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Exhibition paper

Exploring Open-Source 3D Printing as a Transformative Design Tool

Empowering Designers and Enabling Innovation

ABSTRACT
My practice explores how to transfer my design knowledge of embroidery and print into 3D printing technologies and software. My Doctoral practice-based research explores the rationale behind using open-source, low-cost 3D printing technologies and software, which enabled me to change, remix and use the 3D printer as a flexible design tool like a sewing machine. The research aims to investigate the digitalisation of traditional textile craft techniques to produce a new taxonomy of design applications. I have produced a collection of 3D-printed embellished textiles demonstrating my practice-based research's ongoing outcomes. By engaging with online communities and Open-Source Technologies, I have developed the skills to apply my specialist knowledge to this alternative technology to translate and interpret traditional textile and manipulation techniques. The exhibition will showcase these outcomes and demonstrate the opportunities within the fashion, textiles and costume industries. The post-production processes engage with my specialist background knowledge of print and dye techniques.

Keywords:
3D Print, Textiles, Design tools, Digital, Open-source.

INTRODUCTION
3D Printing is a transference of the digital (data) into the Physical (matter). Designs are constructed layer by layer (additive), enabling more complex design innovation.

In the book Digital Handmade (Johnson, 2017), Johnson discusses how digital technologies are beyond mass production or rapid Prototyping solutions. They have become tools that aid the craftsperson from traditional crafts restrictions. Johnson showcases a catalogue of critical artists and designers such as Michel Eden, Anastasia Radevich, and LinLin & Pierre-Yves Jaques. They use digital processes and engage with 3D printing technologies to pioneer their practices that would not be possible with analogue tools and functions.

Hoskins's book, 3D Printing for Artists, Designers, and Makers (Hoskins, 2016), showcases various case studies with pioneering visions of their disciplines and discusses the ever-shifting landscape of 3D printing technologies as a new field for "Craftspeople." Hoskins considers the appealing nature of designing in the virtual realm and materialising the impossible with traditional craftsmanship and therefore evoking design innovation with these new digital technologies.

3D printings additive process is similar to those traditional techniques for decorative textile embellishments. Embroidery beading and stitching processes are applied layer by layer using a variety of materials and techniques. These handcrafted methods are applied through stitching and the maker's needle craftsmanship and can be delicate, precious, time-consuming, and expensive. Digital embroidery technologies have been utilised in the fashion industry as a rapid and cost-effective alternative to traditional handcrafted embellishment techniques. There has been further development of digital embroidery machines such as Coloreel (https://www.coloreel.com), a revolutionary technology which dyes the thread to any coloured desired just before the stitching process. While there is an ongoing development of digital embroidery technologies, the innovations in 3D printing materials and technologies open an opportunity to transfer traditional craft skills and form digital craftsmanship to seek innovative embellishment design and production approaches beyond what digital embroidery currently offers. The opportunities developed by 3D printing technologies have enabled designers to engage with design principles and materials. My practice-based research engages with a range of different materials such as PLA (poly lactic acid), a hard material which could be used for beading and more structural decoration and TPU (Thermoplastic polyurethane) a flexible material which allows authentic translation and innovation in textiles and material outcomes: "Materials are now flexible, malleable things that start as data capable of being formed, shared and edited in a digital environment. We can presently remix objects; materials are like a video or a song" (Bitonti 2019 pg.4).

This ability to edit variables and remix designs into unique outcomes has appealed to many artists, designers and makers, beyond the original purpose of rapid prototyping but as a fundamental process in creating artefacts. Designing in the digital/virtual realm has allowed the liberation of physical restrictions of matter, allowing digital craftsmanship to establish through the transference of traditional knowledge of craftsmanship and materials.

STATE-OF-THE-ART 3D PRINTING

There is a rise in the development of 3D printing technologies and manufacturing for Textiles and the Fashion industry. Stratasys, an internationally renowned additive manufacturing company, has evolved its portfolio of collaborating with makers and designers in art and design, including Fashion and textiles, which they highlight on their website (https://3dprintedart.stratasys.com/portfolio-1). Stratasys collaborations include Julia Koerner, Neri Oxman, and Iris Van Heperen, all highlighted as pioneers for 3D printed textiles and Fashion, all engaged with Stratasys high-end, specialist equipment, processes, and knowledge to produce 3D printed textiles for fashion and costume applications.

Such a high-end level of machinery, knowledge and equipment has allowed for pioneering innovation; however, the exclusivity of the specialist equipment limits the accessibility of knowledge and explorations to designers, makers, and creatives at the ground level.

Stratasys aims to disrupt fast Fashion and its supply chain through localisation and customisation; the current practice results are exclusive and inaccessible to all designers. While there is significant worth in Stratasys research, and these processes could revolutionise embellishment and digital embroidery, the results are for luxury use and luxury goods for luxury prices. My research was initially inspired by the capabilities and development into this state of the art technology, but I found it difficult to access and felt confined to what I could do. By using an open-source 3D printer (Ultimaker Cura and Creality Ender 5 Plus), I could interact with the printer, pause, stop and add materials while printing and, above all, make mistakes that would not cost high monetary value. This allowed me to consider how to use the 3D printer as a design tool and engage with my knowledge of embroidery and print techniques.

DO-IT-YOURSELF: OPEN-SOURCE 3D PRINTING TECHNOLOGIES AND INNOVATIONS FROM THE BOTTOM UP

There has been a rise in self-taught 3D print enthusiasts in Fashion and Textiles who use open-source, affordable 3D print technologies to produce a range of innovative outcomes:

This Do-it-Yourself approach to learning and making has enabled designers to develop their learning processes and techniques of 3D Printing for textiles and Fashion. Users can customise existing creations found in design communities such as MakerBot's Thingiverse (https://www.thingiverse.com/). Thingiverse gives access to downloadable 3D files/ STL files. Anyone can download, print, and remix these files through open-source 3D Printing slicing programs such as Ultimaker Cura to customise, discover and learn from 3D Printing on a desktop printer at home. Designs are usually licensed under a Creative Commons license so everyone can alter and use any design within the Thingiverse community. This is an established practice with subcultures such as Cosplay for making costumes inspired by characters from Comics, Gaming, Films, and TV.

