EmbroChet: A Hybrid Textile Fabrication Approach for 3D Personalized Handicraft via Heat-Shrinking

Guanyun Wang
Zhejiang University
Hangzhou, China
guanyun@zju.edu.cn

Zhiqi Wang
Zhejiang University
Hangzhou, China
zhiqiwang@zju.edu.cn

Fanyu Li
Zhejiang University
Hangzhou, China
fanyu@zju.edu.cn

Qinyang Liu
Central Academy of Fine Arts
Beijing, China
1795346502@qq.com

Tianshu Dong
Zhejiang University
Hangzhou, China
dongts@zju.edu.cn

Zixiang Hong
Hangzhou City University
Hangzhou, China
877532283@qq.com

Xinyi Li
Tsinghua University
Beijing, China
xinyilee006@gmail.com

Kuangqi Eddie Zhu
Cornell University
Ithaca, USA
kz376@cornell.edu

Jiaji Li
Massachusetts Institute of Technology
Cambridge, USA
Zhejiang University
Hangzhou, China
jiaji@mit.edu

Xiaoliang Zhao*
Zhejiang University
Ningbo, China
zhaoxl@zju.edu.cn

Ye Tao*
Hangzhou City University
Hangzhou, China
taoye@zucc.edu.cn

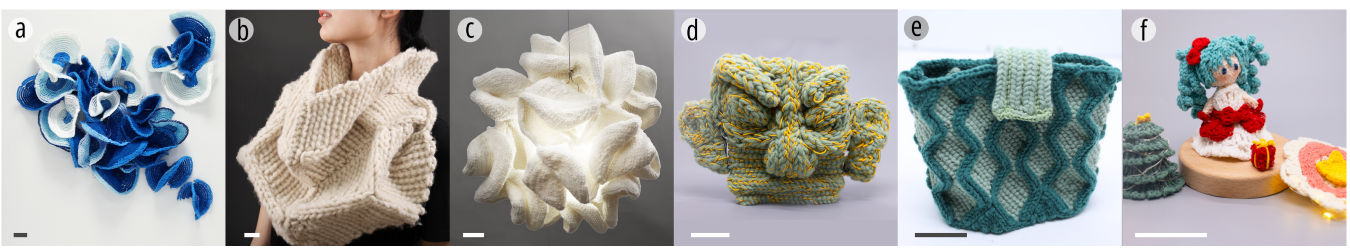

Figure 1: Applications: (a) Installation art, (b) Fashion design, (c) Lampshade, (d) Sculpture, (e) Bag, (f) Doll. (Scale bar: 10 cm.)

Abstract

We propose EmbroChet, a hybrid approach that bridges digital fabrication and textile craftsmanship, empowering individuals unfamiliar with intricate craft techniques to design and fabricate 3D textile handicrafts intuitively. EmbroChet allows the creation of handicrafts by embroidering chain stitches (a fundamental embroidery technique) onto a heat-shrinkable film, which subsequently self-transforms from a 2D composite to a 3D textile through a freely controllable heating triggering process. Through a single stitch type, the method enables custom designs and intricate geometries to be achieved without complex manual skills that often requires expertise between different stitch knowledge. To better demonstrate EmbroChet, we propose a design tool that includes shape-changing libraries to assist users in customizing 3D shapes. The evaluation demonstrates its unique strength in balancing geometric complexity and textile softness. Furthermore, our workshop verifies the feasibility of EmbroChet, exploring its potential for personalized textile fabrication, and synergizing the precision of digital fabrication with the tactile artistry of textile craftsmanship.

*Corresponding Author, zhaoxl@zju.edu.cn, taoye@hzcu.edu.cn.

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CCS Concepts

• **Human-centered computing** → **Interactive systems and tools**.

Keywords

Hybrid Crafts, Personal Fabrication, Computer-Aided Design, Shape Changing

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1 INTRODUCTION

Textiles are cherished for their coziness and comfort property, integral to daily life in clothing, household items, and decorations. Traditional textile crafts like knitting, crocheting, and embroidery each unlock distinct design potentials: knitting generates elastic structures through interlocking yarn loops; crocheting enables 3D morphologies via yarn manipulation [25]; while embroidery transforms fabrics into intricate patterns through stitching. These techniques have fostered a vibrant culture of handmade creations for craft enthusiasts, appealing to diverse communities and inspiring a wide range of artistic expressions. However, traditional textile-making techniques often require specialized knowledge and extensive experience, posing barriers to users without crafting experience. For instance, crochet demands mastery of stitch variations and precise material manipulation. Novices may be uncomfortable with the complexity of certain techniques, which limits their ability to explore intricate 3D forms and fully realize the design potential inherent in these crafts.

In recent years, textile crafts also have emerged as a vital medium in human-computer interaction (HCI) research, particularly for developing tangible interfaces [1, 9, 32] and wearable technologies [40, 68, 70]. HCI researchers have increasingly adopted digital fabrication technologies in textile production to create customized 3D textiles, expanding prototyping possibilities while enhancing efficiency. Among these, 3D printing, valued for its design flexibility, has become a prevalent method. Some researchers utilize the geometric freedom of 3D-printed frames as foundational structures. For instance, PunchPrint employs punch needle manipulation on 3D-printed substrates to create customized surface textures [11]. Others combine different material properties to develop morphing structures—FabriClick integrates digital embroidery with 3D-printed patterns to form bistable buttons that enhance textile functionality [17]. Beyond additive manufacturing, innovative approaches like EscapeLoom utilize water-soluble warp materials to enable the fabrication of customized woven structures without compromising tactile softness [12]. Moving beyond 3D printing, techniques such as laser cutting and machine embroidery demonstrate further potential. Tamara et al. employ laser cutting to create parametric fabric textures through controlled patterns [13]. In conclusion, current research primarily focuses on digitally customizing surface characteristics—visual patterns, textural aesthetics, and tactile feedback. However, when it comes to creating basic 3D shapes, existing approaches often rely on strategies such as joining flat textile sheets or integrating rigid substrates. EmbroChet enables a broader range of 3D geometries, including spheres, cones, and hyperbolic surfaces, pleated textures, convex/concave structures, and elements with controlled bending angles—using the same stitching pattern with varying paths.

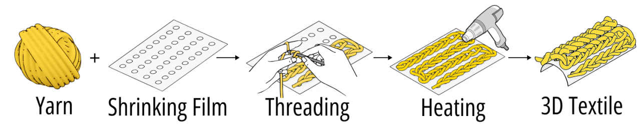

Figure 2: Embrochet create complex 3D textiles by integrating chain stitches into shrinkable materials and applying heat to transform flat fabrics into desired shapes.

Inspired by traditional textile crafts—specifically the chain stitch, a fundamental technique in both embroidery and crochet—and digital fabrication methods, we propose EmbroChet, an innovative personal fabrication method that enables users unfamiliar with craft techniques to create 3D textiles. This method facilitates shape control by applying chain stitches along designated paths on a heat-shrinkable film. When heated, the composite transforms from a flat sheet into a 3D structure, with the film providing moderate rigidity and flexibility to support complex geometries. To enrich the design space, a variety of hands-on techniques, shape-changing libraries, and application directions have been developed. A series of evaluations provide users with textile performance characteristics, demonstrating that EmbroChet achieves an optimal balance between structural stability and material comfort. A design tool has been created to enable real-time customization and visualization, offering parametric control over shape generation. User workshops confirm its usability and highlight its potential for customizable fabrication and versatile applications. EmbroChet combines digital fabrication methods with traditional textile techniques, offering new avenues for personalized 3D handicrafts.

Our contributions are as follows:

- A hybrid fabrication approach transforms 2D composites into 3D textiles through heat-activated morphing, along with collections of hands-on design techniques and shape-changing libraries for wider design space.
- An integrated design tool enables customization and preview of textile effects, along with a platform with digital resources and tutorials for typical troubles.
- Application demonstrations and user creations employing EmbroChet showcase practical innovations, complemented by workshop evaluations and participant discussions that reveal the tool's accessibility and technical limitations.

2 RELATED WORKS

2.1 Textile Interfaces in HCI

Textiles, deeply integrated into human life, have garnered significant attention in human-computer interaction (HCI) research. From diverse morphological expressions [13, 41] to multimodal signal monitoring and feedback [57, 67, 69], from user experience enhancement [40, 42] to the assistance in crafting processes [26, 27, 49], textile research spans a wide spectrum, connecting form and function, usage and creation. Research explores innovative fabrication techniques that modify textile properties for dynamic forms [32, 54], exemplified by KnitDermis, which embeds shape-memory alloys for tactile feedback [32]. Other studies focus on the electronic integration of textiles [6, 47, 66], such as the embedding of sweat-sensing interfaces, as seen in BioWeave, which further bridges textiles with our daily life [70].

Textile morphology serves as a critical carrier for textile interfaces, where the blending of interactive and functional properties constitutes a fundamental research domain that enables expansive design possibilities. Early research, like Monarch [21], focused on shape-changing prototypes to enhance human experiences [9, 55]. With the increasing adoption of digital fabrication technologies, recent studies emphasize reproducible fabrication methods and systematic approaches to broaden accessibility [43, 45, 65]. In creating intricate pleats, Flextiles uses shape-memory alloys for shape-changing behaviors in textiles, enabling users to design textured patterns [22]. For dynamic surfaces, TEX(alive) leverages pneumatic actuators to enable user-responsive 3D textile deformation [37], while Embrogami combines machine embroidery to create microscale mountain-valley structures with shape-shifting capabilities [23]. These works further expands the design space by integrating diverse digital fabrication methods, such as 3D printing, alongside various actuation technologies to create dynamic and versatile textile forms. However, most existing methods are limited to 2.5D forms or planar assemblies, although they take advantage of 3D printed rigid substrates.

EmbroChet introduces a personal fabrication approach to create 3D textiles using heat-shrinking films, including folds, protrusions, and geometric forms, while systematically expanding the application of complex morphologies.

2.2 Textile-making Techniques for Hybrid Craft

Conventional textile techniques like crochet—a yarn-looping method using hooked needles—demonstrate the versatility in creating intricate patterns and 3D forms [14, 29]. Its potential for complex shapes has recently attracted HCI researchers [5, 20, 46]. However, crafting intricate shapes remains challenging for beginners, who often struggle with mastering specific stitches and applying them creatively. Computational tools such as AmiGo, which translates geometric models into crochet instructions [18], and texTile, a system for designing and reconfiguring crochet granny square garments [10], have been developed to enhance efficiency in digital craft workflows. While these tools enhance stitch comprehension and bridge the gap between design and final forms, they fall short in addressing the manual challenges of crafting, lacking systematic support for hands-on fabrication challenges.

Meanwhile, Embroidery, which uses a needle and thread to create intricate patterns on flat surfaces, is characterized by its surface-based process and versatile stitching techniques, such as satin and chain stitches. These methods enable the creation of textured designs that are accessible and visually appealing. This versatility has inspired applications, including creative prototyping [19], electronic textiles [24, 28], and dynamic interfaces [15, 33]. For complex forms, Embrogami achieves bistable structures with embossed effects through machine embroidery [23], while Nabila et al. explored heat-induced bending effects by incorporating PLA filaments into machine embroidery [44]. Despite these advances, current methods are limited in achieving broader morphological richness. Additionally, the rigid qualities of embroidered textiles restrict suitability for diverse applications.

By integrating crochet and embroidery into a planar process, EmbroChet enables complex 3D textile formation beyond the reach of either technique alone.

