THE EMERGENCE OF A NEW MATERIAL CULTURE: FORGING UNPRECEDENTED ALLIANCES BETWEEN DESIGN AND ENGINEERING

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ABSTRACT
This paper addresses a creative multidisciplinary project relevant to making programmable textile called Flexible Textile Structures through the lens of bio-inspired design, with the goal of fostering innovation and excellence in rapid prototyping and additive manufacturing. Flexible Textile Structures explored the reciprocal relationships among design, science, and technology across scales and appraised a wide range of aspects from visualization, fabrication, material ecology, architecture, to interaction and performance. Here, the focus was on conducting a clear line of design research in a school of design that supports creativity while also addressing the relationships between the new generation of textile developments and their shaping processes in the production of form through "form finding" exercises in 3D printing.

Keywords: Additive manufacturing, Flexible Textile Structure, Programmable Material, Multidisciplinary.

1 MAKING UNMAKEABLES

Every technology reflects the epoch and context within which it is created, and is able to transform the dimensions of intangible cultural and social values into tangible ones. If technology is viewed as a means of transcending cultural contexts and initiating progressive change in the world, what future lies on the horizon for design as an important component of culture, given its increasing dependence on technology? Moreover, what is the role of designers at a time when their proficiency is being called into question, and even changed by the consequences of digitally-driven technologies?

Over the past several decades, digital fabrication technologies including additive methods (such as 3D printing) have permeated and transformed many aspects of product design, architecture, fashion, and other design disciplines across the globe. Additive manufacturing, or the deposition of material to form a desired 3D structure through the sequential formation of the structure's cross-sectional layers, constitutes an historical turning point and illuminates the future of design. Likewise, such technology allows for the enhancement and extension of innovative practices within the related industries in the decades to come. Importantly, additive manufacturing can inspire and support an original voice for designers and engineers seeking to create unique designs and quality products in ways never before possible. Much more than a means of producing less waste than with reductive fabrication techniques, additive manufacturing allows designers to precisely create "unmakeable" shapes, structures, and geometries that previously were considered impossible. As a result, designers are increasingly taking advantage of the unprecedented development of additive manufacturing in ways that conventional manufacturing techniques are unable to accommodate.

2 OPENING NEW DESIGN POSSIBILITIES

On design education, additive manufacturing, as the third industrial revolution, represents a potential change in the way students learn, in the way that they think, and in the way they solve problems. Additionally, the fast changing world of additive manufacturing opens new design possibilities that did not exist only a few years ago, and as such it makes for an important addition to education in design.

By providing a setting wherein students could learn in depth about the foundational principles, capabilities, and limitations of 3D printing process, the authors from a school of architecture and design collaborated with several laboratories and departments at Virginia Tech University in the United States specially DREAMS Lab, an additive manufacturing lab in the department of mechanical engineering. Here, in an effort to offer an interdisciplinary approach to textile design through layered fabrication techniques, the goal was to design and produce a new class of material that had some of the intrinsic properties of self-organized and self-transformable natural systems, in which its characteristics were interrelated with its surrounding environment in a responsive way.

At the core of this collaboration was an attempt to respond to emerging technologies in ways that enabled designers to gain a greater understanding of complex issues pertaining to their professional careers. Through access to a number of different 3D printing technologies and resources, the collaboration led the authors to adopt a new perspective in examining the future at this time of rapid technological transition and to sharpen their proficiency in creatively utilizing the available facilities (beyond simply representing their designs in a 3D format). The aims of this collaboration included formulating a focused and coherent approach to restructuring the authors' perception of the manufacturing of 3D textiles by building up material, layer upon layer. As a means of achieving this objective, a working familiarity with the broad palette of principles, techniques, and tools necessary for a reasonable understanding of layer-based fabrication technologies was offered.

To highlight new design strategies for the future of design through additive manufacturing, the above mentioned collaboration drew inspiration from the way nature works and integrated the capabilities of nature into the computational tools. In the not-too-distant future, designs inspired by underlying principles found in nature will offer a range of methods for designers to use in creating products designed to function like living organisms when exposed to different environmental conditions. By responding to changing light, wind load, temperature and more, these buildings could vary their properties according to environmental constraints. In the meantime, with regards to the possibilities of additive manufacturing in printing different thicknesses, densities, levels of hardness or flexibility upon request, the authors attempted to design and print a series of textile prototypes called "*Flexible Textile Structures*" with a basic understanding of the formation and growth processes unique to organisms in states of constant adaptation (Figure 1). In close proximity to the natural sciences, for the authors, the objective was to translate the principals similar to those found in nature into their design, leading to the next generation of fabrics.

