# Drapability of 3D Printed Auxetic Structure Textiles for Wearable Products

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**Introduction and Background.** Advancements of 3D printing (3DP), also referred as additive manufacturing, open up tremendous opportunities for the fashion industry into the on-demand manufacturing process (Lee, 2022; Sun & Valtasa, 2019). With the continuous technology innovation, apparel industry professionals and academic researchers have been pushing their boundaries to integrate 3DP into the wearable product design and development (Sun, 2020). 3DP has been much utilized in producing fashion accessories but not much for wearable apparel products because of its limited stretchability, bendability, or flexibility which are essential material properties related with wearers' comfort and functionality (Lee, 2022). Integrating with auxetic structures – novel and non-conventional patterns that possess the unique elongation characteristic when being stretched (Ge et al., 2013; Saxena et al., 2016), 3D printed textiles have a greater potential to mimic traditional textiles which perform better drapability for fulfilling users' functional and aesthetic needs (Spahiu et al., 2020). Although drapability is an important factor determining the aesthetic and usability of textiles for wearable products (Lee & Kim, 2006), based on our knowledge, little attention has been given to explore drapability of 3D printed textiles. Especially, no previous research was identified to explore drapability of 3D printed textiles with auxetic structures for 3D printed wearable products. Thus, the purpose of this experimental study was to explore drapability of 3D printed auxetic structure textiles with different geometries and their potential applications in 3D printed wearable products design and development.

**Method.** An experimental research design, consisting of 10 (3D printed textile samples) x 3 (repetition), was used for this study. Among all of the 3D printed textile samples used in the study, nine geometries of auxetic structures were adapted from the existing literature in the field of material sciences and medicine (Bhullar, 2015; Borovinšek et al., 2020; Kim et al., 2021; Körner & Liebold-Ribeiro, 2014) and one auxetic structure textile was developed by the researchers inspired by floral motifs. All 3D printed auxetic structure textiles have an identical round shape with 200 mm diameter and each sample consisted of rectangular unit (0.6" for a diagonal distance) or equilateral triangular unit (0.6" for each side). All 10 textile samples were 3D printed using a commercial fused deposition modeling (FDM) 3D printer with thermoplastic polyurethane (TPU) filaments.

Image processing technique was adopted from Kalman et al. (2021) to analyze drapability of 3D printed auxetic structure textiles. All 10 samples were placed on a circular stand of 81 mm of diameter and a digital camera was used to photograph the 10 draped samples from the top. Figure 1 illustrates the geometries of auxetic structures and draped samples of all 3D printed textiles (S1 through S10) used for the experiment in this study.

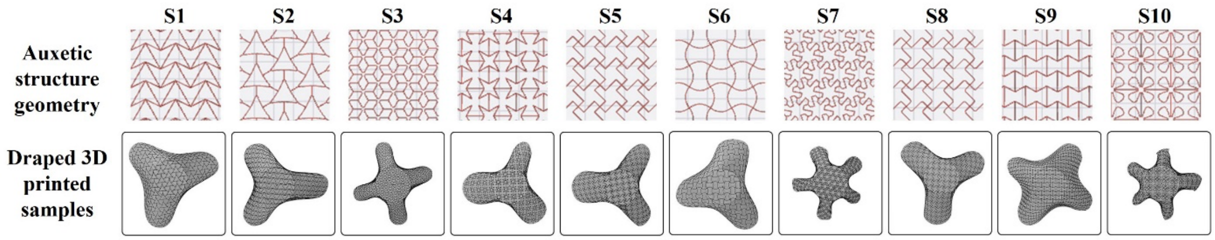


*Figure 1*. Geometries of auxetic structures and 3D draped samples of 10 3D printed textiles

The projecting area of the draped samples were measured in Adobe Photoshop using histogram tool and the draping coefficient (*DC*) of each 3D printed auxetic structure textile was calculated using a mathematical formula, *DC* = Draped Area / Undraped Area x 100%, ranging from 0% to 100%. For *DC*, the higher value indicates the lower drapability of the sample. SAS 9.4 was used for statistical analysis at the significance level of $p < .05$. A *F*-test in ANOVA was used to determine the significant difference of drapability among the 10 samples and a pairwise Tukey adjustment method was used to compare drapability of 3D printed auxetic structure textiles.