2.3 Adopting Shape-Changing Material for Textile Fabrication

In recent years, shape-changing materials have been extensively explored in the field of HCI, particularly for fabricating complex 3D shapes, and have been widely applied in our daily lives [51, 58]. Thermoplastic materials facilitate either the rapid prototyping of intricate geometries [38, 63] or hands-on crafting [53, 61] through their thermoresponsive behavior. Researchers capitalize on this phase-change capability to enhance digital fabrication convenience [8] and engineer interactive material systems with embedded actuation functionalities [3, 62].

Current textile-related research increasingly focuses on utilizing deformable materials for fabric creation. A key strategy for morphing textiles lies in the flexible integration of actuation materials and structures. Examples include fluidic fiber actuators [31] and textiles that leveraging origami-inspired structures for diverse shapes [56]. Researchers have also explored embedding thermally responsive materials into traditional textiles to induce overall contraction [44, 50]. One approach is blending specific yarns into fabrics for applications like computerized knitting dresses [30]. Alternatively, some studies directly utilize thermally responsive fibers to create morphing textiles, such as weaving elastomeric fibers to enable dynamic transformations [16].

EmbroChet introduces morphing techniques into personalized textile creation by incorporating heat-shrink materials, enabling the transformation of textiles from 2D to 3D forms.

2.4 Computer-Assisted Tools for Handicraft

Currently, computational design plays a significant role in supporting the prototype-making process [2, 36, 71]. For example, WeaveMesh employs UV mapping to generate mesh lines, enabling the rapid creation of complex woven forms through stitching [52], while EmTex provides a modular embroidered e-textile construction toolkit for smart textile prototypes of diverse applications, high quality, and high-level textile integration [60]. In addition, Xstrings offers 3D-printed cable-driven mechanisms that can be fabricated in one go, eliminating manual assembly [34].

Researchers are also developing graphical user interfaces to enhance the usability of computational technologies. Some systems allow users to input target shapes directly, generating corresponding procedural files [13, 39]. Additionally, other systems support shape prediction based on custom parameters, streamlining the conceptualization process through intuitive visualizations [48, 64]. For instance, PneuFab enables parameter adjustments and preview effects through auxiliary software, improving structural understanding and reducing learning costs [59]. Furthermore, the All-in-One Print method enables the creation of dynamic objects with kinematic mechanisms in one step, without post-processing [35].

We propose a computer-aided design tool for personalized textile fabrication, offering a library of example shapes to facilitate the selection and refinement of base forms into diverse designs.

It also provides outcome previews and path-guidance to support personalized customization.

3 EMBROCHET METHOD

This section elucidates material selection rationale for deformable textiles and shape-changing mechanism, accompanied by a step-by-step fabrication workflow. Through systematic experimentation, we quantify the deformation patterns and establish a practical foundation for EmbroChet method.

3.1 Material Selection

To achieve deformation control with enhanced efficacy, we established selection criteria for yarns and shrinkable films based on their thermoresponsive properties.

Yarns. Some acrylic or polyester yarns may emit odors when heated. To address this, cotton or blended yarns with higher cotton content are recommended. In this study, EmbroChet used a commercially available yarn composed of 60% cotton and 40% acrylic, a blend widely used in crochet applications. EmbroChet supports a broad range of yarn weights, from delicate lace to thicker bulky yarns.

Shrinkable Materials.

For the shrinkable layer, various commercially available materials were evaluated, including plastic films (PLA, PE, PVC, POF), crafting sheets (Shrinky Dink), and fabrics (organza, 40D nylon), as illustrated in Figure 3. Thermo-plastics like PLA and PE exhibited anisotropic shrinkage, causing inconsistent deformation. Materials like Shrinky Dink and PVC, while shrinkable, lacked flexibility both pre- and post-shrinkage, leading to poor crafting performance: threading often tore the material, and the rigid middle layer compromised fabric flexibility and durability. In contrast, POF film, a non-toxic material, emerged as the optimal choice due to its excellent shrinkage properties and flexibility. With a shrinkage temperature around 60°C, it aligns with the thermal tolerance of most yarns. Additionally, thicker film were found to facilitate needle threading; consequently, 0.04mm POF film (double-sided, 8C2370 cm, Yiwu Huanjing Machinery Equipment Co., Ltd.) was selected for further experimental validation.

To expand material options, common fabrics like organza and nylon were systematically evaluated. While these materials demonstrated excellent pre-shrinkage flexibility, their post-shrinkage performance was inferior to POF film. Although they require higher shrinkage temperatures, they remain viable alternatives for specific applications. Shrunk POF film offers structural support and durability for 3D shapes. In contrast, organza, resembling traditional textiles, is better suited for garment design and fabric integration.

	Baselayer	Flexibility: Before Shrinking	Flexibility: After Shrinking	Isotropic Shrink	Shrinkage Ratio	Temp at Shrinkage	Thickness Range /mm
	PLA	Flexible low elastic	Flexible durable	✗	<5%	≈ 60°C	0.2-3
	Shrinky Dink	Stiff low elastic	Brittle very fragile	✓	60%	60°C	0.2-0.5
Shrinky Film	PE	Flexible low elastic	Flexible durable	✗	30%	65°C	0.02-0.08
Shrinky Film	PVC	Brittle low elastic	Brittle fragile	✓	60%	50°C	0.03-0.12
Shrinky Film	POF	Flexible low elastic	Flexible durable	✓	40%	60°C	0.005-0.04
Organza	Aegean Seersucker Organza	Flexible medium elastic	Little brittle little fragile	✓	37.5%	90°C	0.1-0.2
Organza	Seersucker Organza	Flexible medium elastic	Little brittle little fragile	✓	40%	90°C	0.2-0.3
	40D Nylon	Flexible high elastic	Flexible durable	✓	25%	100°C	0.2-0.3

Material: Recommend / Alternative / Not Recommend

Figure 3: A table of properties for base layer materials.

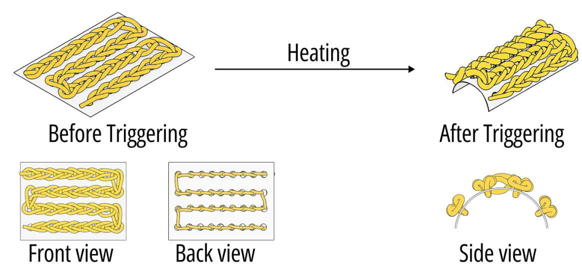

Figure 4: EmbroChet Mechanism: The denser front layer shrinks less, while the looser back layer shrinks more, inducing controlled bending.

3.2 Stitch Method and Hybrid Structure

The shape-changing behavior of EmbroChet is rooted in stitching techniques. This section details how these methods are employed to induce controlled deformation.

The chain stitch, a fundamental technique in both embroidery and crochet, enables diverse textile forms. In embroidery, it creates decorative patterns through interconnected loops, while in the 16th century, it was adapted to crochet "chains in the air" [29], allowing 3D structures to be constructed directly through yarn manipulation without a base fabric. EmbroChet builds on this technique by applying chain stitches to heat-shrinkable films, enabling the hybrid structure to achieve a 3D crochet-like effect after heating.

The deformation is driven by the composite structure formed by chain stitches. As shown in Figure 4, each stitch consists of two strands of yarn on the front side and one strand on the back. When the middle layer of the film shrinks, it pulls the upper and lower yarn layers closer together. This causes adjacent yarn columns to converge, with the denser front layer shrinking less and the looser back layer contracting more, resulting in a bending effect.

3.3 Fabrication Workflow

This section outlines detailed fabrication workflow and users can create shape-changing textiles through following steps:

Step1: Computer-Assisted Base layer Design. The design software tool is implemented as a Grasshopper plugin within the Rhinoceros 3D environment. It allows users to create parametric 2D base layer patterns and preview deformation behaviors using

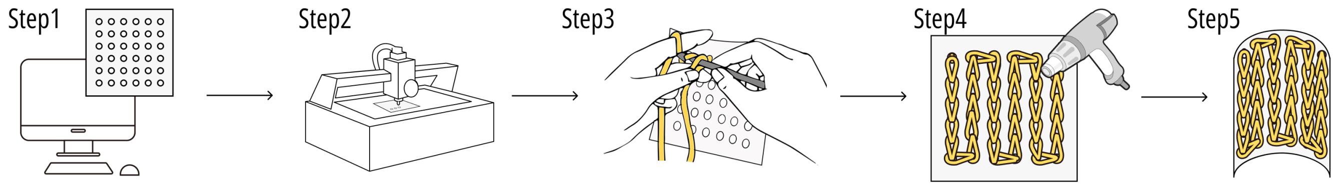

Figure 5: EmbroChet Workflow: Step 1: Design pattern on the base layer with the software tool; Step 2: Laser-cut thermally responsive materials; Step 3: Thread yarn on the base layer; Step 4: Heat to create the desired 3D shape; Step 5: Post-process after the fabric cooled.

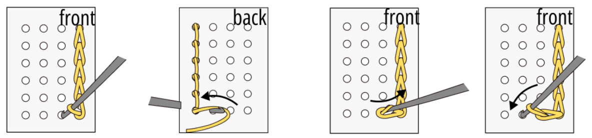

Figure 6: Threading Process: (1) Hold the crochet hook in right hand and insert it into designated hole; (2) Use left hand to guide the yarn, wrapping it around the hook; (3) Pull the hook through, drawing the loop of yarn out of the hole; (4) Proceed to the next hole. Repeat these steps until all holes are filled.

Figure 7: Using a thermal imaging camera, we monitored temperature changes during textile deformation. The textile surface reached 63°C, within the yarn's heat tolerance limits.

the simulation feature. Once satisfied, users can export the final path file in DXF format for cutting. Detailed installation and usage instructions are provided in Chapter 6: User Interface.

Step2: Laser-Cutting of the Base layer. Users can select heat-shrinkable materials like POF or organza as the base layer, with laser cutting serving as the primary digital fabrication method for creating precision perforations. Laser power settings will impact cutting results: excessive power causes material scorching and hole deformation, complicating subsequent steps, while insufficient power results in incomplete cuts that impede yarn threading. For the 0.04mm POF film in this study, the laser cutting conditions using the Voiern 500W system were set at 12% laser power and a cutting speed of 80mm/s. Alternative perforation methods include die-cutting can also be used to create holes.

Step3: Threading with Chain Stitch. As shown in Figure 6, users can create chain stitches along pre-designed paths using a crochet hook, threading yarn through perforated holes in the film substrate to form composite textile structures.

Step4: Heating Process. Users can shape the composite into the desired 3D form using a heat gun or household hairdryer. For optimal results, use a heat gun at 120-130°C, keeping it 5-10 cm away from the fabric. At this distance, the surface temperature reaches approximately 60°C (in Figure 7), inducing significant shrinkage. However, heating above 150°C may risk rupturing the middle layer.

Step5: Post-processing. After the heating process, users can employ further post-processing techniques such as trimming to expand design possibilities. The heat-shrinkable film remains embedded within the textile, and subsequent softness tests were conducted to evaluate its properties in Chapter 5: Evaluation.

3.4 Parameter Customization

Users can achieve diverse morphological effects by adjusting various parameters. This section explores customizable parameters to enhance control over deformation, improve the method's usability, and generate foundational data for computational tool development. The fundamental parameters and experimental results for different parameter settings are shown in Figure 8.