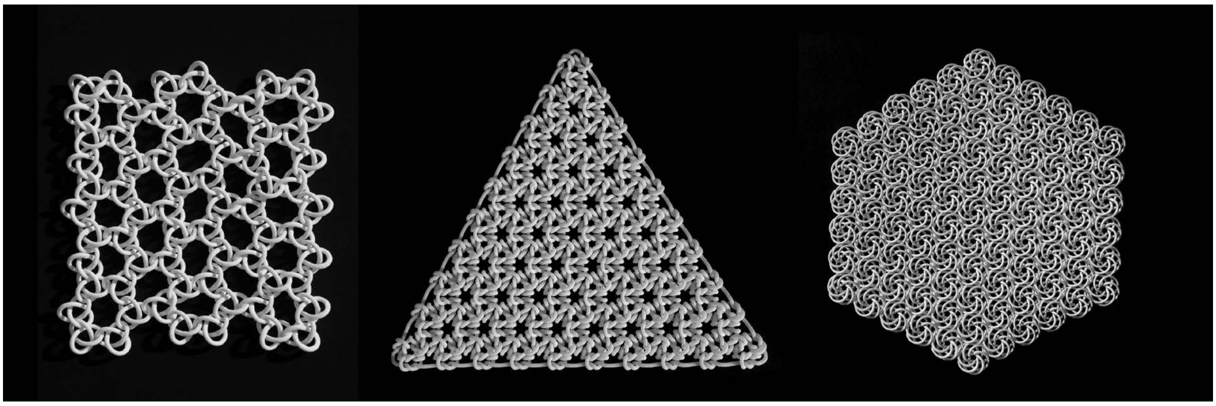

Figure 1. Flexible Textile Structures

To promote the study of both scientific and design significance, two theoretical and the practical interconnected domains were simultaneously persuaded. The theoretical domain was embodied by genuine design and fabrication phases wherein the authors enjoyed hands-on access to additive manufacturing technologies. As such, through hands-on design research opportunities allowing them to decipher and simulate the secrets of the underlying structure of materials found in nature, the authors were encouraged to learn the process of designing nature rather than mimicking it. To this end, the design process of Flexible Textile Structures marked a shift in attention from the formal to the material that relies on both the material appearance and performance. From this perspective, Flexible Textile Structures was about both process and product; both carry equal importance. In this design process the final forms were not predetermined and were a by-product of an iterative and interactive process called “form finding.”

The objectives of the authors’ collaboration were pursued by means of laboratory exercises that addressed the capabilities, limitations, and principles of additive manufacturing technologies, along with the ability to operate across multiple scales with creativity. Through a diverse range of prototypes that span different scales and a variety of novel approaches in action, the authors from very similar points on the creative spectrum engaged in the active investigation of key additive manufacturing strategies for developing the next generation of textiles. By highlighting both the decision-making aspects of each prototype and rigor in its execution, the prototypes raised intriguing issues of current and future additive manufacturing technologies, their underlying material properties, and the impact of these technologies on designing a programmable environment.

3 FLEXIBLE TEXTILE STRUTURES

The degree of flexibility or rigidity of a Flexible Textile Structure is derived from its characteristics and appearance. In general, a Flexible Textile Structure consists of a network of units often referred to as cells. The size of these cells can be modified to perform different structural behaviours as well as different aesthetic influences. Based on the underlying geometry, material properties, and the gap between these cells, the degree of flexibility of a textile can be varied.

Here, the concept of flexibility implies a property of Flexible Textile Structures that can cope with changes in circumstances. Flexible Textile Structures is unlike other flexible surfaces, such as rubber-like surfaces or chain-like surfaces. This research is guided by the question, “How to design 3D printed textiles that can be flexible and rigid at the same time?” Therefore, the main design challenge of this research is to change the property of rigid material by design and 3D printing manufacturing. Flexible Textile Structures is divided into two types as follows:

The first type of Flexible Textile Structures refers to the designs that can adjust themselves when external forces are applied. In this research, solid materials generate flexible surfaces that can hold their forms when the applied forces are removed (Figure 2). A series of interlocking Mobius motifs are fitted together and followed in succession. Each Mobius motif has a range of motion and the textile can be reshaped several times between the flexed position and the extended position.

