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HYBRID TEXTILE STRUCTURES AS MEANS OF MATERIAL-INFORMED DESIGN STRATEGY

This research focuses on potential applications of lightweight textile structures in the building industry. The need of more eco-friendly and lighter materials, more flexible designs and substantial cost reduction create new possibilities for textiles as construction material. Development of highly engineered, programmable fibers as well as new 3D printing technologies allow for re-introducing textiles into the build environment as efficient, smart and sustainable solution. [1]
The project investigates the technique of 3D printing on pre-stressed fabrics in order to create textile composites and explores their potential applications as building envelopes. Design methodology takes advantage of the elasticity and self-shaping properties of such structures while looking into performance, modularity and scalability. The position, geometry and height of the 3D printed form can locally affect the deformation of the textile, once the tension is released. Such method enables precise control over the transformation process and design aiming at minimizing the material needed for fabricating the desired three-dimensional textile modules.
The case study for this investigation is a textile sun-shading module developed into a 1:1 scale prototype as part of the "Self-Shaping Textiles" seminar at the Weissensee Kunsthochschule Berlin. The course was done in collaboration with the „Textile Prototyping Lab" as well as the „Sächsische Textilforschungsinstitut STFI" in Chemnitz, where the large-scale prototype was manufactured.

Keywords: material form-finding, 3D printing on textiles, lightweight textile structures, performative building envelopes, self-shaping textiles

CA2RE
Conference for Artistic and Architectural (Doctoral) Research

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1. ABSTRACT
This research focuses on potential applications of lightweight textile structures in the building industry. The need of more eco-friendly and lighter materials, more flexible designs and substantial cost reduction create new possibilities for textiles as construction material. Development of highly engineered, programmable fibers as well as new 3D printing technologies allow for re-introducing textiles into the build environment as efficient, smart and sustainable solution. [1]

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2. MATERIAL FORM-FINDING
The study uses one of the methods for transforming textiles into desired three-dimensional shapes developed by the MIT Self Assembly Lab and explores its potential to create functional building envelopes. This methodology relies on 3D printing a less elastic material such as plastic on top of an elastic, pre-stressed fabric. Once the textile is released from the pre-stressed state, it folds into a specific shape, influenced by the 3D printed form. [2]

3. MODULE DEVELOPMENT
The first part of the research focuses on the development of one textile module in several iterations that would provide various degrees of porosity. Numerous studies were carried out in order to test and understand the variables that affect the transformation of the textile composites. For the comparability of the results, all the samples have 10 cm diameter and were printed with the PLA filament on a pre-stressed fabric (85% Polyamid and 15 % Elastan) using the FDM printer. In order to ensure the uniform tension of 150%, the fabric was cut into proportionally smaller parts and each piece was sewed around the printing plate to avoid inaccuracies.
A circular module was chosen as a base for testing the transformation principles. The design consists of two 3D printed, concentric rings and a cut in-between them. By varying the length of the cut and the proportions of the rings, different degrees of opening are possible within one module. This strategy was then further tested in order to develop a series of circular modules with different openings.

The transformation was influenced not only by the proportions of the outer and the inner rings and the length of the cut, but also by the direction of the warp threads in relation to printed boundary and position of the cut. The same printed geometry would fold differently once rotated 90 degrees. In order to create symmetrical openings, the direction of the warp threads needed to be perpendicular to the symmetry axis of the cut.
As a result, three various modules were developed with different openings, allowing production of a customized textile sun-shading structure, optimized for the personal needs or environmental conditions. The traditional textile technique of lacing was used to connect the components together and assemble them into a functional scaled prototype.