Yarn weights were standardized according to the Craft Yarn Council classifications[1]: lace (0.5 mm), super fine (1.2 mm), fine (1.65 mm), light (2.2 mm), medium (3.0 mm), and bulky (5.36 mm). To account for hole diameter variances of ±0.05 mm caused by laser cutting precision, the parameter ***L'*** was introduced. 0.04 mm POF films combined with composite yarns (60% cotton and 40% acrylic) ensures consistent manufacturing across the workflows.

Yarn Compatibility. Yarns of different weights were threaded through base films with systematically varied hole diameters to assess threading effectiveness. The extremes of compatibility are illustrated in Figure 8 (a), with the relationship expressed as: D(max)=1.48W+2.60, D(min)=0.56W+1.02. This optimization enhances the manual threading experience by minimizing common issues such as wire slippage and film wrinkling.

Deformation Adjustment. Based on the yarn compatibility, the effect of various parameters on deformation is further adjusted. The influence of row gap on deformation performance reveals the following trend in Figure 8 (b): With smaller row gap, the bend angle was minimal due to insufficient base layer width to support deformation. As the row gap increased, the bend angle peaked and stabilized within a certain range, as the base layer had not fully shrunk before the fabric converged, allowing for optimal deformation. Beyond this point, further increases in row gap led to a gradual decrease in the bend angle, as the fabric could not deform adequately once the base layer reached its shrinkage limit.

[1]https://www.craftyarncouncil.com/standards/yarn-weight-system

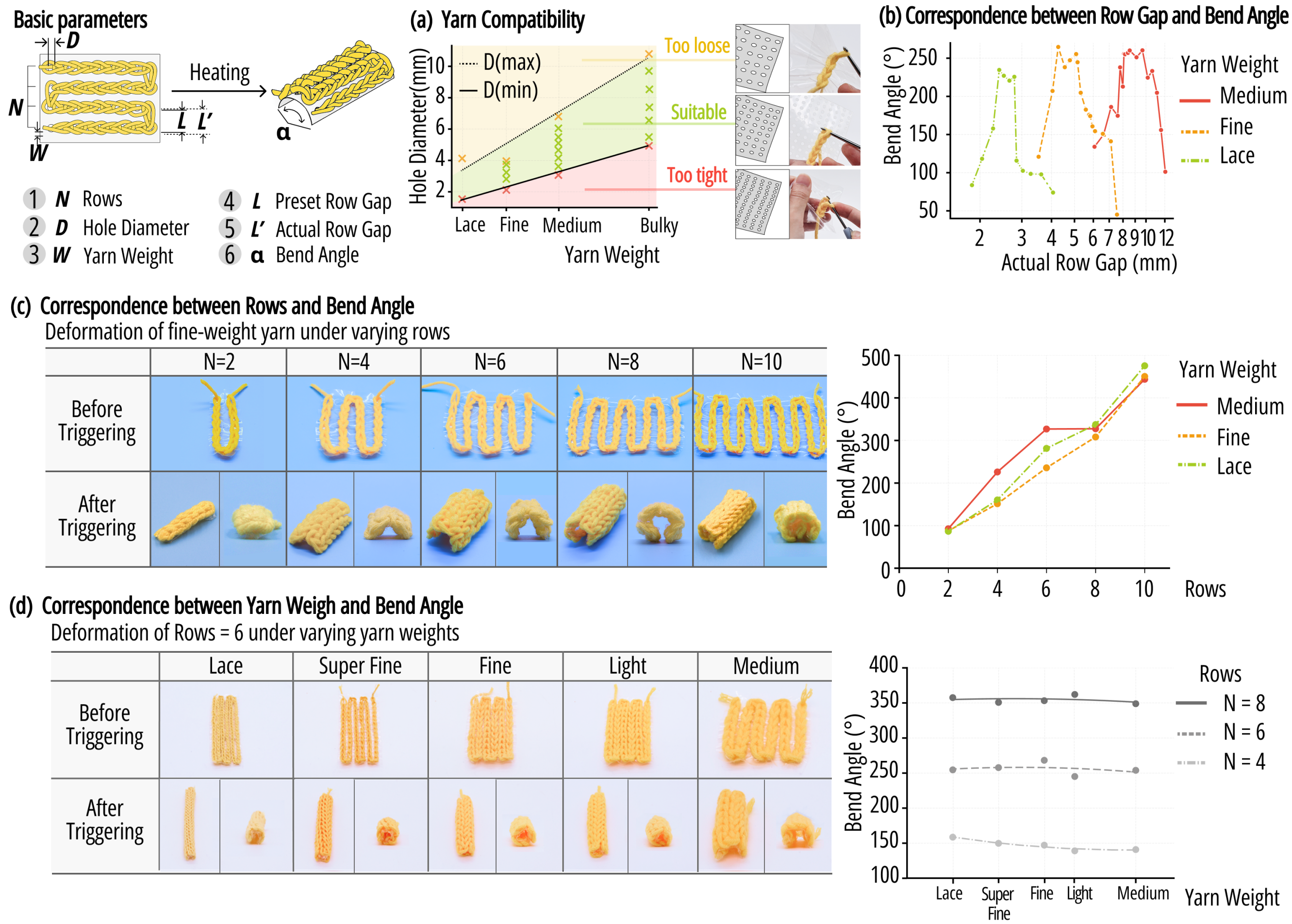

Figure 8: Basic parameters, yarn compatibility and adjustment of deformation parameters. (a) Plotting D(max) and D(min) to define the suitable range. Too Loose: larger Hole Diameter relative to the Yarn Weight results in loose and unstable stitches. Too Tight: smaller Hole Diameter makes threading difficult. Suitable: Proper Hole Diameter and Yarn Weight ensures uniform stitches, (b) Bend Angle (α) in response to Row Gap (L') under different Yarn Weight (W), (c) Bend Angle (α) in response to Yarn Weight (d) under different Rows (N), (d) Bend Angle (α) in response to Rows (N) under different Yarn Weight (W).

The samples also achieved the ideal bending angle across different yarn weight under the set number of rows in Figure 8 (c). This demonstrates the high adaptability of the EmbroChet method to different yarn weights while maintaining deformation control. Furthermore, there is a positive correlation between the number of rows and the bending angle in Figure 8 (d): as the rows increased, the bend angle also gradually increased. This trend was consistent across yarns of different weight.

Path Modification. Different combinations of adjacent holes create distinct paths. On the same base layer, varying hole connections result in diverse deformation outcomes, as shown in Figure 9. The four primary distribution patterns are Parallel Fill, Oblique Fill, Surround, and Radiate.

The parallel fill paths induce perpendicular curling, forming cylindrical structures. Oblique fill paths, when angled relative to edges, generate corresponding oblique curling. In contrast, surround-type paths produce uniform spherical bulges, while radiate-type paths create conical shapes through produce bulging effects with a steeper gradient. These path modification guide the summary of shape-changing library in the design sofware tool.

4 DESIGN SPACE

Based on EmbroChet method, this section presents a comprehensive shape-changing library and a set of hands-on design techniques for users to offer greater creative possibilities.

4.1 Shape-Changing Library

EmbroChet enables the creation of complex geometric morphologies and surface textures through diverse path designs. This section investigates the correlation between target 3D forms and 2D base

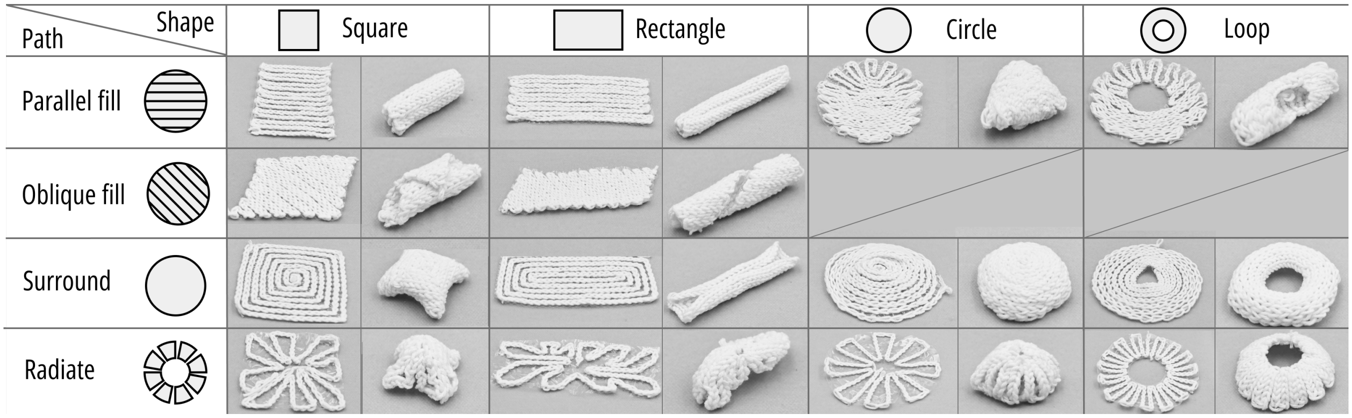

Figure 9: The deformation effects of four base shapes : square, rectangle, circle, and loop under four path distributions: parallel fill, oblique fill, surround, and radiate.

layer patterns through three key components: (1) Primitives defining fundamental deformation mechanisms, (2) Categorized libraries documenting various types of morphologies, (3) Selection of base layer materials (Figure10). Specifically, we summarize two primitives to explain the mechanisms and three structural examples of the deformation for quick use.

Shape-changing Primitives

- **Curving Mechanism.** When the row spacing falls within the optimal range for bending (marked red in Figure 10), the textile undergoes uniform deformation upon heating, exhibiting a curved profile in the side view.
- **Folding Mechanism.** When the row spacing is non-uniform — with the central region within the optimal bending range and the sides exceeding it (marked in blue in Figure 10) — the textile contracts without bending, remaining planar and producing a folded side profile.

Shape-changing Libraries

- **Geometry Library.** Path Test reveals that different organization strategies of path lead to distinct morphological trends. This section combines Parallel Fill, Oblique Fill, Surround, and Radiate path patterns to achieve diverse geometries, including cones, spheres, cylinders, and hyperboloids.
- **Folding, Weaving & Concave-convex Library.** Controlling path spacing and combining weaving techniques can produce diverse textural effects. For instance, Folding ① and Weaving ② leverage spacing to create folding and undulating patterns, while Weaving ③ and Concave-convex ① employ front-and-back threading. Folding ③ and Weaving ④ integrate both approaches to achieve visually striking outcomes.
- **Hollow & Fluffy Library.** Introducing subtle stitch variations can yield unique textural effects. For example, stitching closely spaced points while leaving straight threads between wider spans creates the Hollow ② effect. Executing the first two steps of the stitch method (in Figure 6) repeatedly produces the looped texture in Fluffy ①, while elongating and cutting the loops achieves the fringe effect in Fluffy ②.

4.2 Hands-on Design Techniques

This section summarizes several techniques for achieving richer shape effects, as illustrated in Figure 11, complementing the EmbroChet method. Additionally, case studies highlight the effectiveness of these techniques in creating complex-shaped textiles. **Shape-Control Techniques**

- **Technique 1: Front & Back Threading.** Traditional crafts utilize stitch front/back variations to enhance visual and tactile qualities. Expanding on this, Front & Back Threading technique (Figure 11a) enables stitch switching across the film. By strategically distributing yarn volume between sides, geometric control over the final wave shape can be achieved.
- **Technique 2: Front & Back Heating.** The asymmetrical distribution of yarn across the two sides governs the deformation behavior under heating (Figure 11b). When the denser front side is exposed to heat, it restricts thermal transmission, resulting in planar shrinkage. In contrast, heating the sparser back side allows greater exposure of the base layer, leading to back-gathering and global bending.