The second type of Flexible Textile Structures does not resist deformation in response to applied forces. This type can expand or contract in size to adapt to unforeseen external forces. There is a tendency to return to the original shape and initial size after being deformed. These textiles are flexible in spite of the fact that they are made from rigid substance (Figure 3).

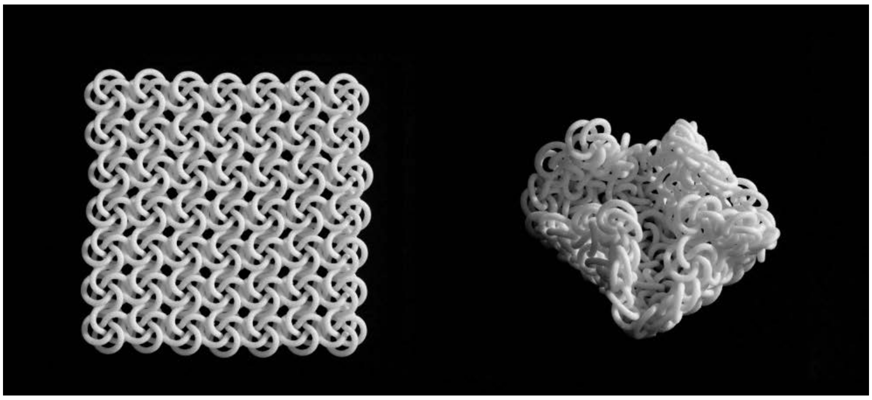

Figure 2. First type of Flexible Textile Structures

Conventional textile techniques can be less expensive in high quantities, but 3D printed textiles are more convenient and efficient when producing relatively small quantities. The main advantage of a 3D printed textile is its ability to create almost any complex pattern or shape that is impossible to produce by any other method. Furthermore, producing textiles via conventional processes requires knowledge, experience, and resources not available to everyone. 3D printed textiles allow a broader cross-section of ideas and experiences to be involved in the textile industry.

Figure 3. Second type of Flexible Textile Structures

Various textiles are generated by different computer-aided design (CAD) software such as Rhinoceros, Grasshopper, and SolidWorks. By tweaking the digital model and print settings, the right tolerance can be applied to eliminate any potential fusion between two parts during printing.

These textiles are fabricated with three additive manufacturing processes: Powder Bed Fusion, PolyJet, and Fused Deposition Modelling (FDM). Each printing process has its own advantages and disadvantages. For instance, unlike FDM or PolyJet processes, Powder Bed Fusion does not need support structures. In addition, by using the Powder Bed Fusion process, a digital model of a large textile can be fitted into the 3D printer's build volume if the model is folded into a more compacted form via CAD software. Based on the selection of 3D printing technology and the size, number, and complexity of the digital model, speed and scale of production are altered. Flexible Textile Structures are made in various strengths and degrees of durability depending on the type of material and how different layers of material are laid down. 3D printed textile can be produced in multiple colours and materials. Flexible Textile Structures can be made from many materials.

This research has potential applications in several domains such as medical, architectural, automotive, sport, and fashion industries. Flexible Textile Structures can be used to create unique clothing tailored to specific individuals; 3D data may be used to develop skin-matching fabric structures.

