PixBric: Precision Morphological Control of Pre-Stretched Fabrics Through Tessellated Primitive Geometries

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Abstract

3D printing patterns onto pre-stretched fabrics has emerged as a promising method for the rapid fabrication of self-shaping textiles. However, the influence of design parameters on morphing behavior remains insufficiently explored, often resulting in heuristic-driven decisions. This study introduces PixBric, a pixel-based textile methodology composed of primitive geometries designed to induce controlled morphing behaviors—such as undulation and bending—and mechanical properties including multistability. By parametrically adjusting geometry, thickness, and inter-pixel spacing, PixBric enables precise morphing outcomes. The framework includes a morphing simulation tool and a design chart linking geometric variables to deformation results. We also propose a streamlined fabrication protocol using biaxial pre-stretching with magnetic framing. These contributions establish a systematic design approach for the functional and interactive deployment of self-shaping textile structures.

CCS Concepts

• **Human-centered computing → Haptic devices**; *Interaction design theory, concepts and paradigms*; *HCI theory, concepts and models.*

Keywords

Self-Shaping; Multi-stability, Tessellation; Textile; Additive manufacturing; Pre-programmed structure; Tangible Interfaces, HCI

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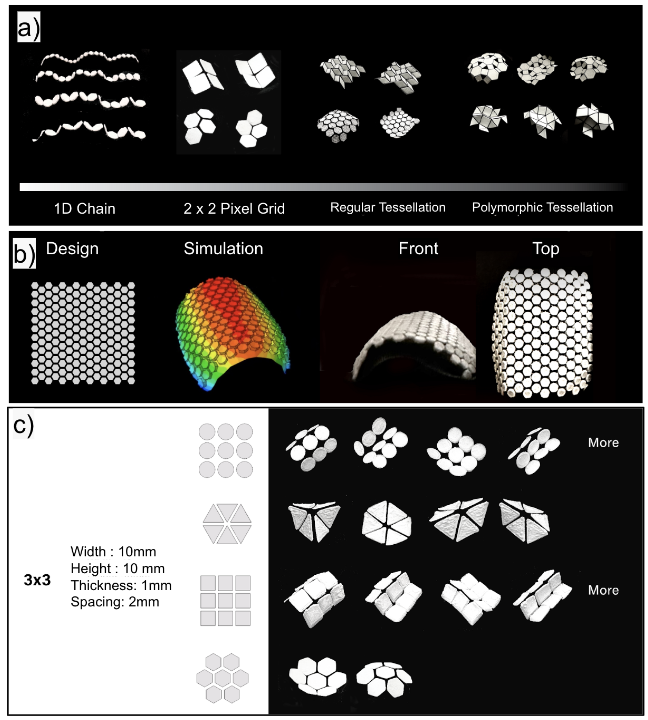

Figure 1: a) from 1D Chain of 1–3mm Pixels, 2×2 pixelExhibiting Bistability to Various Tessellations with Multiple Stable States. b)Simulation (Abaqus). c)Multiple Stable States of Primitive Geometry-Based Pixels in 3×3 Grids.

1 Introduction

The Human–Computer Interaction (HCI) and textile research communities have explored self-shaping fabrics by integrating patterned structures on pre-stretched textiles using methods such as 3D printing, stamping, and embroidery [1–3, 5, 6]. These techniques enable flat fabrication with 3D transformation via stress release, offering benefits like compactness, rapid prototyping, and low weight [4, 7, 8]. However, current approaches often rely on heuristically defined geometries and lack precise control over curvature and deformation, limiting the complexity and accuracy of resulting morphologies. PixBric's contributions include the evaluation of primitive shapes (e.g., rectangles, triangles, hexagons), thickness and inter-pixel spacing to produce localized deformation; the development of a CAD-based interface for generating parametric geometries, integrated with simulation capabilities to visualize and validate morphing behavior; and a systematic investigation of tessellations to map their design space and induce mechanical properties—such as multistability—for multifunctionality; and a fabrication method using biaxial pre-stretching with magnetic framing (Figure 1).

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2 PixBric Software and Simulation

Design Primitive is a Python-based software built in Rhinoceros 3D and Grasshopper that lets users import 2D images or models and customize geometry type, pixel size, and pattern density. It generates a parametric grid that adapts to image brightness, normalized via the image brightness function, with geometry sizes dynamically mapped to brightness values.

Finite element simulations using *ABAQUS* (Dassault Systèmes) were conducted to predict shape-morphing behavior, enabling rapid iteration and minimizing material waste. Fabric and 3D-printed PLA components were independently modeled and selectively tied at key nodes. The fabric was modeled with S4R shell elements using the Holzapfel–Gasser–Ogden hyperelastic model ($C_{10} = 0.01$ MPa, $k_1 = 0.4$ MPa, $k_2 = 0.03$ MPa, $\alpha = 0.3$), and a 50% in-plane contraction was applied to simulate prestrain release. PLA components were modeled with C3D8R elements, using a density of 1,250 kg/m^3, a Young's modulus of 2,890 MPa, and a Poisson's ratio of 0.35.

