



DIGITAL SASHIKO: A COMPUTATIONAL FRAMEWORK FOR AUTOMATED TEXTILE REPAIR VIA ADDITIVE MANUFACTURING

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ABSTRACT: Extending the functional lifetime of garments is a critical pillar of textile circularity, yet manual repair remains a significant bottleneck due to the high level of skill and time required. The present research introduces “Digital Sashiko” a workflow that integrates computational design with additive manufacturing to automate the structural reinforcement of damaged textiles. Inspired by the Japanese tradition of visible mending, the proposed method utilizes Grasshopper™ to generate algorithmic patterns that are topographically mapped to specific garment tears.

The study investigates the use of Thermoplastic Polyurethane (TPU) for its high elasticity and superior interfacial bonding, ensuring that the mended area retains the necessary flexibility for wearable applications. By treating the textile as a primary substrate for direct-to-garment printing, this research explores the mechanical interlocking between the polymer and fabric weave to enhance garment longevity. This computational approach transforms the “visible mending” philosophy into a precise, scalable industrial process, addressing key barriers to clothing repair and advancing the goals of a circular fashion economy.

Keywords: 3D Printing, Sashiko, Grasshopper, TPU, Circular Design, Textile Adhesion, Visible Mending.

DIGITALNI SAŠIKO: RAČUNARSKI OKVIR ZA AUTOMATIZOVANU POPRAVKU TEKSTILA PUTEM ADITIVNE PROIZVODNJE

APSTRAKT: Produžavanje funkcionalnog veka trajanja odeće predstavlja kritičan stub cirkularnosti tekstila, ali ručni popravci i dalje predstavljaju značajnu prepreku zbog visokog nivoa veštine i vremena koje su potrebni. Ovo istraživanje predstavlja „Digitalni



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Sašiko“, tok rada koji integriše računarski dizajn sa aditivnom proizvodnjom kako bi se automatizovalo strukturno ojačanje oštećenih tekstila. Inspirisan japanskom tradicijom vidljivog popravljavanja, predložena metoda koristi Grasshopper™ za generisanje algoritamskih uzoraka koji su topografski mapirani na specifična oštećenja na odeći. Studija ispituje upotrebu termoplastičnog poliuretana (TPU) zbog njegove visoke elastičnosti i superiornog međupovršinskog vezivanja, čime se obezbeđuje da popravljeno područje zadrži neophodnu fleksibilnost za nošenje. Tretirajući tekstil kao primarnu podlogu za direktno štampanje na odeći, ovo istraživanje istražuje mehaničko preplitanje između polimera i tkanine kako bi se poboljšao vek trajanja odeće. Ovaj računarski pristup pretvara filozofiju “vidljivog zakrpljivanja” u precizan, skalabilan industrijski proces, rešavajući ključne prepreke u popravci odeće i unapređujući ciljeve cirkularne modne ekonomije.

Ključne reči: 3D štampanje, Sašiko, Grasshopper, TPU, cirkularni dizajn, adhezija tekstila, vidljivo zakrpljivanje.

1. INTRODUCTION

The fashion and textile industry is one of the largest contributors to global waste and carbon emissions, with fast fashion creating a culture of disposability, where garments are discarded instead of repaired, significantly shortening their lifespans. While extending garment lifespans is a critical circular strategy, practical pathways for scalable repair remain underexplored [1, 2].

Traditional textile repair methods, such as darning, patching and hand-stitching, require a high degree of manual skill and are time-consuming. While cultural practices like the Japanese Sashiko, a form of functional embroidery that reinforces worn fabric with running stitches, demonstrate the aesthetic and structural potential of visible mending, they cannot be realistically adapted to industrial-scale production. This gap between artisanal repair and scalable manufacturing represents a significant opportunity for computational and digital fabrication technologies [1, 3].

Additive manufacturing (AM) has demonstrated considerable versatility in depositing materials onto complex substrates. Recent advances in direct-to-textile 3D printing have shown that thermoplastic elastomers can be bonded directly to fabric surfaces, creating flexible, durable composite structures. Fused Deposition Modelling (FDM) with Thermoplastic Polyurethane (TPU) filament is particularly promising due to the material's elasticity and adhesive properties on textile substrates [4, 5].

Furthermore, parametric and algorithmic design tools such as Grasshopper™, a visual programming environment for Rhinoceros 3D, facilitate the generation of complex, geometry-driven patterns that can be adapted to specific repair scenarios. The combination of these tools creates a new paradigm: the automated, computationally driven structural repair of textiles.