Additional Techniques

- **Technique 3: Yarn Combination.** Traditional yarn-switching methods involve complex thread-end concealment and tension maintenance. The Yarn Combination technique simplifies this process by utilizing heat-shrinking holes to secure yarns (Figure 11c). This approach enables distinctive aesthetic effects and deformation textures, with alternating thicker and thinner lines creating an embossed appearance.
- **Technique 4: Pull Out.** Beyond thermal shaping, the target form can be achieved by placing yarn at specific holes and then pulling the yarns. For example, spherical forms can be created by decomposing the shape into curved surfaces and threading apex holes to gather and assemble the components (Figure 11d). The base layer enhances threading flexibility, offering interactive potential.
- **Technique 5: Trimming.** Unlike traditional crochet, where cutting a single yarn strand can unravel entire piece, EmbroChet maintains structural integrity during continuous trimming. This allows for precise shapes without compromising fabric coherence (Figure 11e), enhancing design flexibility.

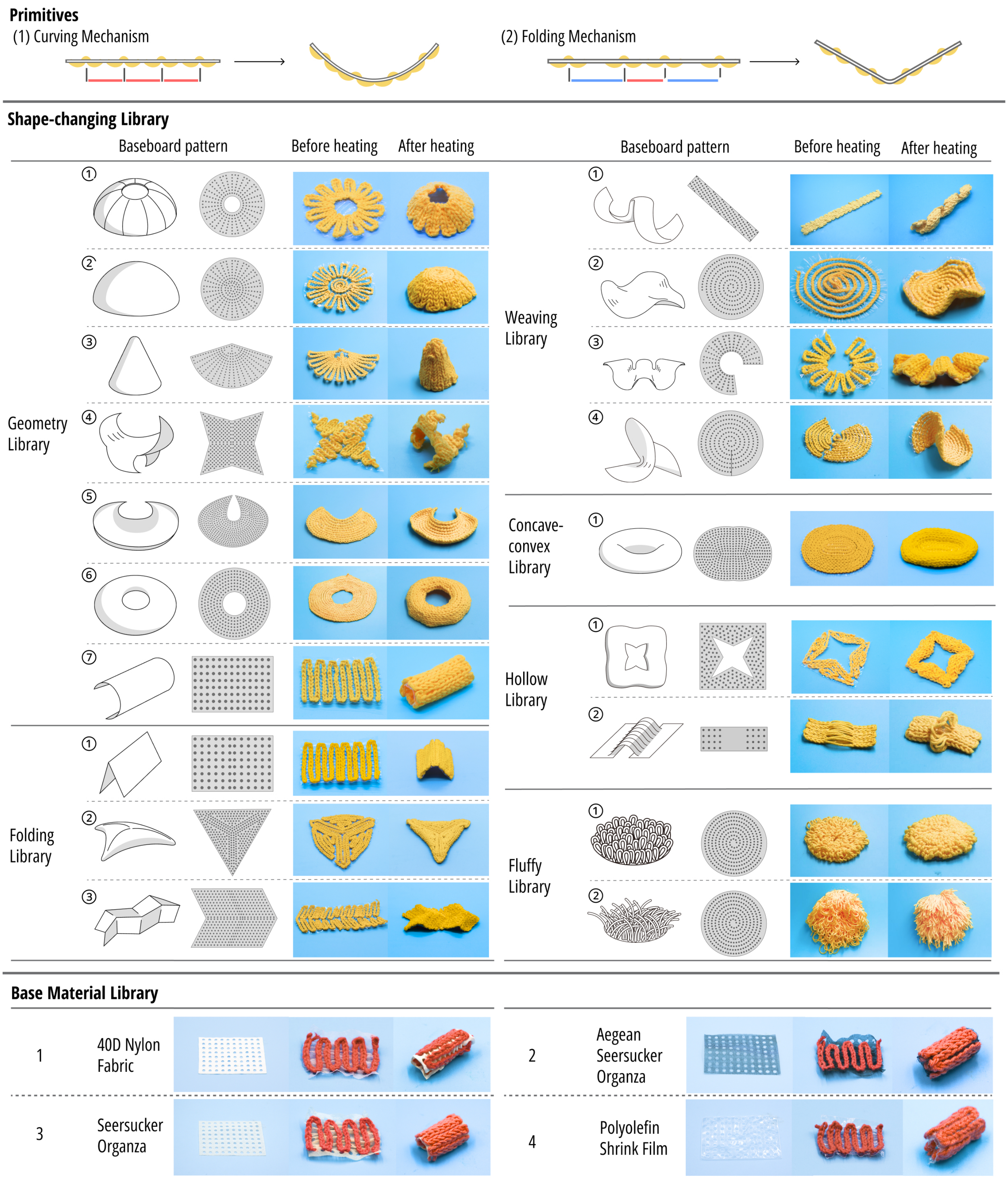

Figure 10: Shape-changing library: (1) Primitives: Row gap affects the basic deformation method, including curving and folding; (2) Shape-changing library of geometric form and the texture of textile, deriving various shapes such as curves, folds and waves; (3) Base materials library describes what types of materials can drive deformation.

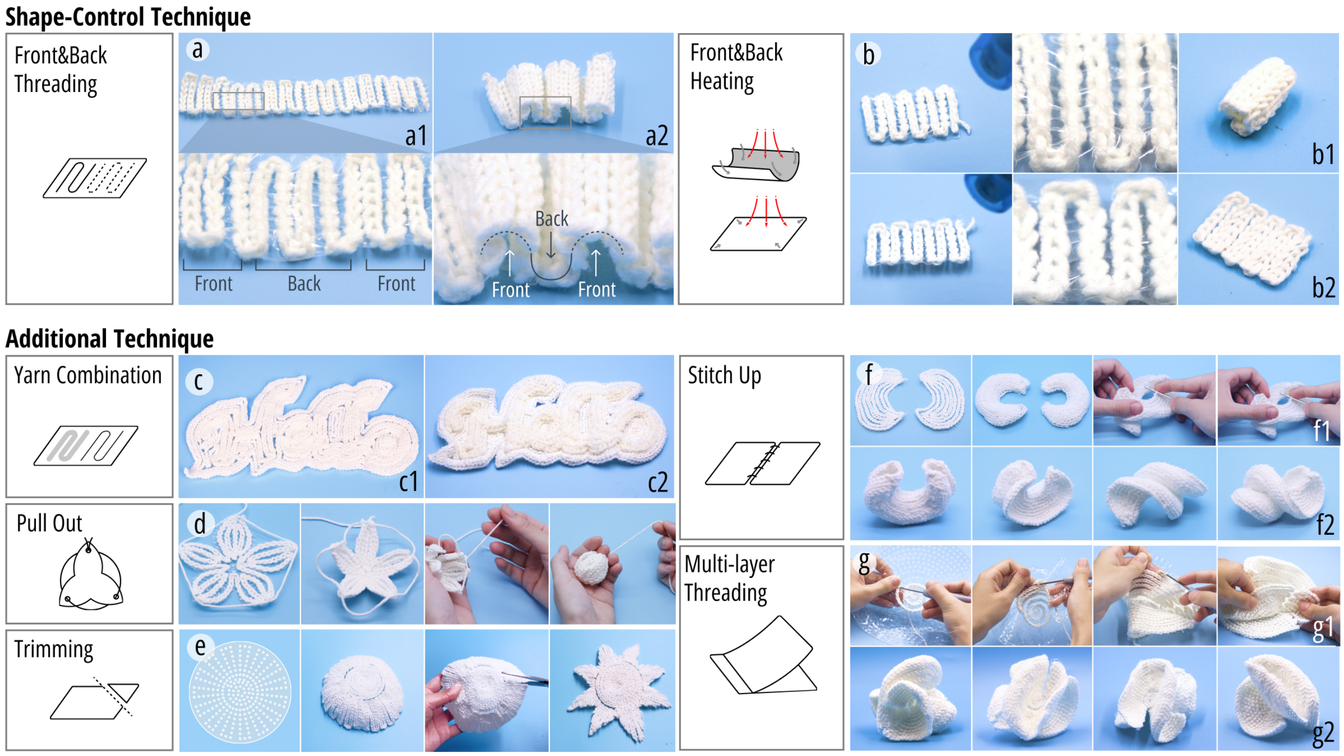

Figure 11: Summarized techniques to achieve richer shape effects. Shape-Control Techniques include Front & Back Crocheting and Front & Back Heating. Additional Technique such as Pull Out, Stitch Up and Multi-layer Threading.

- **Technique 6: Stitch Up.** Traditional crafts build large, complex works by stitching together smaller pieces—an approach adapted here to construct composite surfaces from modular sections. It also introduces controlled flexibility variations within the fabric, thus endowing the combined textile with special properties, such as multi-stable shapes (Figure 11f).
- **Technique 7: Multi-layer Threading.** The overlapping base layers allows for flexible assembly, where multiple layers can be integrated or separated to create richly shaped fabrics. For merged sections, identical pathways allow single-yarn threading across layers (Figure 11g), while separable sections maintain independent threading per layer.

5 EVALUATION

Textiles have to meet user standards for comfort, durability, and functionality. To evaluate these, we compared traditional textiles with EmbroChet samples (Figure 12,13). The traditional sample utilized crochet short-stitch techniques to resemble EmbroChet's texture, while both samples used lace, fine, medium-weight yarns (60% cotton, 40% acrylic) and 0.04 mm POF films.

5.1 Softness Test

Since heat-shrinking film becomes tougher when heated, we compared the softness of an EmbroChet sample with that of a crocheted sample (Figure 13).

Both samples were approximately 3mm-thick and 120×80mm rectangular pieces made with fine yarn. The EmbroChet sample is lighter, with looser row connections. In natural state, it drapes well and can be easily curled, similar to the crocheted sample. Moreover, The heat-shrinkable film, sandwiched between two yarn layers, contracts upon heating to pull surrounding yarns closer together while keeping the outer surface soft for skin contact.

5.2 Shape Resistance & Recovery Test

The mechanical properties of textiles determine their performance under pressure, strain, and daily wear. We conducted single and cyclic load tests to assess the ability of shape resistance and recovery. Both EmbroChet and crocheted hemispheres (25mm radius) exhibited comparable compressibility under pressure, achieving full deformation at 12.04N and 8.23N respectively (Figure 12a).

In terms of dynamic performance, we tested sample displacement under continuous pressing with a consistent force of 0.8N. The EmbroChet sample deformed less than the crocheted sample, showing about half the displacement. After pressing the sample 3000 times, the EmbroChet sample's displacement was 6.62mm, compared to 11.84mm for the crocheted sample (Figure 12b).

5.3 Thermal, Tensile & Breathability Test

Thermal insulation, tensility and breathability is essential textile properties that ensure adaptability across various environments.