DIY design communities offer new learning, creation and thinking regarding making and designing. This way of making and creating has enabled an online Think Tank, decentralised from the elite, advanced technology companies that dominate in 3D printing technologies. The shared experience allows users to engage and customise products and ideas displayed in the design community or to share original ideas they have created and printed at home using an FDM 3D printer. I built the skills I needed to learn by watching YouTube videos and engaging with the 3D print community through Discord and social media platforms. This has enabled me to develop my toolkit of knowledge to produce my practice.

PRACTICE-BASED RESEARCH

The Exhibition showcases the practice-based research that investigates the technical and aesthetics of 3D printing textiles design. It applies my specialist knowledge of fabric manipulation, embroidery, and print & dye techniques to inform the research and develop a new taxonomy of design. I have focused on digitalising traditional craft skills through the development of four categories:

- *Fabrication*: Digital Fabrication – using Open-Source, accessible 3D printing technologies
- *Simulation*: Motif Generation/Translation – textile design and manipulations techniques to create outcomes purely materialised from 3D printing
- *Generation*: Decorative Embellishment Techniques -simulating traditional embellishment techniques with 3D printing onto a multitude of textile surfaces
- *Elaboration*: Postproduction Processes – using a range of textiles manipulation, embellishment, print and dye techniques to add colour and further design features.

This research aimed to identify processes that could digitalise traditional textile craftsmanship and review which techniques could contribute to new knowledge. Figure 1 demonstrates the critical process stages of practice-based research. It illustrates the flow of design practice, followed by a table of definitions of these stages.

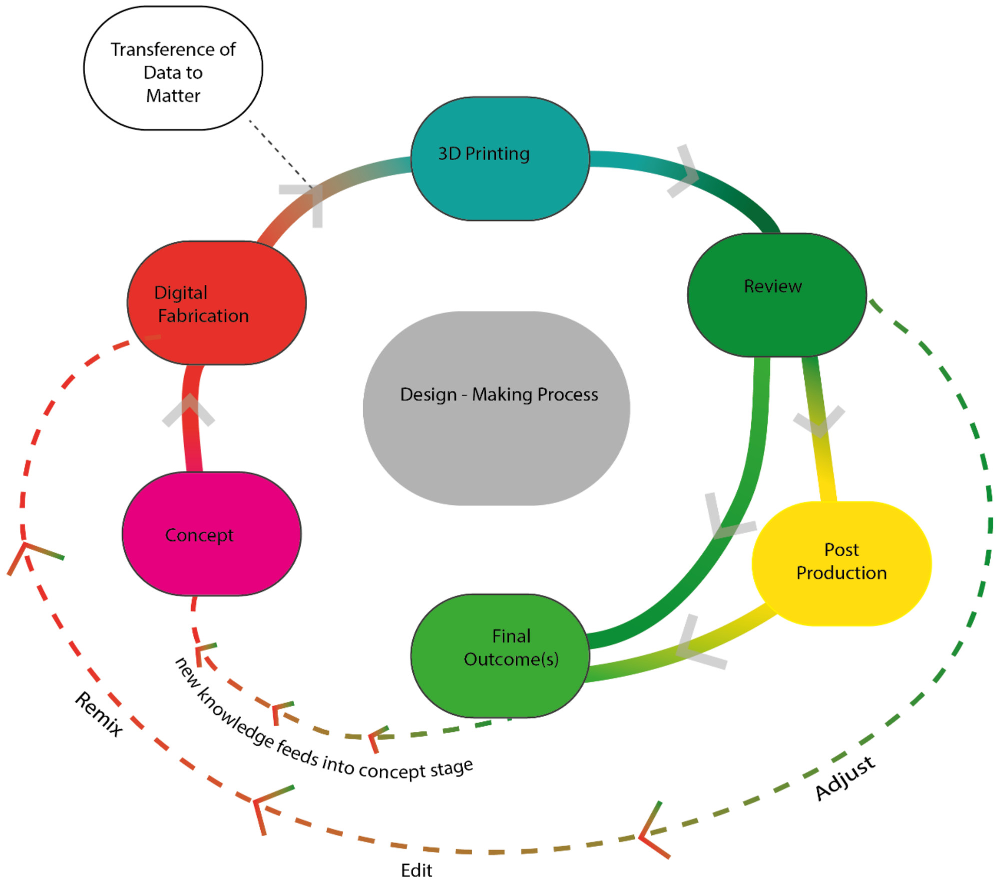


FIGURE 1. A Flow Diagram to demonstrate the design- make process created by the Author *K*. McLaughlin.

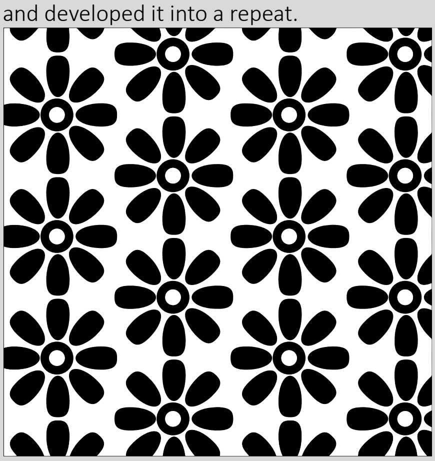
TABLE 1. Definition of Design – Making Process Stages.

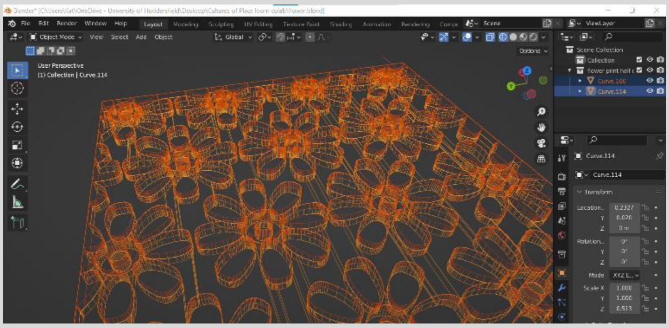
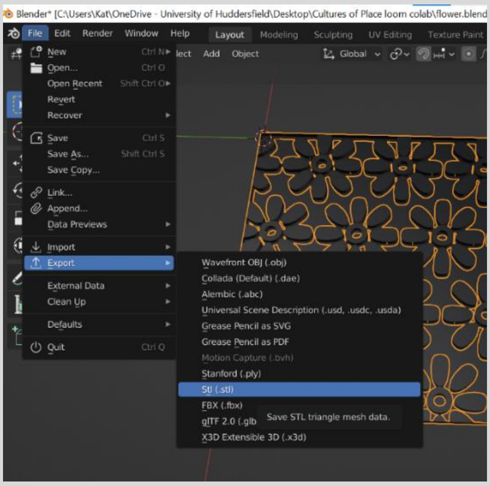
Stage	Description
Concept	Ideas behind the design, i.e.:- a reference to textiles craft processes such as smocking and visual reference such as nature. Ideas actualised by drawing
Digital Fabrication	The conceptual drawings are translated into 3D models using the Open-source software Blender. The 3D model (data) is transferred into G-Code (*see fabrication section for a further expansion of this process*), ready to 3D print.
3D Printing	G-code (Data) uploaded to Creality Ender 5 Plus 3D printer. The printer is used as an active tool and is paused, slowed down, sped up and adjusted to allow the practitioner to live edit and engage with the printer as a textiles design devise.
Review	Reflection of aesthetics, function, and execution. A review of the processes (design and make) to see if there need to be any adjustments to any previous stages.
Postproduction	Textile embellishment techniques are added to the 3D print, such as heat setting, embroidery, and Print Dye techniques, to enrich the aesthetics and function.
Final Outcomes	The designs are reviewed and considered for fashion, costume, and textile contexts. The new knowledge and design processes are fed into the design concept stages.