This paper presents “Digital Sashiko”, a comprehensive workflow that integrates Grasshopper™-based algorithmic pattern generation with fused filament fabrication (FFF)



3D printing using TPU to perform structural reinforcement on a cotton-polyester blend textile substrate. The goal is to translate the aesthetic and functional philosophy of Sashiko into a precise, repeatable, and scalable industrial process that addresses the core barriers of clothing repair within a circular economy context.

2. BACKGROUND AND RELATED WORK

2.1. The Sashiko Tradition and Visible Mending

Sashiko is a Japanese stitching technique historically used to reinforce and repair textiles, particularly work garments and quilted layers of fabric worn for warmth. The term translates roughly as “little stabs”, and the technique produces geometric patterns of running stitches, typically in white thread on indigo-dyed fabric. Beyond its functional role in reinforcing worn fabric, it is distinguished by its deliberate visibility, the mend is not hidden but celebrated as evidence of care and continued use [3, 6].

The contemporary “visible mending” movement draws on this philosophy, reframing repair as a creative and ethical practice in opposition to disposable consumption. While this movement has gained cultural traction, its dependence on manual skill limits its scalability and potential for industrial application.

2.2. Additive Manufacturing on Textiles

The use of 3D printing directly on fabric substrates has been an active area of research. Studies have demonstrated that FFF printing with flexible filaments such as TPU can achieve strong mechanical bonds with woven and knitted textiles through a combination of thermal bonding and mechanical interlocking between the deposited polymer and the fabric weave structure [4]. Key parameters affecting bond strength include print temperature, bed temperature, layer height, and fabric weave density [4, 5, 7].

TPU is particularly favoured for textile applications due to its high elongation at break, excellent abrasion resistance, and the fact that its flexible nature does not restrict the natural drape and movement of the fabric. Research has shown that the first printed layer is critical for adhesion, as it must penetrate the textile surface sufficiently to create a mechanical interlock without causing thermal damage to the fibres [4, 5].

2.3. Algorithmic and Computational Pattern Design

GrasshopperTM is a visual dataflow programming interface for the Rhinoceros3DTM computer-aided design (CAD) environment. It enables the parametric and algorithmic generation of geometry, allowing designers to automate the production of complex forms via the definition of rule-based systems. Its application in textile design has been explored for generating knit structures, weave patterns, and surface textures, including for direct-to-textile printing workflows [8, 9, 10, 11], but its use in the context of structural textile repair is novel.

By encoding the geometric logic of traditional Sashiko patterns into algorithmic rules, GrasshopperTM can generate repair geometries that are topographically mapped and conformed to the specific shape and extent of a garment tear. This approach moves beyond

fixed templates, allowing the repair pattern to adapt dynamically to different damage profiles.

3. METHODOLOGY

3.1. Overview of the Digital Sashiko Workflow

The Digital Sashiko workflow consists of four primary phases: (1) damage assessment and digitisation, (2) computational pattern generation in GrasshopperTM, (3) toolpath preparation and FFF printing with TPU, and (4) geometric and aesthetic evaluation.

3.2. Damage Assessment and Digitisation

The extent and geometry of a fabric tear were documented through image-based digitisation. Damaged garment panels were photographed and the resulting bitmap image was imported directly into the GrasshopperTM definition using the VectorizeTM plugin. The boundary was extracted computationally using said plugin within GrasshopperTM, applying a binary threshold of 0.5 and a 100-pixel speckle filter to eliminate texture noise (Figure 1).