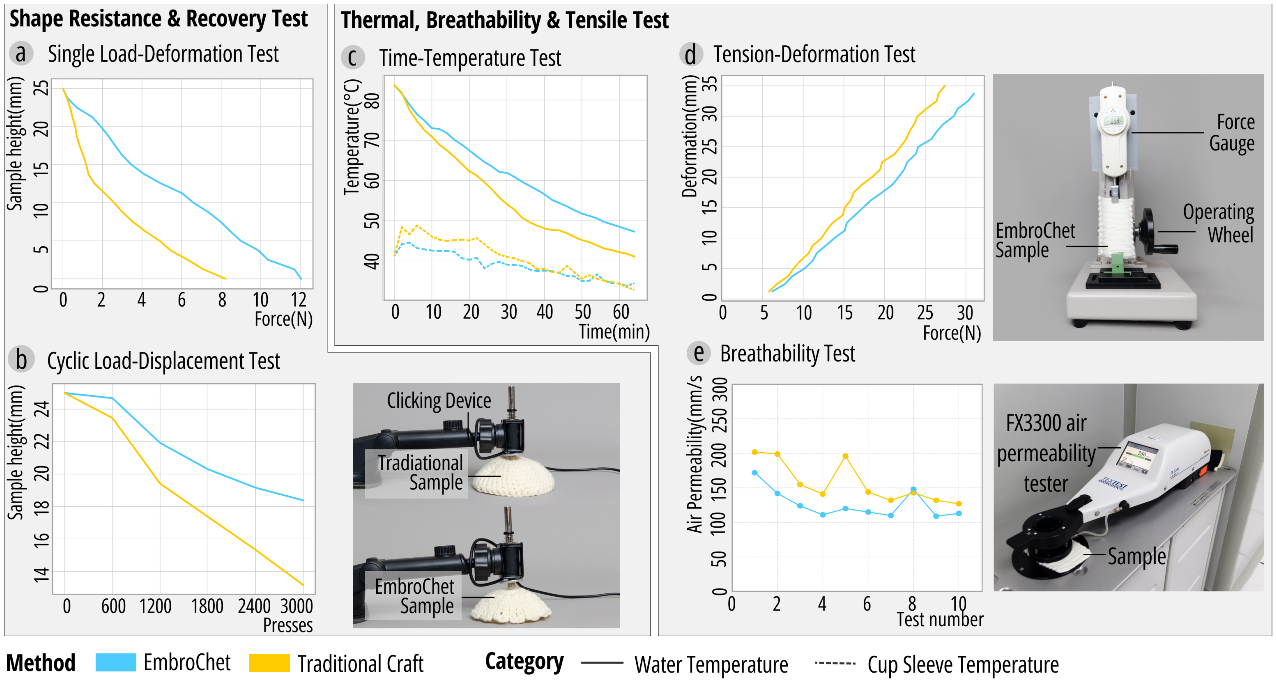

Figure 12: Evaluation of Shape Resistance & Recovery properties and Thermal, Tensile & Breathability properties of EmbroChet sample compared to traditional craft sample.

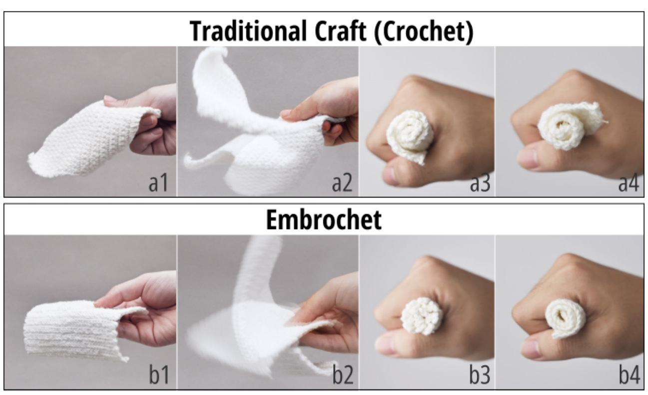

Figure 13: Softness comparison of lamellar samples: (a1, a2) Fabric gently swings in hand, while (a3, a4) curls into a tube. EmbroChet sample exhibited similar behavior, gently swinging in hand (b1, b2) and curling into a tube (b3, b4).

We compared thermal insulation and heat retention by making two cup sleeves of the same size using EmbroChet and crocheting with medium yarn. We monitored the water temperature and cup sleeve temperatures over time. The water in the EmbroChet group cooled more slowly. In the first 16 minutes, the temperature dropped by 13.6°C (from 83.7°C), while in the crocheted group, it dropped by 17.8°C. After 64 minutes, the temperature in the EmbroChet group stabilized at 47.3°C, while the crocheted group cooled to 41.1°C (Figure 12c). During the same period, the surface temperature of the EmbroChet cup sleeves was approximately 0.9 times that of the crocheted. These results demonstrate that EmbroChet sample offers thermal insulation and heat retention like crocheted sample due to the additional shrinkable layer.

We also conducted tensile tests to evaluate whether EmbroChet sample is as stretchable as crocheted sample. At the same tension, its stretch displacement was about 0.77 times that of crocheted sample (Figure 12d).

In terms of breathability, we conducted air permeability tests using an FX3300 Air Permeability Tester, following standard settings of 120 Pa pressure and a 20 cm² measurement area. To ensure reliable results, multiple measurements were taken across each sample and averaged. The tested samples (120 × 80 mm) were made with fine yarn (1.65 mm diameter), and both traditional crochet (short stitches) and EmbroChet samples had similar thicknesses ($\approx 3mm$). The results showed air permeability values of about 125-200 mm/s for traditional crochet and 105-175 mm/s for EmbroChet, indicating that EmbroChet retains breathability comparable to that of conventional textile structures (Figure 12).

6 USER INTERFACE

Building on prior explorations, we have developed an integrated design software that incorporates a shape-changing library to expand users' design possibilities. To facilitate a complete digital design workflow, we have deployed a static site on GitHub Pages, utilizing GitHub's robust hosting infrastructure for open-source

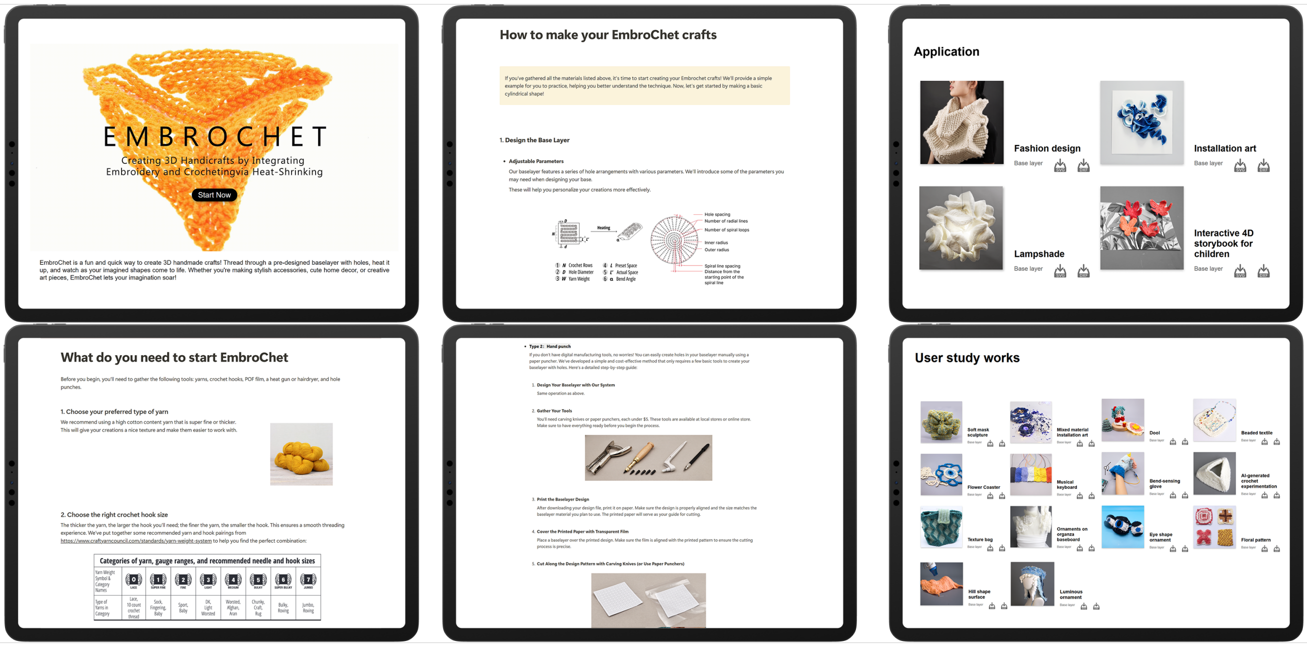

Figure 14: The website provides detailed steps on what users need to prepare and how to begin the crafting process. Additionally, it offers all the baseboard files, available in both SVG and DXF formats.

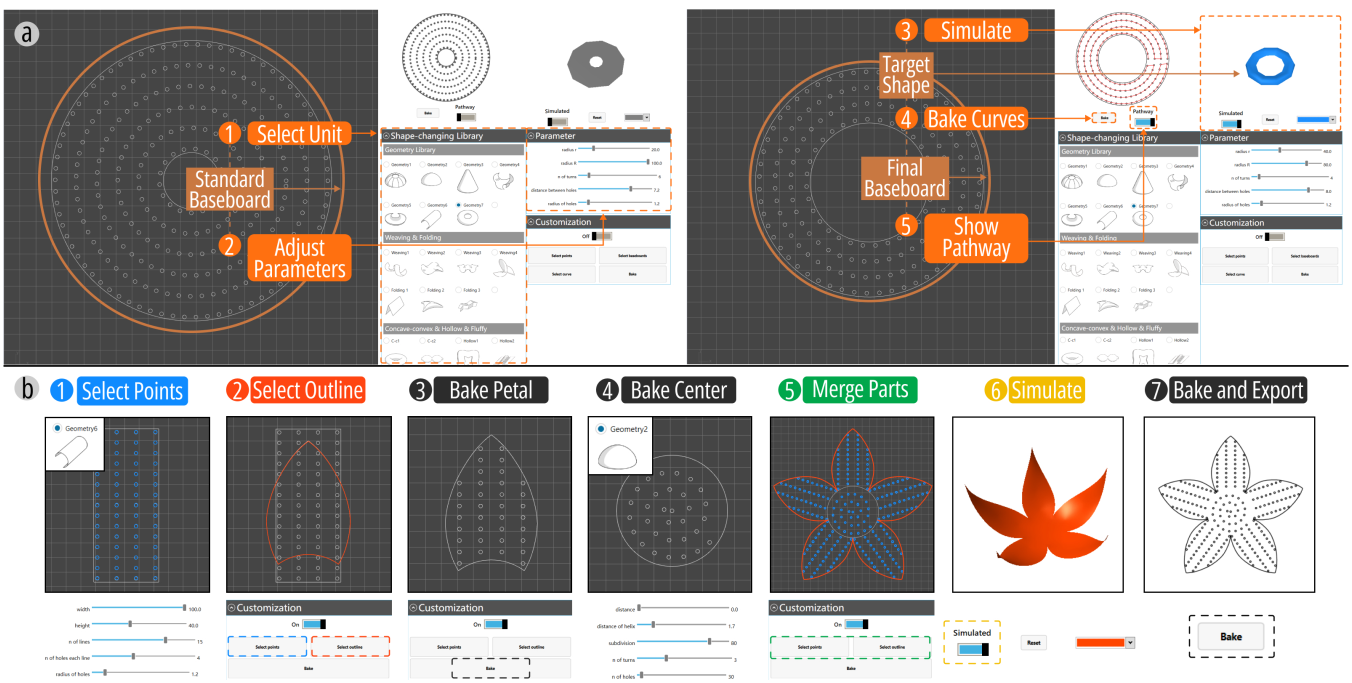

Figure 15: The workflow of EmbroChet design tool. Modifying standard shape-changing library: (a1) Select a shape-changing unit, (a2) Adjust the structure parameters, (a3) Simulate the effect, (a4) Bake curves. Customization: (b1) Select desired points, (b2) Draw and select your outline. (b3) Bake the petal base layer, (b4) Bake the center base layer, (b4) Merge all base layers, (b5) Simulate the effect, (b6) Bake the curves and export them in DXF format for cutting.

projects. The website[2] displays the existing base layers from the shape-changing library and provides guidance on exploring and selecting suitable designs. Users can follow the website's instructions to install the auxiliary design software tool and access a wealth of design resources to support their creation process.