FABRICATION

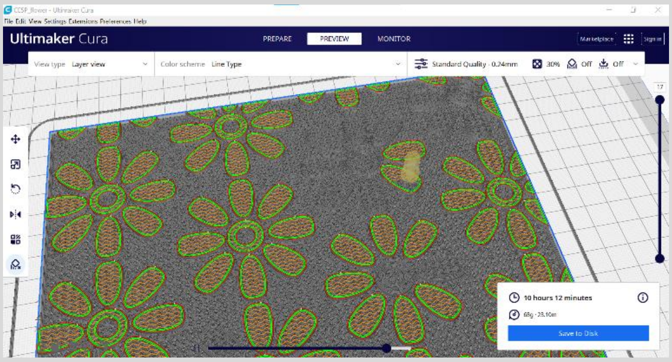
One core area of practice-based research is fabrication. The digital design to the materialisation of the 3D printed textiles is a process where data becomes matter. The ability to edit a design in the digital realm enables the maker not to be limited to traditional tools restrictions. Table 2 demonstrates the design evolution of digital to material fabrication.

TABLE 2. A flow chart of the Design Evolution of Digital to Material Fabrication.

Step	Notes and reference image (If applicable)
Concept	The Idea:- Drawing/Sketch of design created (by hand or vector graphics) In this example I developed a flower design commonly used in printed textile motifs by hand. I translated it using Adobe Illustrator and developed it into a repeat. 

3D model in Blender	 Blender is an open-source 3D computer graphics software. You can enable plugs ins for 3D print, modelling, and modifier tools made by the community.
Export as STL file	 screenshot of exporting a design as an STL from Blender, Image Authors own 2022 STL:- Standard Tessellation Language, a file format for stereolithography CAD software
Open in Ultimaker Cura.	Ultimaker Cura is an open-source slicing application for 3D printing.

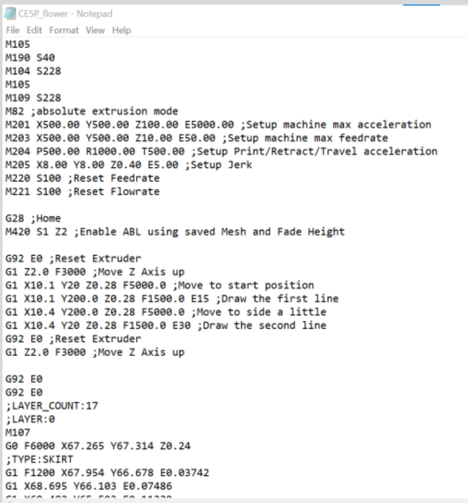
Edit in Ultimaker Cura



screenshot of previewing print animation in Ultimaker Cura. Image Authors own 2022

In this slicing software, you can edit the; properties scale, size, quantity, and density to be 3D printed and set the speed, material, and information for the 3D printer. In the example above, you can see there are 17 layers which make up this design.

Slice design to create G-Code.



CE5P_flower - Notepad

File Edit Format View Help

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M105
M190 S40
M104 S228
M105
M109 S228
M82 ;absolute extrusion mode
M201 X500.00 Y500.00 Z100.00 E5000.00 ;Setup machine max acceleration
M203 X500.00 Y500.00 Z10.00 E50.00 ;Setup machine max feedrate
M204 P500.00 R1000.00 T500.00 ;Setup Print/Retract/Travel acceleration
M205 X8.00 Y8.00 Z0.40 E5.00 ;Setup Jerk
M220 S100 ;Reset Feedrate
M221 S100 ;Reset Flowrate

G28 ;Home
M420 S1 Z2 ;Enable ABL using saved Mesh and Fade Height

G92 E0 ;Reset Extruder
G1 Z2.0 F3000 ;Move Z Axis up
G1 X10.1 Y20 Z0.28 F5000.0 ;Move to start position
G1 X10.1 Y200.0 Z0.28 F1500.0 E15 ;Draw the first line
G1 X10.4 Y200.0 Z0.28 F5000.0 ;Move to side a little
G1 X10.4 Y20 Z0.28 F1500.0 E30 ;Draw the second line
G92 E0 ;Reset Extruder
G1 Z2.0 F3000 ;Move Z Axis up