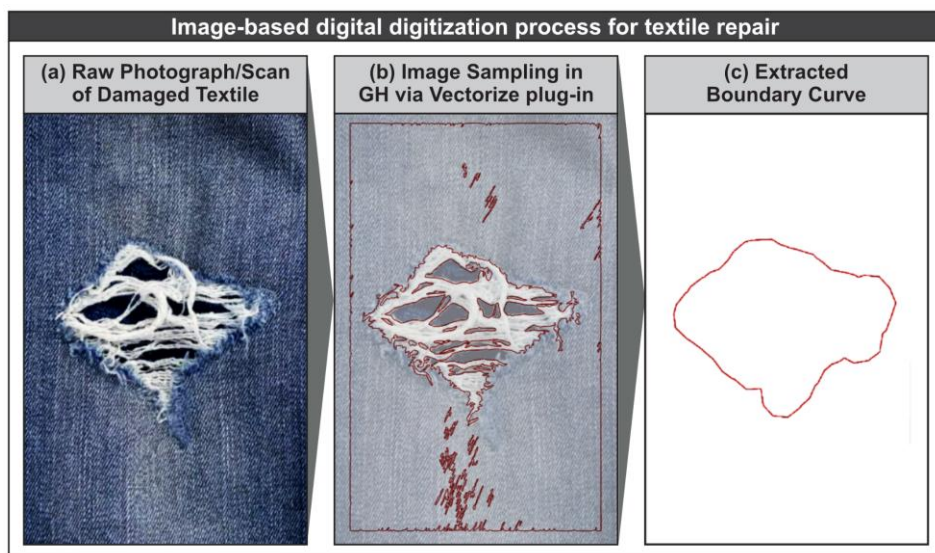


Figure 1: Digitised garment tear with extracted boundary curve

The resulting contour curves were further cleaned and remapped to produce a single closed boundary curve, which served as the target geometry for the pattern-generation stage described in Section 3.3.

3.3. Algorithmic Pattern Generation in GrasshopperTM

A parametric GrasshopperTM definition was developed to generate Sashiko-inspired repair patterns and conform them to the geometry of the identified tear. The definition operates in three stages (Figure 2).

First, a base stitch-pattern grid is generated parametrically. A Stream Filter component allows the designer to switch between several candidate grid topologies, including rectangular, radial, hexagonal, and triangular arrangements, each driven by two shared parameters: a base cell Size and a pattern Extent that controls the overall density and repeat count of the grid. For the case presented here, the radial topology was selected, producing a fan of concentric and radiating cells reminiscent of traditional Sashiko motifs. The selected grid is converted into a mesh, which forms the topological “skeleton” of the repair pattern and provides the set of vertices and edges manipulated in the following stage.

Second, the base grid and its derived mesh are topographically mapped onto the tear boundary curve obtained in Section 3.2 through a physics-based relaxation step using the Kangaroo2TM solver. The base grid establishes the initial fit, while the mesh is conformed to the tear boundary through combined Length, On-Curve, and Direction goals to maintain pattern character despite the irregular tear shape. To optimize computational responsiveness, the solver is triggered manually, converging within seconds.

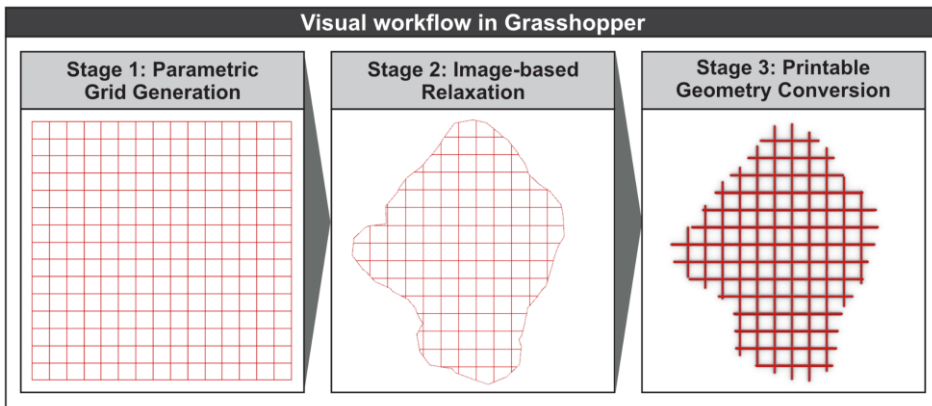


Figure 2: GrasshopperTM definition showing (left) parametric grid-type selection and base mesh generation, (centre) image-based tear curve extraction and Kangaroo2TM relaxation goals (Length, On-Curve, Direction), and (right) the solved mesh converted to printable pipe geometry

Third, once the mesh has relaxed onto the tear boundary, its edges are converted into solid, printable geometry using a pipe operation, in which a uniform radius (set to 0.7 mm in this study) is applied along each edge to generate a tubular mesh representing the raised TPU stitch lines. This final mesh is exported directly for slicing and 3D printing.