The aforementioned design software tool was developed within Rhinoceros 7[3] as the design environment. The tool leverages Grasshopper[4], the visual programming language of Rhinoceros, and Human UI[5], a Grasshopper plugin, to create a visually interactive and user-friendly interface.

The user workflow involves selecting a unit from the shape-changing library, specifying parameters, previewing the base layer, simulating deformation, and generating cutting files. Most shape-changing units are composed of four basic patterns: parallel lines, spirals, concentric circles, and radial lines. Additionally, The design software tool offers customization features, allowing users to determine the base layer's shape and size. The tool employs the Kangaroo solver for simulation, which synchronizes with user adjustments to base layer parameters.

6.1 Tutorial Website

To assist beginners in creating 3D textiles, we have developed a Tutorial Website that provides a step-by-step guide through the process. The tutorial covers essential techniques and fabrication steps, including selecting appropriate yarn and crochet hook sizes, gathering base layer materials, and preparing heating and cutting tools. Additionally, the website features a resource library that includes case studies, user-generated designs, and open-source baseboard data to inspire and support users in their creative endeavors.

Designed with usability principles in mind, the website ensures a clear information hierarchy and smooth interaction flow. Figure 14 highlights some of its core content.

6.2 Modifying Standard Shape-changing Library

The design process follows a systematic workflow that guides users from initial selection to final fabrication-ready output. This four-stage approach enables both novice and experienced designers to effectively utilize the shape-changing library while maintaining creative control throughout the development process.

Choose a Shape-Changing Unit. The design software tool consists five categories of the shape-changing library: geometry, folding, weaving, concave-convex, hollow, and fluffy (Figure 15a1). Each category contains multiple shape-changing units, offering users a diverse selection to suit their needs.

Specify the Structure Parameters. Each shape-changing unit allows users to specify parameters, resulting in different deformation effects (Figure 15a2). Users can adjust the corresponding parameters by moving sliders on the interface. For example, in the geometry7 *torus*, users can modify parameters such as the inner and outer radius of the ring base, the number of concentric circles, the spacing between holes, and the hole radius. As users adjust the parameters, the changes to the base layers are displayed in real-time.

[2] https://mossinblue.github.io/Embrochet2025/
[3] https://www.rhino3d.com
[4] https://www.grasshopper3d.com
[5] https://www.food4rhino.com/en/app/human-ui

Simulation. The design tool allows users to preview simulated results of the base layer after threading and heating (Figure 15a3). This feature supports iterative adjustments of parameters, enabling users to refine their designs until the desired outcome is achieved.

Bake Curves and Show Pathway. After achieving the desired results in the preview, users can click the "Bake" button to bake the curves into Rhinoceros (Figure 15a4) and switch the toggle to see the pathway. The baked results can then be exported in DXF format for cutting.

6.3 Customizing Target Outline

Beyond predefined templates, our tool enables full customization of shape-changing structures through an intuitive outline editing workflow. This process empowers designers to create unique base layers tailored to specific functional or aesthetic requirements.

Select Customized Outline. Once the user finalizes the shape and position of the curve, they can click the "Select points" button to choose the desired points (Figure 15b1), then click the "Select outline" button to select the outline (Figure 15b2). The design tool will automatically generate the final base layer.

Merge Multiple Baselayers. The principle of merging multiple base layers is essentially the same as customizing the outline. Users need to select the desired points and outline to complete the merging process (Figure 15b5). The design tool will eliminate points that are too close together to prevent issues during laser cutting.

Preview and Export. After selecting the points and outline, users can view the base layer in the UI and enable the simulation feature to preview its deformation after threading and heating (Figure 15b6). This allows for iterative design, minimizing trial-and-error costs. Once satisfied with the results, users can click the "Bake" button to export the curves in DXF format (Figure 15b7).

7 APPLICATIONS

Building on the shape-changing libraries and hands-on strategies, we present a series of applications to demonstrate the extensive application space with EmbroChet.

7.1 Fashion Design.

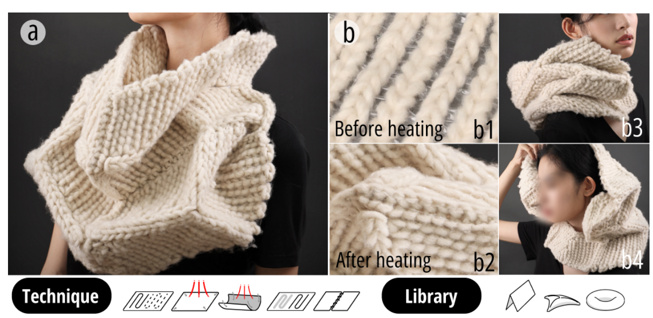

Figure 16: Fashion and clothing design. (a) A textured scarf using the folding library, (b1,b2) Textile before and after heating, (b3,b4) Various forms of wearing styles.

EmbroChet facilitates the creation of sculptural yet soft fabric forms for fashion design, merging foldable structures with comfortable textures. For example, we developed this garment by scaling up the base layer and employing bulky yarn for enhanced texture, inspired by the multi-folding library (Figure 16). We produced two fabric components using Front & Back threading and heating techniques and assembled into a versatile, multifunctional scarf.

7.2 Life Aesthetics.

EmbroChet empowers users to assemble organic forms (e.g., waves, hyperbolic surfaces) from the shape-changing library into functional aesthetic objects, including spherical lampshades (Figure 17) and decorative walls (Figure 18). The spherical lampshade demonstrates modular fabrication: adjusting parameters for target geometry, multiple hyperbolic fabric components are batch-produced and assembled through stitch-based joining.

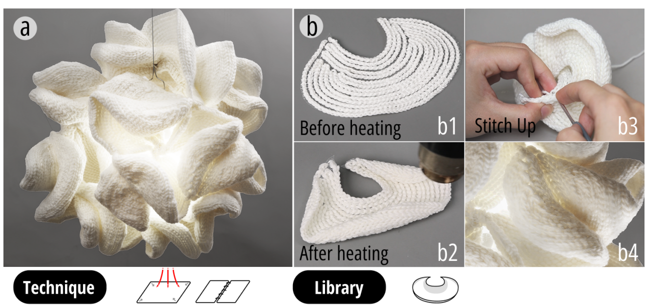

Figure 17: Lampshade. (a) Modularly assembled spherical lampshades. (b1,b2) Textile before and after heating, (b3) Stitching up elements together, (b4) Fabric close-up detail.

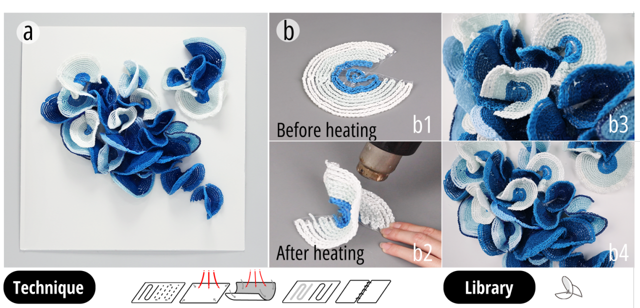

Figure 18: Installation art. (a) Wave artwork assembled from colorful modules. (b1,b2) Textile before and after heating, (b3,b4) Fabric close-up detail.

Similarly, we created the wave artwork by employing more complex base units, enhanced through color variation and front-back threading/heating techniques for organic curvature. Variably-sized modules are stitched to achieve layered, dynamic wave structures.

7.3 Augmenting Story-telling.

We integrated deformable elements into physical storybooks to enrich narratives through multi-dimensional sensory engagement, fostering vivid educational experiences (Figure 19). For garden-themed picture book, two interactive flower designs utilizing outline customization: a five-petal flower with inward gathering and a flat-to-wavy petal transformation. The fabrication process involved illustrating the background scenery with reserved interactive spaces, followed by creating multi-colored floral textile components that were attached to complete the interactive storytelling experience.

7.4 Functional Cushion.

EmbroChet enables circuit integration directly into the base layer, allowing personalized electronic functionality in everyday textiles (Figure 20). The impact of heating process on conductive performance depends on the type of conductive material. The resistance of carbon-infused threads decreased during heating and returned to baseline after cooling.

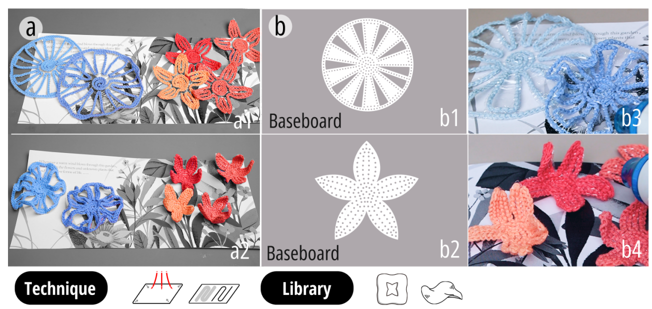

Figure 19: Interactive storybook. (a) Transformation of the picture book before and after triggering. (b1,b2) Base film shape, (b3,b4) Close-up schematic of textile deformation.

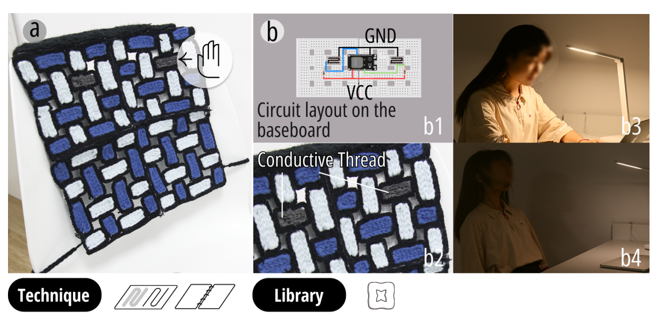

Figure 20: Functional Cushion. (a) Customised cushion with conductive thread. (b1,b2) Base film shape and circuit layout, (b3,b4) It detects user's movements that stretch the conductive yarn, causing resistance changes to control the lighting.

8 WORKSHOP AS EVALUATION

We organized a workshop to evaluate the usability of EmbroChet, gathering feedback and exploring its application potential. This section covers participant details, workshop process, analysis of questionnaire data and outcomes.