G92 E0
G92 E0
;LAYER_COUNT:17
;LAYER:0
M107
G0 F6000 X67.265 Y67.314 Z0.24
;TYPE:SKIRT
G1 F1200 X67.954 Y66.678 E0.03742
G1 X68.695 Y66.103 E0.07486
```

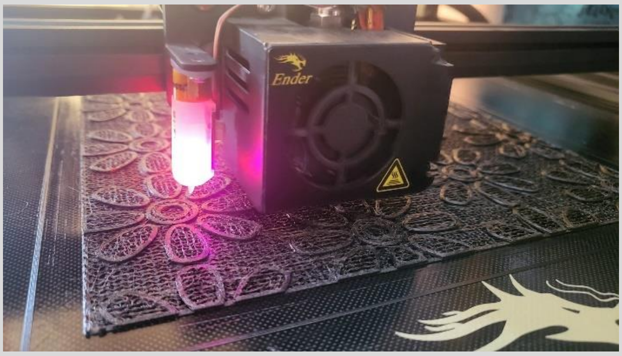
screenshot of a sample of G-Code for floral design

The slicing application divides the 3D object into individual material layers using the X, Y and Z axis.

This is presented to the 3D printer as G-Code is a computer numerical control programming language.

(Optional) Edit G-code if necessary

Like most computer coding languages, the G-code is editable and can be given further instruction, such as pausing the printer at a certain height, adding generative design to enhance the aesthetics, or altering the manufacturing processes.

Load onto micro-SD for 3D print	Load from a computer onto Micro SD> Insert into the 3D printer.
3D Print on Creality Ender 5 Plus	 Screenshot of Ender 5 Plus printing design. Creality Ender 5 plus is self-assembly, open-source FDM (see glossary of terms) 3D printer. It has a build volume of 350x350x400mm, allowing for a larger build volume than most print-at-home printers. The TPU filament can be extruded to 0.2mm allowing more refined and delicate detailing and larger thicker designs. The thickness of the filament is changeable during the slicing and Gcode generation process.
(Optional) Edit print manually	 Capture of Ender 5 Plus edit function during the printing process, Image Authors, own 2022 While printing, you can pause, speed up or down, change the layer height and add fabric onto the 3D printer.

Outcome	 Image of the final result of 3D printed floral lace, materials TPU, Image Authors own 2022
Review	Reflect, re-design, remix, edit and contextualise the outcome. The floral lace sample was printed using a flexible material which has a stretched due to the knitted gyroid structure of the design. This enables it to emulate a knitted/ lace like structure.