4. UP-SCALING
Galileo in "Dialogue on Two New Sciences" elaborates on scaling laws and observes that bones of large animals are proportionally much thicker than those of smaller ones. [3] Similar principles apply to the structural elements that need to take certain loads in construction, where the scalability depends on many factors and becomes a very complex, challenging task.
The second part of the research focuses on scaling up the textile module into an architectural building component. It is not a linear transformation, since the fabric doesn't change and the only element that can be enlarged is the 3D printed geometry. This non-uniform scaling process relies on a series of trial and error experiments until the desired setup is found. Besides increasing the overall size of the rings, the focus is also put on scaling the manufacturing process such as the thickness of the printing path or layer height.
The following series of experiments aimed at scaling the circular module from the 10 cm diameter into the 30 cm diameter. The 1:1 scale prints were produced at the „Sächsische Textilforschungsinstitut STFI"in Chemnitz using a larger FDM 3D printer with built-in mechanism for tensioning the fabric. The PLA filament was replaced by polyolefin and the thickness of the printing path was significantly increased from 0,4 mm to 1mm in order to speed up the printing process.

Optimizing the printing time turned out to be the first challenge. After a series of experiments with the printing speed and printing path we managed to print the module of a 30cm diameter in 1h 20 min, just as long as the 9 times smaller initial module. The customized circular printing path with more height distance ended up not only speeding up the manufacturing process, but also affecting the aesthetic appearance of the printed form, where the printed layers followed the geometry.
The second challenge was adjusting the proportions of the 3D print in order to replicate the desired geometry, but after plenty of iterations we managed to reconstruct the initial form. The height of the print had to be varied depending on the length of the cut and the inner circle had to be stiffened along the opening boundary.

Specifications of the final prototype:
- Manufacturing technology: FDM 3D printing on pre-stressed textile
- Fabric: 85% Polyamid and 15 % Elastan, Filament: Polyolefin
- Tension 120 %
- Outer ring: W 10mm, H 30mm, inner ring: W 5mm, height 30mm
- Path gap: 1,3 mm, Layer height: 0,6 mm, first layer height: 1 mm

4. CONCLUSIONS
3D printing on pre-stressed fabrics is a robust methodology for creating three-dimensional, lightweight, transformable materials with potential applications as architectural structures or smart textile facades.
One of the remaining challenges is the process of scaling up the design solutions and manufacturing processes, however the carried out project demonstrates that the geometric and the self-shaping principles can be translated to the architectural scale. Increasing the size of such element has also advantages when it comes to the production process. Small printers with fine printing resolution require more precision and accuracy in adjusting the height of the printing bed and the nozzle, so that the filament can get in-between the threads and attach to the fabric. Printing in lower resolution with thicker lines and more material allows compensating the differences and as a result the filament attaches very well to the fabric.

Demonstrated project shows a passive design strategy for a customized performative facade solution. Currently the material transformations are irreversible and remain in the deformed state after the tension is released. Could such process be reversed and these structures become dynamic? The next step of the research will focus on implementing movement into the textile structures in order to create active building envelopes adapting dynamically to the ever-changing environment.

5. REFERENCES
1.Kycia A.: "Material form-finding of modular textile structures",Ca2Re, 2017
2. Papadopoulou A., Laucks J., Tibbits S. : "General principles for programming material" in "Active matter", MIT, 2017
3. Galilei G. : "Dialogues Concerning Two New Sciences", 1638

SELF-SHAPING TEXTILES /// EXPERIMENTS IN A SMALLER SCALE

A catalogue of experiments

2 different modules demonstrating various transformation

A couple of 3D printed modules

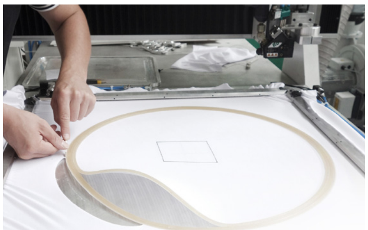
Textile module: Diameter 10cm, Fabric: 85% Polyamid and 15 % Elastan, filament: PLA)

Assembly of 9 circuar modules, 10cm diameter each

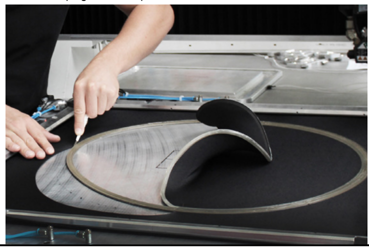
UP-SCALING /// MANUFACTURING PROCESS OF A 1:1 SCALE PROTOTYPE

Assembly process of the 1:1 scale prototype

Textile self-forming while releasing the tension



Self-shaping textiles experiments



1:1 scale prototype

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