ID	Sex/Age	Background	Textile Experience
P1	Female 21	Intelligent Engineering and creative design	Never tried handcrafting
P2	Female 21	Museum staff interests in Integrated material fabric design	Crocheted for 3 years as a hobby
P3	Female 22	Student majors in Interior Design	Crocheted for 5 months as a hobby
P4	Female 21	Student majors in Digital Media & Technology	Embroidery beginner
P5	Male 24	Student majors in Industrial Design	Never tried handcrafting
P6	Male 24	Student majors in Electronic Science keening on music	Once made a crocheted doll, but didn't turn out very well
P7	Female 22	Student majors in Geographic Information Science	Never tried handcrafting
P8	Female 26	Student majors in Graphic Design & Social Design	Embroidery beginner
P9	Female 21	Student majors in landscape design and loves crocheting dolls	Crocheted for 2 years as a hobby
P10	Female 22	Student majors in intelligent manufacturing	Beaded for 3 months as a hobby
P11	Male 22	Student majors in Industrial Design Engineering	Never tried handcrafting
P12	Male 28	Master student majors in Architecture keening on AIGC	Never tried handcrafting
P13	Female 22	Designer works in Institute of Media and interaction	Making stoneware clay crafts
P14	Female 22	Student majors in Industrial Design	Crocheted for 1 month as a hobby
P15	Male 23	Student majors in Environment Design	Crochet beginner
P16	Female 20	Student majors in Visual Culture	Knitting and sewing as a hobby

Figure 21: Participant information on basic information, background and textile experience.

8.1 Participants and Procedure

We recruited participants through social media (Figure 21). The 16 participants (11 female, 5 male; aged 19-28) included 8 from engineering/technology and 8 from art/design backgrounds. Half had prior digital fabrication experience (e.g., 3D printing), while 11 had varying textile expertise and 5 were novices. All participants provided informed consent and received $40 for their participation. Our workshop process is structured as follows:

- **Pre-interview**: Participants signed informed consent forms and completed a 20-minute semi-structured interview to assess their textile experience and creative expectations.
- **Skill Learning and Practice Session:** Participants were provided with instructional videos, a printed user manual about how to use design space and assistant design tool. They were trained in base skills, including threading chain stitches directly on the base layer, identifying the optimal temperature range and the suitable distance between the heat gun and fabric. This content was integrated into our website. They practiced designing and adjusting base layers on pre-installed tools, with staff available for support.
- **Freestyle Creation:** Participants brainstormed in groups to foster ideation, supported by a variety of hooks and yarns. They were given one week to complete their projects, with regular progress updates to track their creative endeavors. Most finished in 5 hours, spread over 3-7 days.
- **Post-interview:** Participants engaged in a semi-structured interview to discuss experiences and challenges. They also completed a self-assessment questionnaire on their designs and a system usability scale (SUS) to evaluate the method. Finally, they were asked for permission to open-source their work on project website.

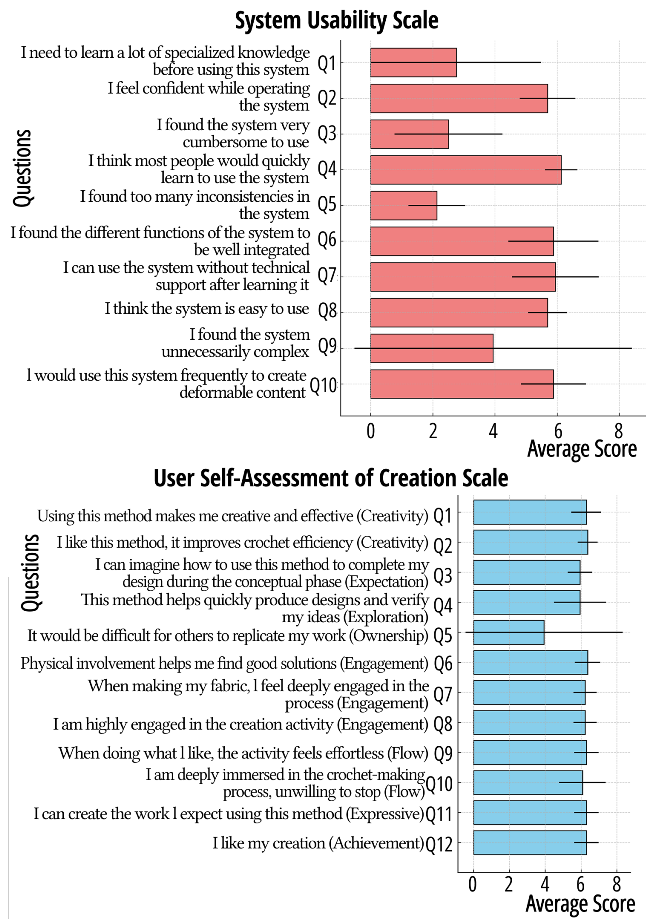

Figure 22: The Result of System Usability Scale and User Self-Assessment of Creation Scale analysis of users.

8.2 Quantitative Result

To evaluate system usability, participants completed a seven-point System Usability Scale [4] (1: strongly disagree, 7: strongly agree). Most found the system easy to learn (Q4), user-friendly (Q2, Q7), and well-integrated (Q6), with features that were easy to use (Q8) and supportive of current and future creative processes (Q10). However, opinions varied on the system's prior knowledge requirements (Q1: M=2.75, SD=1.65) and perceived complexity (Q9: M=4.12, SD=2.11).

Participants also assessed their creative process using a seven-point Creativity Stimulation Scale [7]. Results showed that EmbroChet enabled creative expression (Q1) and met design expectations (Q4, Q11), with many describing the process as enjoyable and immersive (Q8, Q9). Reproducibility ratings varied (Q5: M=3.93, SD=2.02), as some relied on universal shape-changing libraries while others incorporated custom designs or additional crafts, increasing complexity.

8.3 Outcomes

Participants created diverse works using EmbroChet (Figure 23). Some retained traditional styles incorporating original ideas (P7, P9, P14), while others innovated by integrating cross-disciplinary techniques, revealing additional advantages of EmbroChet (P1, P2, P10, P12). Several works embedded electronic circuits into the fabric (P5&P6, P11).

8.4 Findings

8.4.1 Challenges in the Fabrication Process.

Software Usage. We observed differences in users' reliance on and exploration of the shape-changing library, with varied responses to the statement "I found the system unnecessarily complex" (M=4.12; SD=1.84). Novice users heavily relied on the library but utilized it differently: some adjusted parameters of basic shapes (e.g., P2, P13), while others, overwhelmed by the dense interface, stuck to default settings (e.g., P10, P15). This underutilization contributed to perceptions of unnecessary complexity.

Experienced users were neutral about the library, as they could create classic shapes (e.g., spheres) using familiar stitches. However, they valued advanced libraries (e.g., Folding, Concave-Convex) for enabling traditionally challenging shapes and appreciated the selective heating feature, which supports shaping via external forces. They noted that the current yarn thickness limits fine detail control (P15), motivating future development of advanced editing tools for personalized 3D surface calculations and shape customization.

Some users found the library and tools insufficient for planar pattern design. They designed flat shapes manually and used the design tool to fill them (P4) or redesigned 3D shapes independently (P12). The lack of automated path generation for custom base layers and combined deformation previews reduced practicality, requiring manual sketches (P9) or iterative ideation (P1), which impacted efficiency. These insights guide future tool optimizations. Participants also mentioned current barriers to adoption, such as the need to download Rhino and install plugins. They expressed interest in a material toolkit: "I would not hesitate to purchase a toolkit with film and recommend it to novice friends" (P9). In response, we created an open-source website for direct resource access.

Hands-on Practice. Despite guidance provided through user manuals and group sessions on controlling hole spacing and achieving evenly heating, users still faced challenges during hands-on practice. In traditional methods, controlling textile size is difficult due to yarn choices and tension application, often requiring to increase or decrease stitches depending on the situation. While our method eliminates stitch calculations, there also exist shortcomings in controlling the size and shape of the textile. During film threading, excessive spacing (beyond recommended parameters) and improper tension caused wrinkles or final sizes smaller than expected. Although moderate tension differences do not significantly affect shape, they confuse users (P5) and complicate subsequent steps. To address this problem, users also figure out some solutions, such as adjusting heating time to control shrinkage degree.

However, controlling the heating time introduced new challenges. The film's limited temperature tolerance meant that exceeding the threshold could cause melting. Since the heating process is not directly visible to users, it was difficult for them to judge the heat limits accurately. To expedite shrinkage for larger items, some users increased temperatures beyond recommendations, causing the film to tear. Others, lacking experience in judging shrinkage, either stopped heating prematurely (resulting in under-shrinkage) or continued past full shrinkage, damaging the film. To address these recurring issues, we updated tutorials with detailed reminders and enhanced website resources, including revised teaching details and video guides.

8.4.2 Advantages for Creation and Ideation.

How to Craft: Immersive Experience and Effortless Creation. EmbroChet streamlines handcrafting through predefined hole positions on the base layer while enhancing the immersive crafting experience. Beginners, often hesitant to attempt complex crochet shapes, found EmbroChet accessible for realizing their creative visions (M=6.29, SD=0.83). Novice participant P1 noted, "I've admired crochet works online but felt they were beyond my skill. EmbroChet only requires one stitch." Similar feedback was shared by participants by P4, P7, and P16. Users reported improved production efficiency (M=6.36, SD=0.74). P7, who crafted a textured handbag, explained, "The material's shrinkage replaces the need for precise stitch tension control, simplifying the process." Additionally, feedback highlighted EmbroChet's potential to assist special groups, such as the elderly, visually impaired, or individuals with limited dexterity. P4 shared, "My mother, a former crochet enthusiast, struggled due to declining vision. EmbroChet's pre-designed hole patterns made it easier for her to identify stitch placements."

EmbroChet enhances crafting experience by eliminating calculations through design tool. Threading repeating stitches allows users to become more immersed in the creation process. Users reported high engagement (M=6.35, SD=0.84) and deep immersion (M=6.07, SD=1.14). P7 remarked, "Handcrafting is therapeutic due to its thought-free nature. Traditional crochet requires learning new stitches, adjustments, and stitch count calculations."

How to Think: Empowering Creativity with Supportive Tools. EmbroChet enables users to realize creative concepts or reproduce admired works through its library. Most users reported confidently envisioning design plans to achieve desired effects (M=5.93, SD=0.83). Unlike traditional methods reliant on existing tutorials, P9 noted, "With EmbroChet, I can create unique cartoon characters and scenes without guides, which is convenient."