SIMULATION

Simulation focuses on motif generation/translation – textile design and manipulation techniques to create outcomes purely materialized from 3D printing. Lace (fig 2 and65), smocking (fig3), knit (fig 4-5), and embroidery (fig 7) are referenced and simulated using TPU. This printing method was best for trial and testing to benchmark the standard file format and settings for 3D printing with TPU. The outcomes allowed the researcher to understand the potential of using 3D printing for textile design. Below is a selection of samples which used simulation in their process.

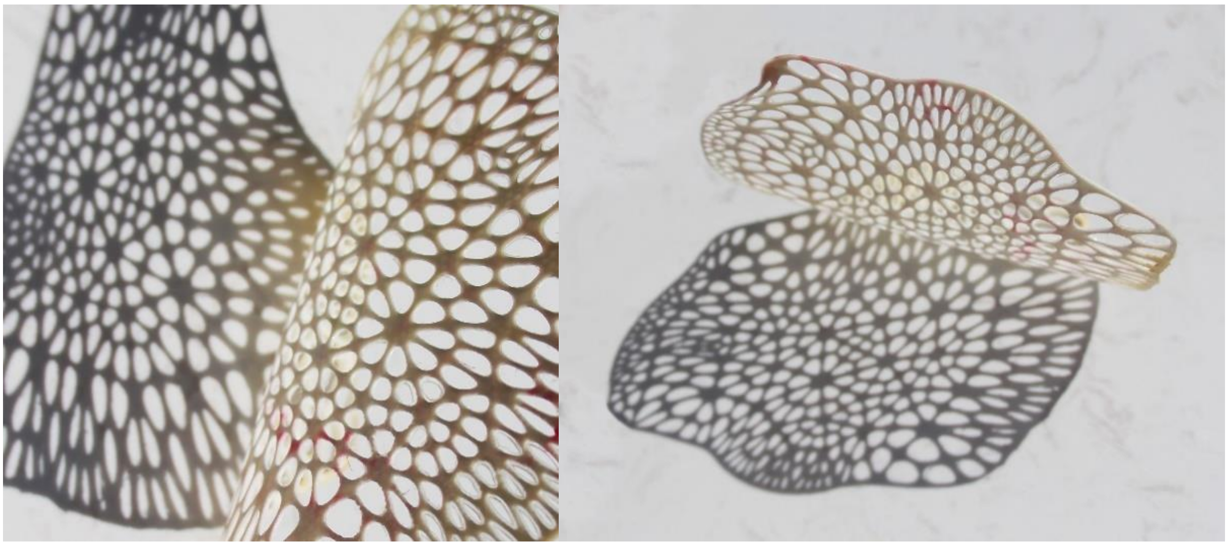


Figure 2. Embroidered lace / cut work and Ernst Haeckel Art Forms in Nature inspire Lace X. Created and photographed by author, materials: White TPU, 3D printed. The shadows omit an additional decorative design element: this was one of the first 3D prints using just 3D printing and took 1 day to 3D print. Created 2021.

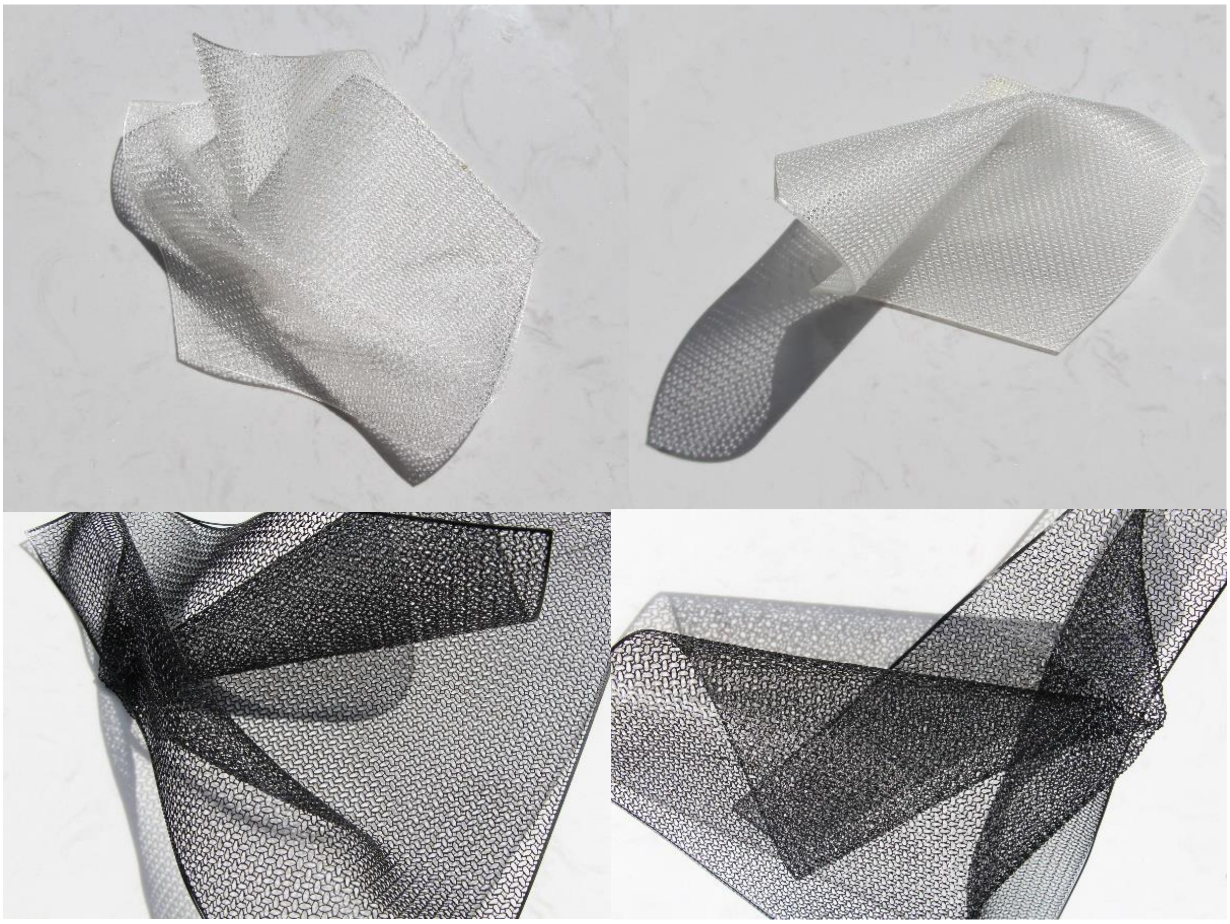


FIGURE 3. 3D printed White and Black iterations of Gyroid infill Hexagon. Created and photographed by the author, materials: black or white TPU. The infill was edited during the slicing process to generate a gyroid knit. The samples are pinned or folded into position this was to experiment with how the samples would work when shaped and formed post print. Created 2022.

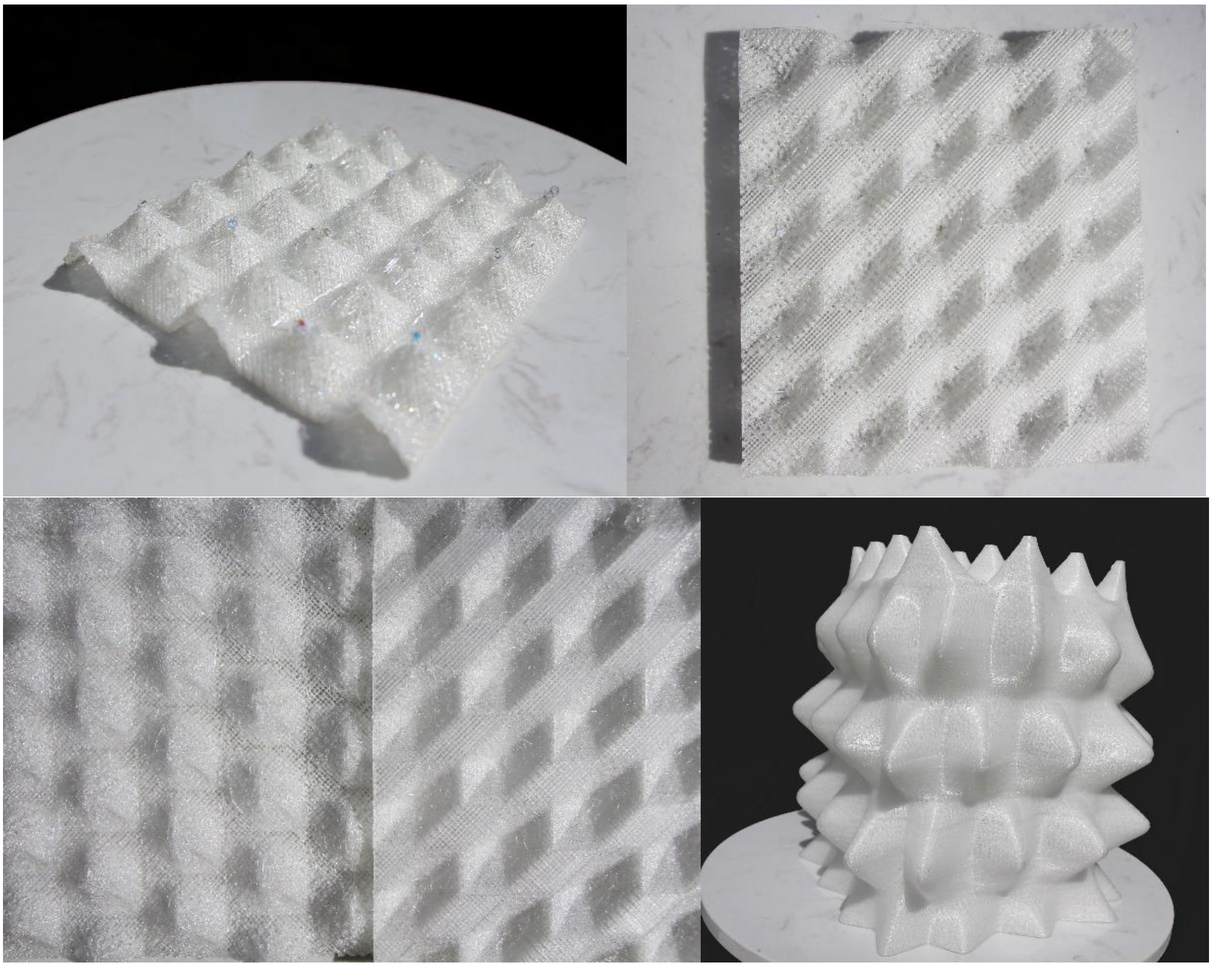


FIGURE 4. 3D printed White iterations of smocking design. Created and photographed by the author; materials: white TPU. Created 2022 The pieces were exhibited as part of the Cultures of Place event.

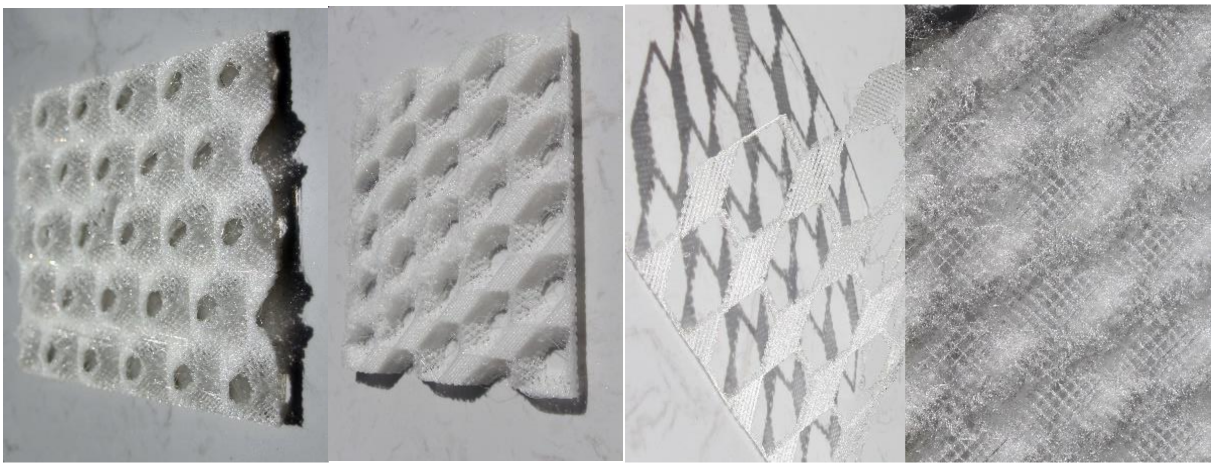