**Results and Discussion.** In this study, to explore the potential use of 3D printed auxetic structure textiles as alternatives to traditional textiles for wearable products, drapability of the 10 samples (S1 through S10) were evaluated. The mean *DC* value of the 10 3D printed auxetic structure textiles ranged from 26.15% to 52.07%. The *F*-test in ANOVA revealed the statistical significance of all 10 textile samples in terms of drapability ($F(9,20) = 22.51$, $p < .0001$). The Tukey's pairwise comparisons resulted these textile samples into five drapability groups, Group 1 = *much lower drapability* to Group 5 = *much higher drapability*. Within each group, the mean *DC* value of the samples were not significantly different. The mean *DC* value of Group 1, consisting of S2, S6, and S9, demonstrated *much lower drapability* ($M_{S2} = 52.07$; $M_{S6} = 44.52$; $M_{S9} = 43.98$). Group 2, consisting of S1, S5, S6, S8, and S9, exhibited *lower drapability* ($M_{S1} = 42.61$; $M_{S5} = 36.24$; $M_{S6} = 44.52$; $M_{S8} = 38.68$; $M_{S9} = 43.98$). Group 3, consisting of S3, S4, S5, and S8, represented *moderate drapability* ($M_{S3} = 30.24$; $M_{S4} = 32.23$; $M_{S5} = 36.24$; $M_{S8} = 38.68$). Group 4, consisting of S3, S4, S5, and S7, had *higher drapability* ($M_{S3} = 30.24$; $M_{S4} = 32.23$; $M_{S5} = 36.24$; $M_{S7} = 29.68$). Lastly, Group 5, consisting of S3, S4, S7, and S10, exhibited *much higher drapability* ($M_{S3} = 30.24$; $M_{S4} = 32.23$; $M_{S7} = 29.68$; $M_{S10} = 26.15$).

Variations of *DC* among five groups were due to the variation in geometries of the 10 3D printed auxetic structure textile samples. To explore the potential of 3D printed auxetic structure textiles for the use in the wearable product design and development, the *DC* of 3D printed auxetic structure textile samples was compared with that of traditional textiles. Prior studies demonstrated that the *DC* of traditional textiles ranges between 19% and 90% based on their different fabric composition (Gaucher et al., 1983; Mizutani et al., 2005; Robson & Long, 2000; Uçar et al., 2004). Since the *DC* range, 26.15% to 52.07%, of the 10 samples experimented in this study were within the *DC* range exhibited by the traditional textiles mentioned above, it can be interpreted as 3D printed auxetic structure textiles have a great potential for mimicking traditional textiles and could be used for 3D printed wearable products as alternatives.

**Conclusion.** This study explored drapability of 3D printed textiles with 10 different geometries of auxetic structures by measuring *DC*. The results of this experimental study demonstrated the viability of using different auxetic structures in the 3D printed textile design and development, which will eventually booster its application to develop 3D printed wearable products that can provide better comfort to wearers through enhancing 3D printed textile's properties such as stretchability, flexibility, or bendability. Specifically, 3D printed auxetic structure textiles with *high drapability* can be used for wearable products such as lingerie. With *moderate drapability*, they can be applicable to blouses and shirts. With *low drapability*, they can be suitable for pants or outerwear. In future study, researchers need to further investigate the relationship between *DC* and different geometries of 3D printed auxetic structure textiles. The textile samples used in this study were printed using a FDM 3D printer with TPU filaments. Using different 3DP methods and materials may lead to different results, which urges further research investigation. Since this study only focused on examining drapability of 3D printed auxetic structure textiles, further textile property testing is needed to explore the effectiveness and feasibility of 3D printed textiles used for wearable products.

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