Another notable finding is that reproducibility elicited mixed responses. While some felt their unique ideas and techniques made

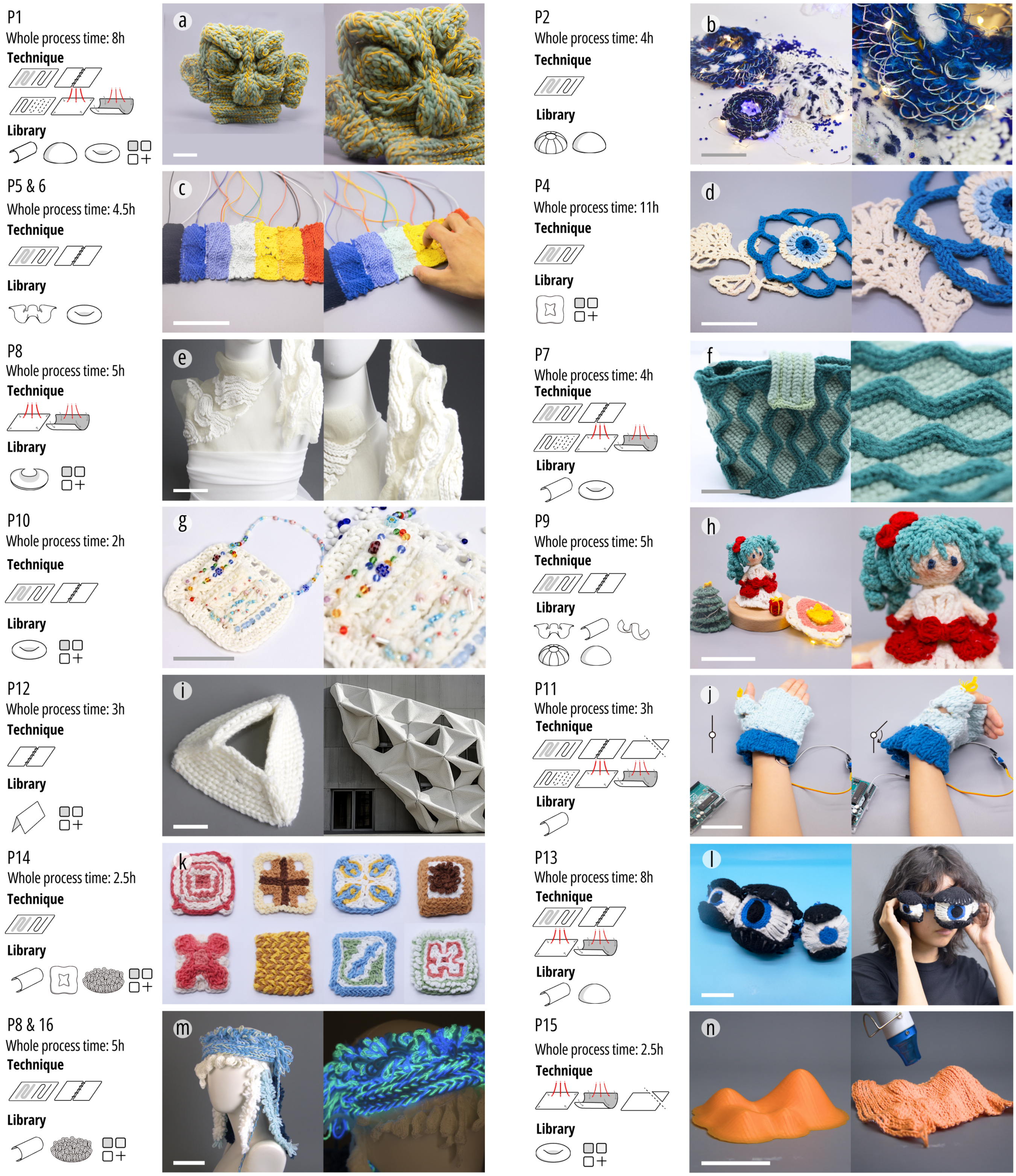

Figure 23: The showcase of the user study works. P1: Soft mask sculpture, P2: Mixed material installation art, P4: Flower Coaster, P5&P6: Musical keyboard, P7: Texture bag, P8: Ornaments on organza base layer, P9: doll, P10: Beaded textile, P11: Bend-sensing glove, P12: AI-generated crochet experimentation, P13: Eye shape ornament, P14: Floral pattern, P15: Hill shape surface, P8&P16: Luminous ornament.

replication difficult, others viewed their methods as shareable resources, highlighting it can foster community culture.

Users expanded beyond traditional textile applications, leveraging EmbroChet's unique advantages. P1 crafted a soft sculpture of the Sanxingdui bronze mask, achieving a sturdy shape more effectively. P8 created flexible accessories, stating, "The textured form is ideal for jewelry-comfortable and complementary to clothing." Others innovated techniques and materials: P10 and P14 added refined edges, while P2 combined materials for installations, noting, "This method achieves rigid 3D shapes unattainable with traditional crochet, and the holes allow free material overlays."

8.4.3 *Combinations of Traditional Craft and EmbroChet.*

Drawing Inspiration from Traditional Craft Techniques. Traditional craft techniques deeply inspired users during conceptualization and creation phases. P2 adapted the "float" technique from weaving, skipping holes to create a visual effect where fabric sections appear to float above the base layer. She also incorporated tufting methods, trimming the fabric to achieve a fluffy texture. P8, inspired by embroidery, replaced the POF film with organza—closer to traditional embroidery backing—and heated only one of two identical textiles, creating a flat-3D contrast.

Adapting and Enhancing Traditional Product Forms. Some users directly drew from classic textile styles, often refining techniques unconsciously during production. P10 mimicked beadwork by combining beads and yarn in dual-material weaving. Inspired by traditional beadwork—where beads are pre-threaded and selectively added—she first crafted the main body with thick yarn, then wove thin yarn and beads through it, enabling more flexible bead placement. P14, inspired by floral crochet motifs, used a 9×9 hole base layer, combining color blocks and cutting out hollow areas. She primarily heated the front side to achieve target shapes, enhancing traditional crochet with fluffy materials, interwoven textures, and created 3D textiles by heating pieces from the back.

Complementing Strengths and Selective Substitution. Some users integrated traditional methods with EmbroChet, selectively combining their strengths to address EmbroChet's limitations. Participants noted that EmbroChet's fabric texture and flexibility closely resemble traditionally crafted textiles, making the hybrid approach intuitive. For instance, P1 crafted 3D facial features (eyebrows, nose, eyes) for a mask using EmbroChet, then reinforced connections and added single crochet stitches for a cohesive finish. P9 created uniformly sized curls traditionally but used EmbroChet for hair with varying lengths and widths. She later employed the shape-changing library to design the doll's face and experiment with new skirt styles.

9 LIMITATION, DISCUSSION and FUTURE WORKS

9.1 Pathway Influence on Shape: Guiding Solutions for Improved Transformation

Although EmbroChet simplifies the manual stitching process for complex textiles, challenges remain in precise shape control. Threading path organization is crucial for final deformation, but current methods still rely heavily on experience to predict results. Our shape-changing library consolidates existing testing results to provide more accurate guidance. This library includes predefined patterns alongside specific paths in the design tool. Users can also follow these paths using printed manuals and the website. Additionally, path guidance has been embedded into base layer parameter setting shown in Figure 24. However, limitations in customizing paths remain, restricting flexibility in achieving diverse results. Our design tool, while effective for many parametric shapes, struggles with simulating complex structures like hollow or fluffy forms. These shapes pose difficulties in accurately predicting deformation, limiting their use in shape-changing applications. To address these challenges, we will further refine deformation simulation through more quantitative studies, enabling greater precision and flexibility in shape customization for broader applications. Furthermore, we will explore more intuitive guidance methods, such as printing threading paths directly onto base layer to improve user experience.

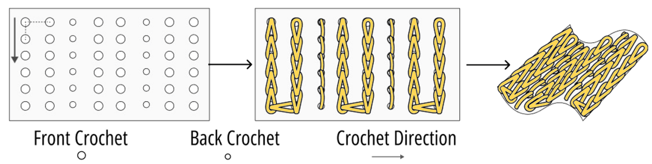

Figure 24: Holes of varying sizes and spacing are used to distinguish front& back thraeding and guide the path.

9.2 Facilitating Accessibility: Democratizing Digital Crafting Tools

POF film is a widely used packaging material with shrink properties similar to other packaging materials, while organza is a fabric commonly found in the apparel industry. Despite the ubiquity of materials like POF film and organza, EmbroChet offers a more customizable approach to creating deformable textiles compared to traditional craft, presenting challenges in its preparation process. Specifically, substrate perforation requires laser cutting equipment (e.g., Cricut or comparable systems starting at $200), which users identified as the primary adoption barrier due to equipment costs.

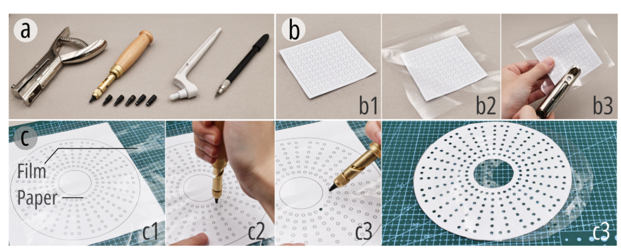

Figure 25: Cost-effective hole-making process and tools. (a) Four types of cutting tools. Punch, Paper Cutting punch, Rotating carving knife and Ceramic pencil sharpener. (b,c) Use cutting tools punch holes in the film along the pattern.

To reduce reliance on digital manufacturing tools, we propose a cost-effective method for creating holes in the base film (Figure 25). We sourced two carving knives and two paper punchers, each under $5, from local stores and online platforms. Users can print base layer designs at home using downloadable files from our website. By covering the printed paper with a transparent film and cutting along the pattern with the tools, both the paper and film can be cut simultaneously to create the base film with holes. This process takes approximately 15 minutes. In future work, we also plan to explore more possibilities of EmbroChet as a toolkit, allowing more users to access this technology.

9.3 Exploring the Synergy: Rethinking Hybrid Craft Through EmbroChet

Design Challenges and New Expressive Dimensions. EmbroChet introduces new design paradigms that depart from traditional shaping, bringing both challenges and opportunities for users across skill levels. For novices, the material-driven approach provides an exceptionally accessible entry point. As observed in our workshops, participants with no prior craft experience were able to transform simple creative ideas into tangible, complex 3D prototypes. While experts must adapt from direct manual control to "collaborating" with the material's behavior, they valued the ability to create visually striking forms that are difficult to achieve with conventional methods. This highlights EmbroChet's role not just as a tool, but as a catalyst for new aesthetic and structural expressions in fiber art.

The Role of Digital Tools in Supporting Diverse User Needs. Our findings highlight a crucial design tension between accessibility and control in digital crafting tools. Many novices and traditional crafters found the basic functionalities sufficient, valuing the direct, hands-on experience without advanced settings. In contrast, users with engineering or graphic design backgrounds appreciated the granular control offered by advanced features, such as adjusting the pattern to manipulate the final deformed shape. This finding suggests that a one-size-fits-all interface to digital craft tool design is suboptimal. Future digital craft tools should consider adaptive or layered interfaces, which provide a simple entry point for beginners while offering advanced functionality for experts. This ensures that a tool can support both immediate creative exploration and deep, long-term mastery.

Broader Implications for Textile and Digital Fabrication Research.

EmbroChet contributes to the growing body of research at the intersection of computational tools and traditional crafts, but its approach marks a departure from prior work. Much research has focused on digitally augmenting traditional techniques—for instance, using projection mapping to guide stitching or machines to automate weaving patterns. These methods often treat the digital and the traditional as separate layers, with the former assisting or guiding the latter.

In contrast, EmbroChet reinterprets traditional craft logic within a material-driven workflow. The crochet structure is not merely a passive recipient of digital instruction; it is a integral component whose interaction with the shrinkable film is the computation. This reframes the craftsmanship as a form of physical programming, where the final 3D form is an emergent property of the material system. By centering materials in the design process, EmbroChet extends the trajectory of hybrid craft, raising new questions about how computational principles can be embedded into materials to enable novel forms of making. It opens up future research avenues, such as exploring other "material grammars" by combining different smart materials with other traditional crafts thereby creating a richer and more integrated future for hybrid craftsmanship.

10 CONCLUSION

We present EmbroChet, a novel hybrid fabrication approach that bridges digital fabrication and traditional crafts to enable creation of 3D handicrafts. Combining heat-shrinkable films with chain stitching techniques, users can create intricate designs through heating. We summarized crafting techniques and provided a comprehensive shape-changing library. Based on parameter experiments, we introduced an assistant software tool that supports personalized design with visualized simulations. Through various applications ranging from fashion design to functional devices, we demonstrate EmbroChet's versatility. Workshop confirmed the tool's effectiveness and its potential to democratize 3D handicraft creation. Overall, we hope our research serves as a meaningful contribution to bridging traditional craft and digital technology. We hope to inspire further exploration and creativity in personal fabrication, opening new paths for engaging designs within the HCI community.

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