FIGURE 5. 3D printed White iterations of smocking design that were unsuccessful due to Print faults. These samples enabled the author to reflect, respond and test their ideas further to see how the smocking samples could work. Created and photographed by the author; materials: white TPU. Created 2022.

FIGURE 6. 3D printed floral lace, Black and White. Created and photographed by the author; materials: white TPU. Created 2022.

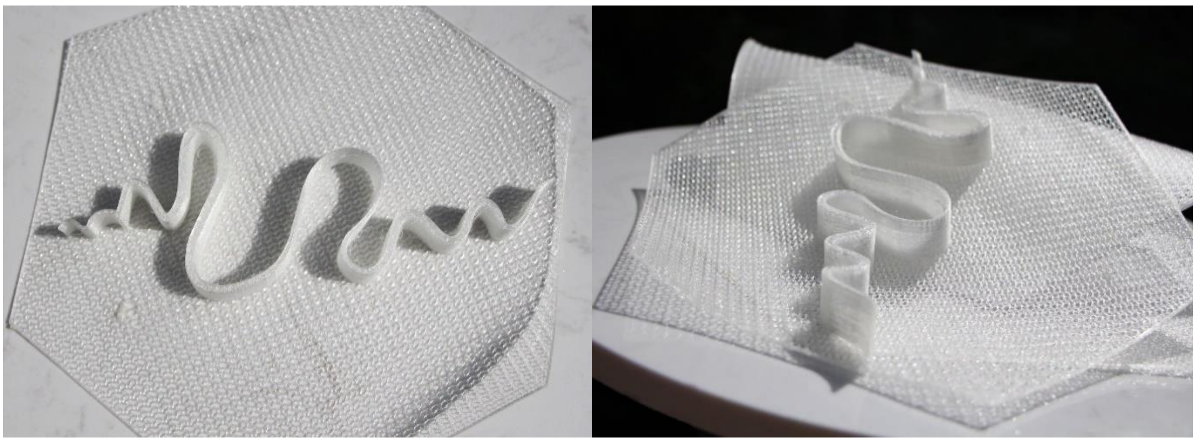


FIGURE 7. 3D printed Decorative Stitch Hexagon design. Created and photographed by the author; materials: Clear TPU. Created 2022 This print referenced traditional whip stitch, goldwork and coaching techniques to consider how the 3D printer could make decorative details.

GENERATION

Generation focuses on decorative Embellishment Techniques translating traditional embellishment techniques with 3D printing onto a multitude of textile surfaces. The designs were printed directly onto fabric (fig 9), or material was sandwiched in between (fig 8). The work referenced traditional embroidery techniques, including blackwork and Sashiko(fig 8. A range of materials was 3D Printed onto to evaluate the possibilities of aesthetics and function.

FIGURE 8. Traditional Japanese Sashiko textilesdesigns, Patterns stitch to reinforce the fabrics and also used as a mending method. Images from Inspiration studios. https://www.inspirationsstudios.com/the-history-of-sashiko/#:~:text=Sashiko%20is%20a%20style%20of,designs%20and%20ease%20of%20stitching.

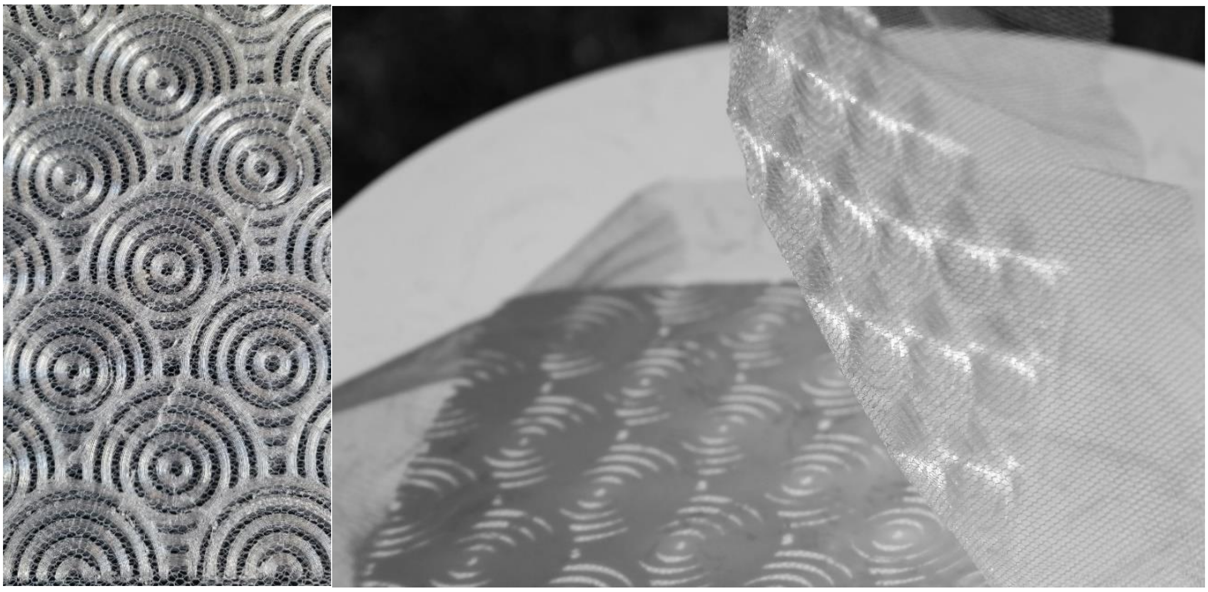


FIGURE 9. 3D printed Sashiko-inspired design onto mesh. Created and photographed by the author; materials: Clear TPU. Created 2022 This design decorates and reinforces the fabric, which follows the principles of Sashiko mending techniques. The material is sandwiched in between layers or TPU therefore making the fabric stronger and enforcing the traditional property of Sashiko. This method allowed the research to engage with the printer as a malleable tool rather than a machine for reproduction. Below is a selection of samples which used generation in their process.