3.4. Material and Print Parameters

FFF printing was performed using a BambuTM Lab P2S 3D printer (Bambu Lab Co., Ltd., Shenzhen, China). The key print parameters were set as follows and refined through a series of preliminary adhesion tests:

Table 1: FFF print parameters for TPU direct-to-textile printing

1	Parameter	2	Value
	Material		TPU 95A
	Nozzle temperature		230 °C
	Bed temperature		35 °C
	Layer height		0.20 mm
	First layer height		0.20 mm
	Nozzle diameter		0.40 mm
	Chamber temperature		30 °C
	Elephant foot compensation		0.15 mm
	Print speed		30 mm/s
	Infill density / pattern		15% / Gyroid

3.5. Printing Process

The fabric substrate was secured flat on the print bed using heat-resistant adhesive tape. The pipe-converted mesh produced by the GrasshopperTM definition (Section 3.3) was exported as an STL file and sliced using BambuTM Studio (v1.10, Bambu Lab Co., Ltd.). The print paths were designed to deposit TPU filament along the stitch-pattern lines, creating a raised polymer structure on the fabric surface that replicates the visual appearance of Sashiko stitching while simultaneously reinforcing the tear boundary through mechanical interlocking with the weave (Figure 3).

4. RESULTS AND DISCUSSION

4.1. Geometric Fidelity and Pattern Versatility

The continuity and structural distribution of the printed TPU patterns were evaluated across the tested cotton-polyester blend fabric substrate, demonstrating high geometric fidelity. As shown in Figure 4, the computational framework successfully translates different algorithmic grid topologies, including rectangular, triangular, and radial configurations, into physical, well-defined polymer structures directly bonded to the textile surface.

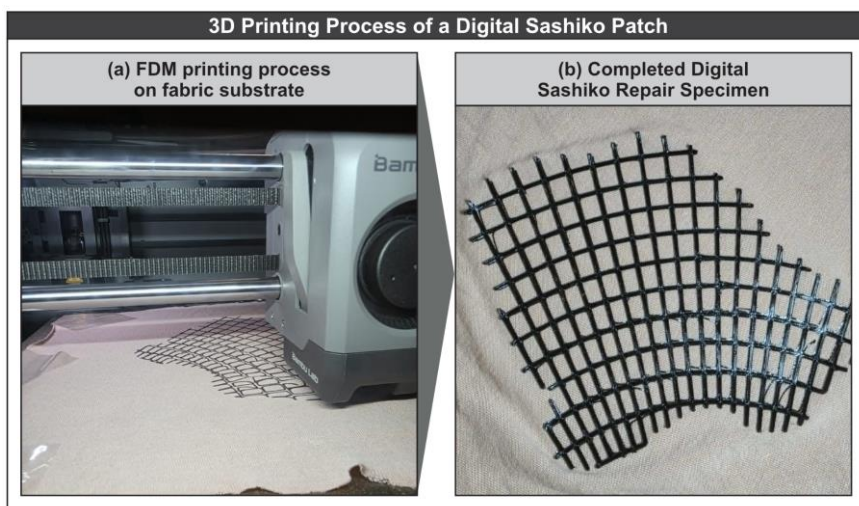


Figure 3: (a) FFF printing process on fabric substrate; (b) completed Digital Sashiko repair specimen

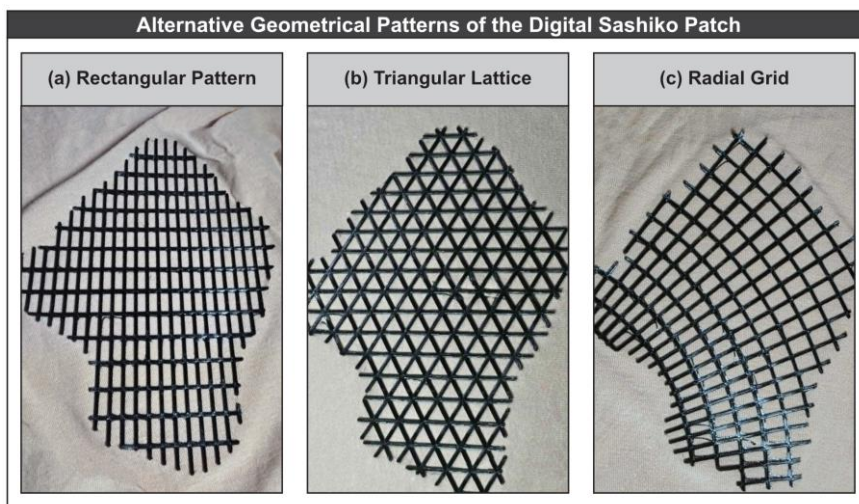


Figure 4: Macro-views of printed specimens showcasing pattern versatility: (a) Rectangular Pattern, (b) Triangular Lattice, and (c) Radial Grid

This multi-pattern capability confirms that the GrasshopperTM definition can dynamically adapt the visual and structural density of the mend based on the specific aesthetic or directional flexibility required by the garment.