3 3D Printing Using a Magnetic Frame

We used biaxially pre-stretched fabric for uniform extension and enhanced 3D morphing. To avoid clip or tape waste, a 6 mm-high magnetic frame with embedded neodymium magnets was designed for Prusa MK4S printers, securely holding the fabric during printing without extruder interference

4 Pixel-Based Textile Morphology

Experiments show that spacings between 0.5–3 mm enable bending and bistable snapping, with optimal performance at 1–2 mm due to sufficient energy barriers for reconfiguration. Spacings > 3 mm produced predominantly flat with diminished shape-morphing capabilities.

Pixel sizes ranging from 1 mm to 20 mm were explored with a consistent inter-pixel spacing of 1 mm. Groupings of more than five pixels with widths of 1–2 mm effectively generated subtle undulations. In contrast, pixels wider than 3 mm typically clustered into groups of 2–3 and behaved as discrete, button-like units. As pixel scale increased, the energy barrier also increased, necessitating greater force to deform the structure.

An optimal thickness range of 0.5–2 mm was identified for fabric structures measuring up to 200 × 200 mm. 3D printed regions exceeding 3 mm in thickness exhibited insufficient morphing capability, primarily due to the added weight, which limited deformation on fabrics.

Four primitive geometries — circle, triangle, rectangle, and hexagon — were evaluated in 2×2 and 3×3 tessellated grids (10 mm width, 1 mm thickness, 1 mm spacing). Circular pixels, due to their radial symmetry and inefficient packing, resulted in non-uniform inter-pixel spacing, which limited their ability to support stable bending or bistability. Rectangular and triangular units exhibited localized deformation, with bending primarily occurring between adjacent pixels, enabling discrete, segmental morphing. In contrast, tessellated hexagonal pixels facilitated cohesive, global deformation across the patterned region. Rectangular, triangular, and hexagonal configurations all demonstrated multistability, exhibiting the capacity to maintain more than two distinct stable states.

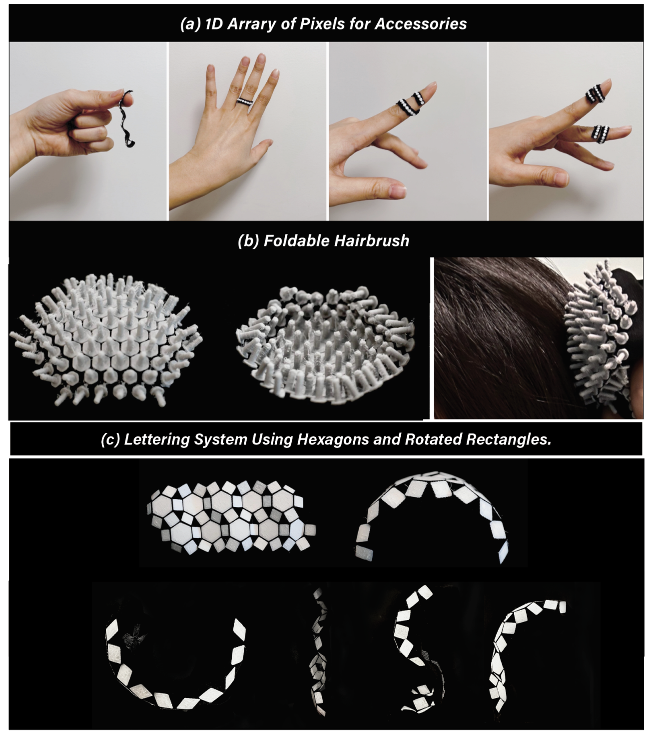

Figure 2: (a) A 1D Chain Adaptable Ring ; (b) Bistable Hairbrush; (c) The "UIST" formed using rectangular tessellations.

5 Potential Use Cases

We designed three prototypes composed of tessellated geometries (Figure 2). Using multistable hexagonal and rectangular poly tessellations, we developed a reconfigurable fabric structure that spells "UIST." Each pixel snaps independently between flat and curved, dome-like states, with an interspacing of 1 mm to maintain multiple stable configurations.

Body-conforming rings were also prototyped using one dimensional hexagonal arrays with 0.5 mm width and spacing. In their resting state, the structures exhibit undulating forms, and when worn, they conform to body contours due to their inherent bistability. A ring prototype maintained its shape while accommodating various finger sizes without requiring design modifications.

A hairbrush prototype was developed using hexagonal pixels embedded with pins. Dome geometries were generated via a parametric tool by tuning inter-pixel spacing within the hexagonal grid. This configuration enabled uniform snapping under pressure and reconfiguration with minimal force, allowing pins to retract or emerge as needed. The design offers a functional solution for protecting pins during transport, improving portability and durability.

6 Conclusion

We introduced the design rules and functionalities of primitive geometries for self-shaping fabrics. Future work will address the scalability of the system and explore dynamic, stimuli-responsive morphing beyond current passive self-shaping mechanisms.

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