibility by wearing reflective or glowing wearables attracting and alerting others to the presence of the wearer has a significant impact on child pedestrians' safety (Federal Highway Administration, 2023; Green, 2021). Integrating with 4DP materials, 3D printed wearables can possess a glowing effect in the dark which is easier for drivers to spot and avoid collisions. Although 4DP materials have a great potential for developing wearables corresponding to environmental conditions for improving wearables' performances and satisfying users' unique needs, little attention was given to develop 3D printed functional wearables with the integration of 4DP materials for improving child pedestrians' safety in the low-light environment. Therefore, we aimed to design customizable 3D printed shoes with a special ability to emit light in the dark using novel 4DP materials.

Aesthetics. By adopting Li and Lee's (2021) modular design approach used in the 3DP design, this shoes design, considering the child pedestrians' safety, is comprised of an internal frame, an external upper, an outsole, and a customizable insole (see Figure 1). The flowing shape of the external upper was inspired by the fluctuating nature of light, which represents the core design concept of visibility and safety. Both white and yellow were selected as the main colors for this shoes design because of the symbolization of luminance and good visibility in the low-light environment; specifically, yellow can promptly elicit a sense of heightened awareness from drivers (OMEGA, 2017). With the considerations of functional, expressive, and aesthetic attributes, multiple triangular structures with symbolic meanings of stability and strength were embedded at the bottom of the outsole, which specifically fulfill its functional purpose to optimize tractions and grips. By incorporating flexible TPU filaments, the repeated triangular structures consisting of grooves and channels also create friction between the shoes and the ground surface to minimize the risk from slipping, which increases child safety.

Figure 1. All 3D printed components

Process, technique, and execution. The design process included: brainstorming and sketching, 3D foot scanning, CAD modeling, prototype testing, 3DP, and assembly. To customize the design for satisfying wearers' ergonomic needs, a 3D foot scanner was used to first capture the left foot of a volunteer. The 3D data of the foot then was cleaned, converted, and imported into Rhino 3D software for digitally modeling all the 3D shoe components. The unique dimensions, contours, and shapes of the foot model with precise measurements were extracted and extruded into the insole model to provide a proper fit and optimal support (see Figure 2). All the components were separately exported as OBJ files for slicing and 3DP. The internal frame, outsole, and customizable insole were printed with a FDM 3D printer using flexible TPU filaments, which provide sufficient cushioning and enhance the overall support while walking. A special glow-in-the-dark 4DP material was utilized to print the external upper which enables the upper part of the shoes to glow in the dark after being exposed to light (see Figure 3). The novel 4DP material with the ability to absorb and emit light is suitable for developing wearables which can enhance visibility in the low-light environment. A total of 62 hours were spent printing all the components. All parts then were assembled manually.

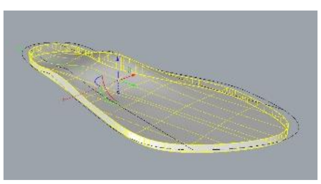

Figure 2. The model of customized insole

Figure 3. The external upper with a glow-in-the-dark 4DP

Cohesion. With the integration of innovative design technologies (3D foot scanning, CAD modeling, 3DP, and 4DP), ergonomic design method, and modular design approach, this design, *Luminance Guard*, fulfills users' functional, expressive, and aesthetic needs; specifically, the customized insole as well as the use of flexible 3DP and novel 4DP materials maximize the child pedestrian's comfort and safety. The inspirations from fluctuations in light and the concept of visibility for children were consonantly embedded in the design, which reflect the overall design purpose of improving child pedestrian's safety and potentially saving their lives.

Contribution. By incorporating the modular design approach, this design presents the possibility of adopting the cost-effective FDM 3DP method in the footwear design for enhancing aesthetic value and performance. Considering 4DP still being in its early stage, our shoe prototype integrating with the 4DP material showcases a true potential of using 4DP for developing functional wearables in the apparel and footwear industry. This experimental design is innovative and original at (a) creating a customizable footwear design using the FDM 3DP method, (b) using the 4DP material in the design process and unlocking its potential in the wearable product development, and (c) developing 3D printed functional wearables with novel design technologies to prevent child pedestrian's injuries by improving their visibility in dark.

Date Completed: May 22, 2023

References

Aflatoony, L., (2019). Flex, breathe, fit, and walk: Exploring technologies accessible in academia for design and production of a custom fit shoes. *International Textile and Apparel Association Annual Conference Proceedings 76*(1). https://doi.org/10.31274/itaa.8263

Becher, B. (2023). *4D printing technology creates 3D-printed objects that respond to stimuli*. Built In. https://builtin.com/3d-printing/4d-printing

Federal Highway Administration. (2023). *Nighttime visibility for safety*. https://www.fhwa.dot.gov/innovation/everydaycounts/edc_7/nighttime_visibility.cfm

Ferenchak, N. N., & Abadi, M. G. (2021). Nighttime pedestrian fatalities: A comprehensive examination of infrastructure, user, vehicle, and situational factors. *Journal of safety research*, *79*, 14-25. https://doi.org/10.1016/j.jsr.2021.07.002

Green, M. (2021). *Seeing pedestrians at night*. https://www.visualexpert.com/Resources/pedestrian.html

Hu, W., & Cicchino, J. B. (2018). An examination of the increases in pedestrian motor-vehicle crash fatalities during 2009-2016. *Journal of safety research*, *67*, 37-44. https://doi.org/10.1016/j.jsr.2018.09.009

Lee, Y. A. (2022). Trends of emerging technologies in the fashion product design and development process. In Y. A. Lee (Ed.), *Leading edge technologies in fashion innovation: Product design and development process from materials to the end products to consumers* (pp. 1-16). Palgrave Macmillan.

Lee, Y. A., & Li, Y. (2022). Bouncing with 3D printed soft cells. *International Textile and Apparel Association Annual Conference Proceedings*, *78*(1). https://doi.org/10.31274/itaa.13291

Li, Y., & Lee, Y. A, (2022). Modularity in 3D printed backpack. *International Textile and Apparel Association Annual Conference Proceedings*, *78*(1). https://doi.org/10.31274/itaa.13456

Momeni, F., Hassani, M., Liu, X., & Ni, J. (2017). A review of 4D printing. *Materials & design*, *122*, 42-79. https://doi.org/10.1016/j.matdes.2017.02.068

National Highway Traffic Safety Administration. (2020). *Pedestrians: 2018 data* (No. DOT HS 812 850). https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812850

OMEGA. (2017). *The psychology of safety colors*. https://www.omegaindl.com/blog/psychology-safety-colors

Ota, H., Chao, M., Gao, Y., Wu, E., Tai, L-C., Chen, K., … Javey, A. (2017). 3D Printed "Earable" smart devices for real-time detection of core body temperature. *ACS Sensors*, *2*(7), 990-997. https://doi.org/10.1021/acssensors.7b00247

Sun, L. (2018). Instilled: 3D printing elastic lace. *International Textile and Apparel Association Annual Conference Proceedings*, *75*(1). https://www.iastatedigitalpress.com/itaa/article/id/1355/