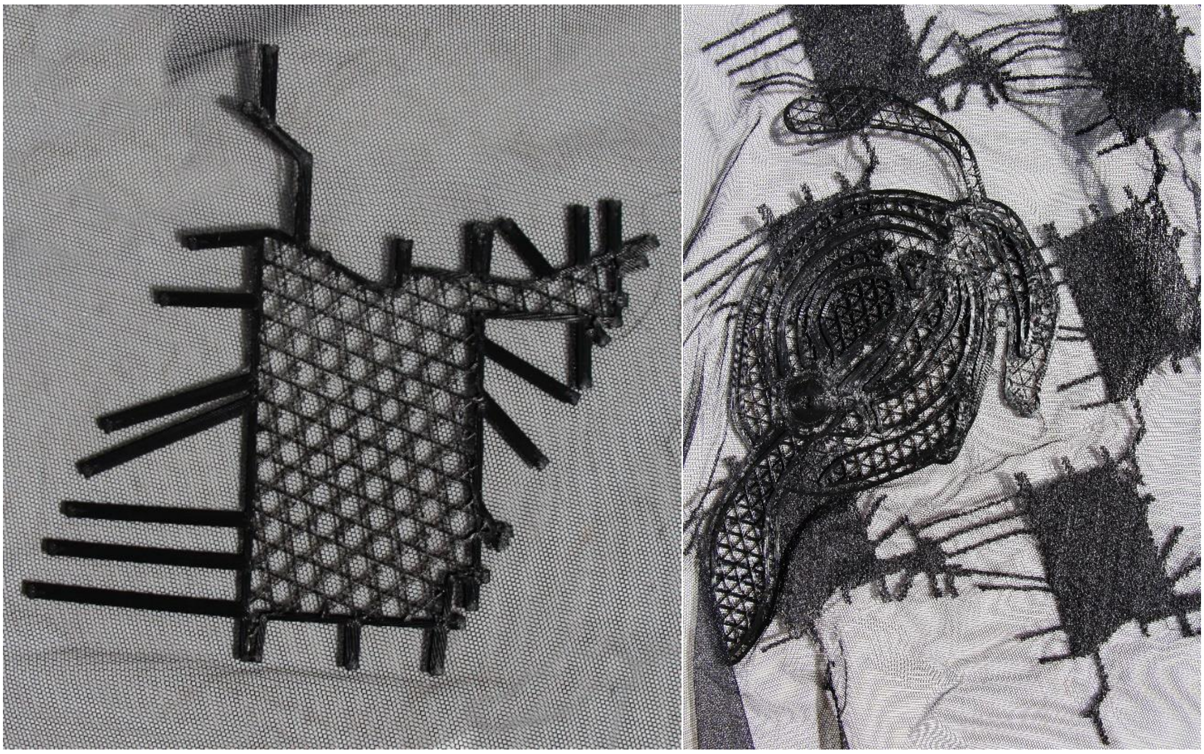


FIGURE 10. 3D printed designs onto mesh. Created and photographed by the author; materials: BlackTPU. Created 2022 This print translates Bea Gomez-Martin's drawings for the Cultures of Place Exhibition. The designs are inspired by black work traditional embroidery techniques. The image on the right demonstrates a design 3D printed onto pre-digitally embroidered fabric.

ELABORATION

Elaboration focuses on the post-production textile processes to add colour and other design features. Using a range of textiles techniques and manipulation such as heat setting (Fig11), Embellishment (Fig11), Print (Fig 12) and dye (Fig 13). The results were reviewed and considered for future development.

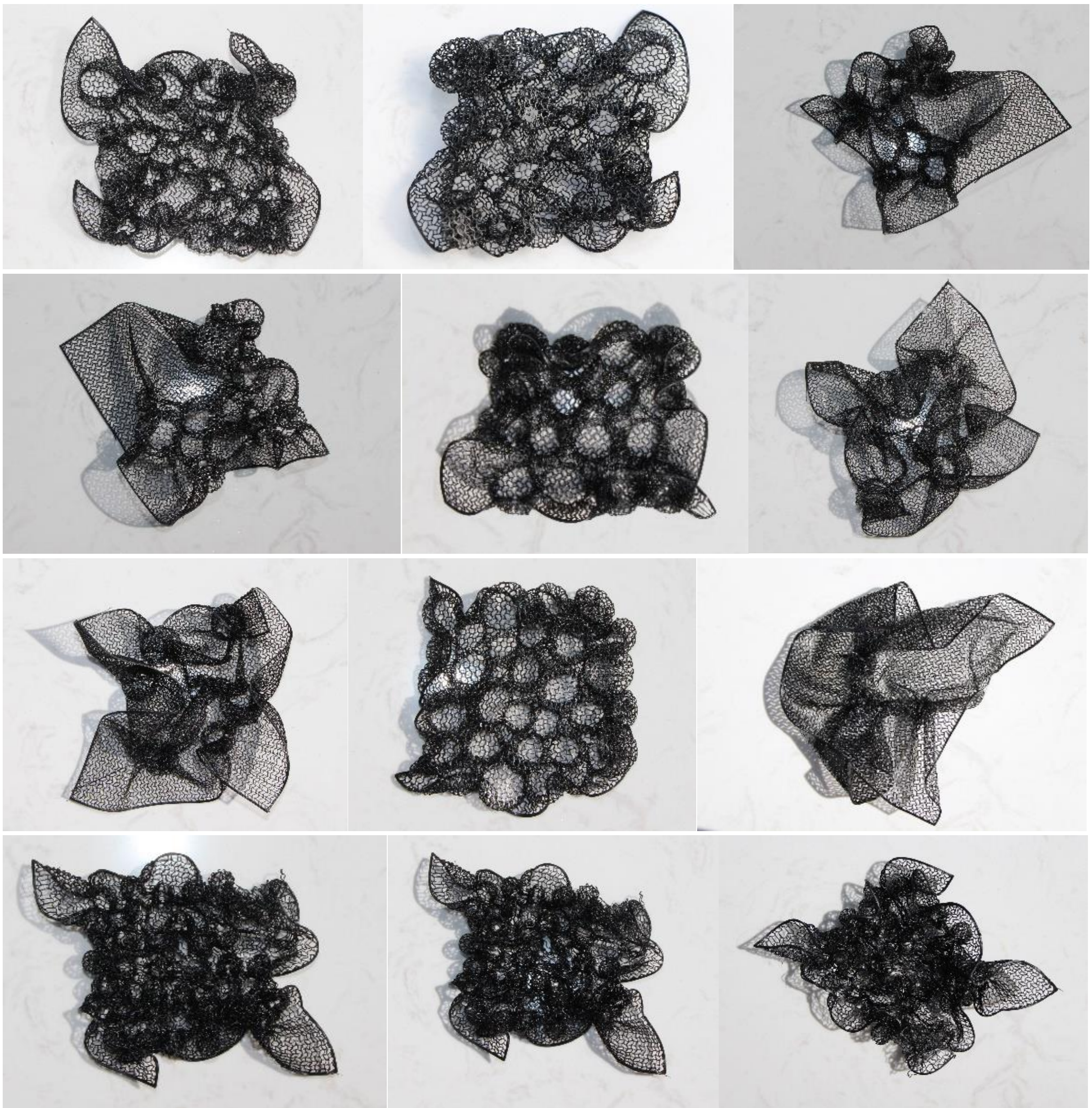


FIGURE 11. Design iterations of 3D printed Square with various heat setting techniques. Created and photographed by the author; materials: Black TPU. Created 2022. 2p,5p and 10p coins and baking beads were tied into the 3D-printed fabric and then set with heat. The fabric is noticeably glossier on some iterations due to the heat when being processed.

FIGURE 12. 3D printed TPU samples hot water dyed using dispersed dyes. Created and photographed by the author; materials: TPU White. Created 2022. There was a mix of success with the results that the author continues to reflect on.

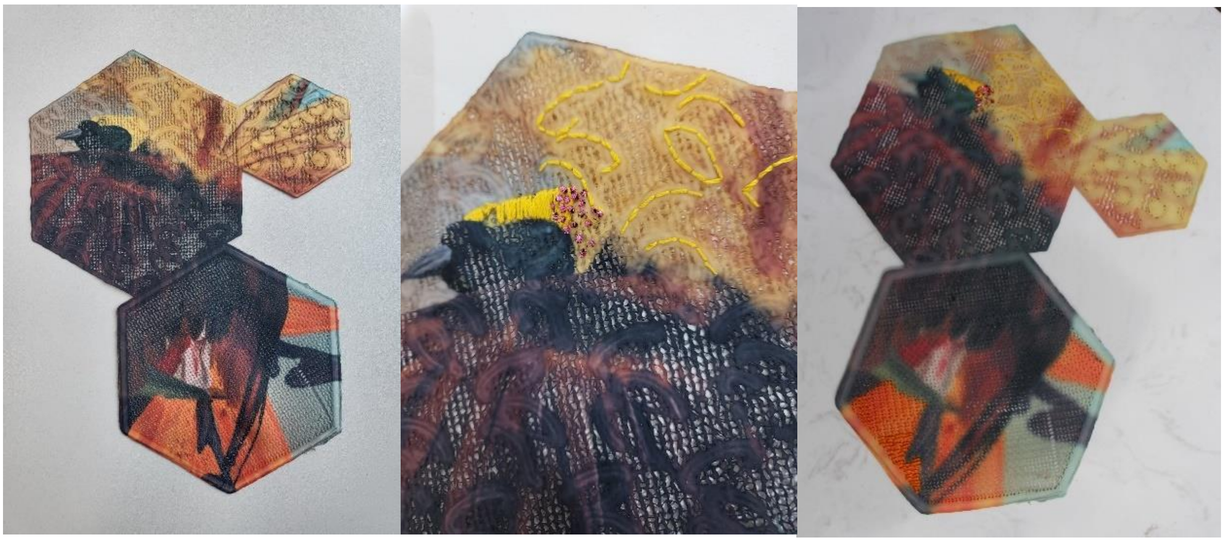