4.2. Aesthetic Integration and the Visible Mending Principle

The Digital Sashiko approach produces a repair that is visually prominent by design. The raised TPU stitch lines are clearly visible on the fabric surface, translating the cultural philosophy of Sashiko into the language of digital fabrication. An informal visual evaluation conducted with five participants confirmed that the geometric patterning was perceived as intentional and decorative rather than as a defect, with all participants identifying the repair as a design feature. The parametric nature of the GrasshopperTM definition allows the pattern geometry, stitch density, and orientation to be customized per garment (Figure 5).

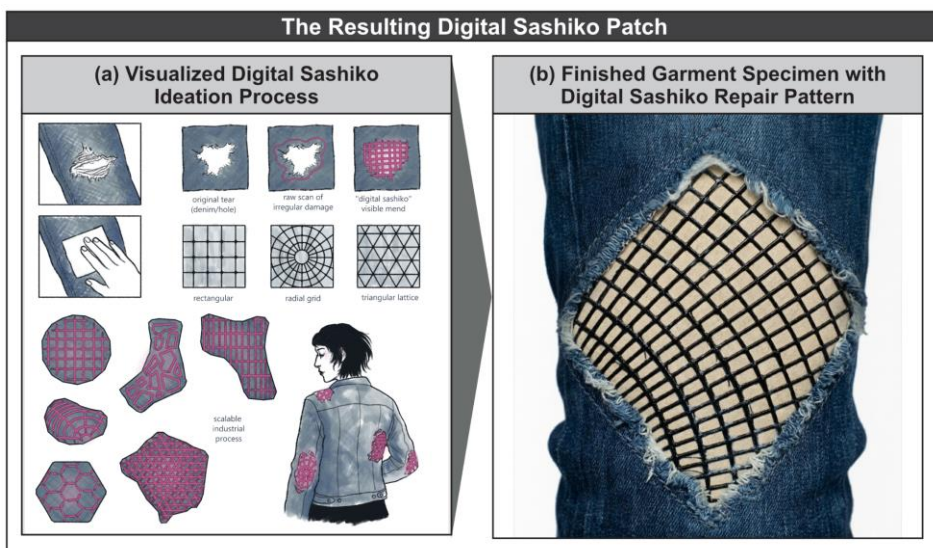


Figure 5: Finished garment specimen with Digital Sashiko repair pattern

4.3. Scalability and Industrial Applicability

The workflow presented in this study is designed with scalability in mind. The GrasshopperTM definition is non-destructive and fully parametric, meaning it can be adapted to any tear geometry without manual redesign. Integration with automated damage detection systems, such as computer vision or structured light scanning, could enable a largely automated pipeline from damage identification to repair fabrication. This has



significant implications for garment repair services, rental fashion platforms, and textile recycling operations seeking to extend product lifecycles efficiently.

5. CONCLUSION

This paper has presented Digital Sashiko, a computational framework for the automated structural repair of damaged textiles using GrasshopperTM-driven algorithmic pattern generation and FFF 3D printing with TPU. The proposed workflow bridges the cultural and philosophical tradition of Japanese visible mending with the precision and scalability of digital fabrication.

Building on established principles of TPU-textile bonding, qualitative manual handling of the physical prototypes confirmed that the printed open-grid structures easily maintain fabric flexibility without experiencing cracking or delamination. The GrasshopperTM-based pattern generation demonstrated high geometric fidelity, enabling the dynamic adaptation of varied grid topologies and repair geometries to specific damage profiles. This transforms an artisanal repair practice into a repeatable, parameter-driven industrial process.

The Digital Sashiko approach directly addresses key barriers to scalable garment repair, skill requirements, time costs, and aesthetic stigma, and thus represents a meaningful contribution to the goals of circular fashion. Future work could focus on integrating automated damage detection via computer vision, exploring multi-material printing for enhanced aesthetic and functional differentiation, and conducting user studies to evaluate consumer acceptance of visibly repaired garments produced through this method.

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