Polymer Membrane Tensegrity: Inverse Design of Polymer Films Morphing into Arbitrary 3D Surfaces with Digital Photopatterning Technique

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As Goethe discussed in his seminal work, "Metamorphosis of Plants" published in 1790 [1], diverse plant morphologies, such as flowers and fruits, originate from transformed leaf-like structures. Recent studies have shown that these transformations occur through in-plane differential contraction and growth, along with the distribution of differential rigidity. Similarly, we propose a technique "Polymer Membrane Tensegrity" to fabricate arbitrary 3D surfaces from self-morphing 2D polymer films. Our technique combines polymer science and origami engineering, leveraging the expertise cultivated by our team members over the years. Fukunishi et al. have developed a method called Digital-Photopatterning using a 3D printer, where monomers embedded in the parent polymer film are selectively polymerized in specific areas, creating films with varied in-plane material properties [2]. This method thus precisely controls in-plane swelling or shrinkage in selected areas, facilitating the spontaneous formation of 3D surfaces from 2D films.

However, designing an arbitrary 3D surface still requires an inverse design approach to compute the in-plane patterns of material properties. To address this, we applied an algorithm proposed by Shimoda et al., which optimizes the locations and geometries of rigid rods on the shrinking membrane to create the desired 3D surfaces [3]. The resulting 3D surfaces are established as tensegrity structures, where the rigid rods do not connect each other but rather balance the membrane's tension to maintain the overall structural integrity. This approach enables the inverse design of 2D film patterns to achieve the intended 3D transformations [Fig.1]. We report our findings on the potential of Polymer Membrane Tensegrity in creating diverse 3D surfaces, including minimal surfaces such as Gyroid[4].

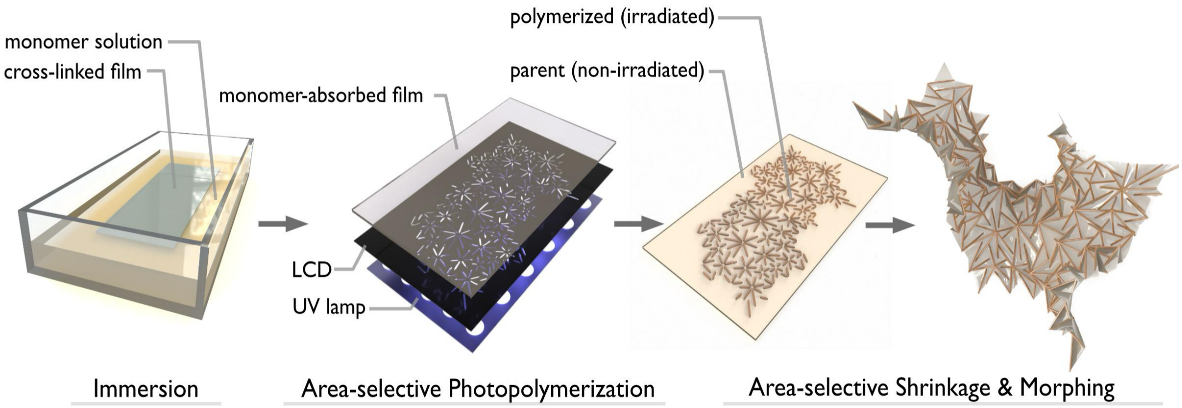

Figure 1 Fabrication process of polymer membrane tensegrity for inverse design of a target 3D surface.

[1] J.W. Goethe, "Metamorphosis of Plants" (1790).
[2] H. Fukunishi, M. Hayashi, S. Ito, N. Kishi, *ACS Appl. Polym. Mater.,* **5**, 6 (2023).
[3] Y. Shimoda, et al. *Advances in Architectural Geometry* (2023).
[4] A.H.Schoen, *National Aeronautics and Space Administration (1970).*