FIGURE 13. 3D printed Hexagon with digitally printed birds of paradise design. Created and photographed by the author; materials: Clear TPU. Created 2021. The bird design was digitally printed onto paper using sublimation dyes and then transferred onto the TPU hexagons. Melissa Fletcher added further hand stitch. After approximately eight months of sun exposure, the design faded, as seen in the right image. The author intends to keep testing this process as it offers a new aesthetic for the 3D prints.

CONCLUSION

Open-Source 3D printers can be used as a fully dynamic tool for making rather than a manufacturing process enabling innovation and empowerment for designers to build this application as a transformative design tool. Communication between makers, designers and thinkers from many disciplines is starting to be woven, resulting in new knowledge, ideas and languages. For 3D printing textiles, translating practice and expertise will result in more modular, customizable, and bespoke design and manufacturing.

Practice-based research has enabled me to develop new knowledge, skills and concepts based on the digitalization and translation of textiles design, my specialism. Investigating the rise in 3D printed textiles, from the state-of-the-art 3D print technologies applied by Stratasys and leading designers to the pioneers from the bottom up in the DIY design community leading that enable 3D printing to be accessible for all, highlights the opportunity to contribute to knowledge within this continuing developing field of design and making.

The research will continue to establish a materials library to record the stages of my practice. I will continue to translate traditional and specialist design knowledge with digital innovations through open-source 3D printing technologies to develop a new language and design tool for users resulting in a new design taxonomy.

ACKNOWLEDGEMENTS
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