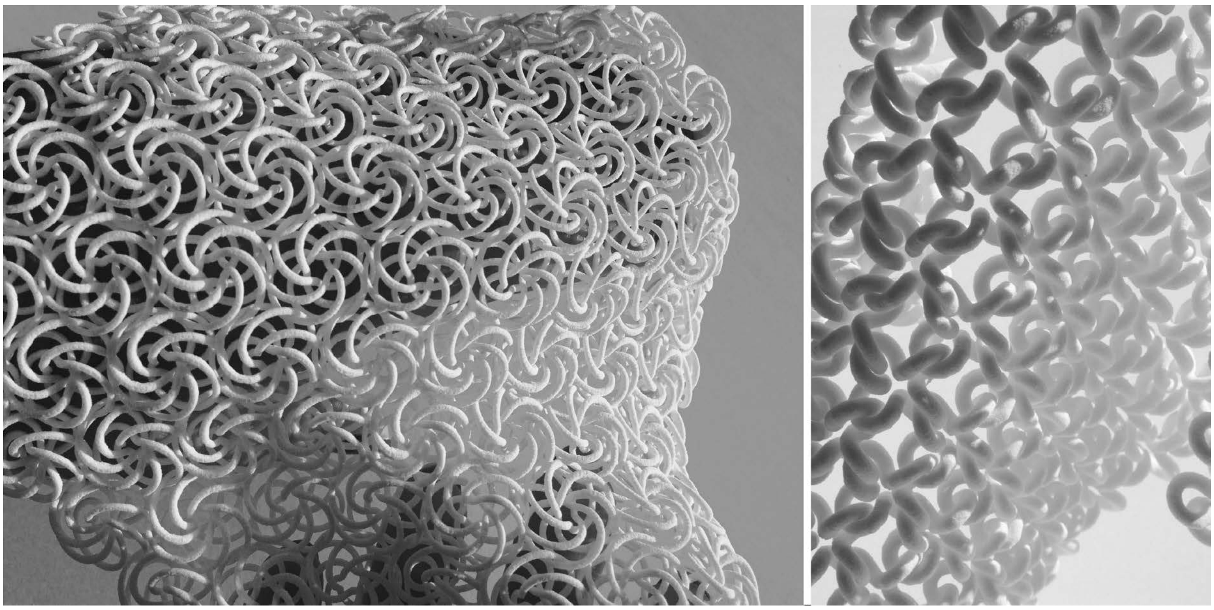

Figure 4. Skin-matching fabric structures

Flexible Textile Structures will be developed to use and convert 3D data into skin-matching fabric structures (Figure 4). By following a body scan of a person, 3D printed textiles will be entirely customized to fit the contours of the human body. Unique to Flexible Textile Structures is a dress that will be printed in one piece without any cutting and stitching. The potential for flexible textile structures tailored to the specific individual will be as accessible as the patterns that can be created, from interlocking Mobius motifs to tightly woven meshes. The size of patterns can be easily manipulated and their shape can be morphed from one design to another.

4 DESIGNING MATERIAL BEHAVIOUR

Although product design is a material practice, there is a dominance of formal concerns. In some working practices, product designers embrace design methods that privilege the formal aspects of design. Therefore, material considerations are too often an afterthought and brought in during the later phases of the design process as subservient agents. The prioritizing of form is cause to consider material as a servant of form.

Through questioning the historical distinction between form and material and finding a way to compensate for this distinction, the authors discuss how the appearance of material might be intertwined with and dependent upon its performance, through an exploration of their printed textiles. By placing an emphasis on the performative agencies of design, the use of emerging technologies such as 3D/4D printing and advances in materials science offer the possibility of designing the behaviour of material, rather than simply shaping already existing material. Via extending the possibilities of the digital realm into multifaceted material behaviours, the design process of 3D printed textile provided insight into the near future of resources called programmable materials.

Through inspiring new approaches to designing and producing bio-inspired textile, the authors gained an extensive understanding of how 3D printed materials became programmable and made to respond to various environmental triggers. By using the principles learned from nature and printing layer upon layer of materials, the goal was to control the spatial distribution of materials and fabricate textile that offer both flexibility and rigidity on demand (Figure 5). By crossing the boundaries of various fields such as biology, material science, computation, the textile industry, and additive manufacturing, Flexible Textile Structures aim to highlight the search for a way of thinking about issues of adaptation, change, and performance in different fields of design. Through the adaptation of functions, configurations, or behaviours, Flexible Textile Structures promise new possibilities for programmable actuation, sensing and self-transformation. In a sense, power source-less, motor-less and wireless components transform into new shapes to adjust their properties when confronted with changes in temperature, pressure, or moisture.

Figure 5. Flexibility and rigidity on demand

Flexible Textile Structures inherently have the ability to perform in a programmable fashion, based upon input such as autonomous sensing, user input, or external stimuli. By embedding programmability into material, all of the shape changes of the material and its relevant behaviour can be predictably controlled during the design stage and before the material is subjected to external forces. In such cases, the number of times, direction, and even the angles at which the textile's cells should react can be simulated and determined beforehand.

The outcome of research on Flexible Textile Structures is to create profound explorations within the boundaries of programmable materials which can act as the underlying structure of a responsive building skin (Figure 6). The authors' research on Flexible Textile Structures represents a geometric understanding of the constraints and opportunities of different substances that are combined to generate the intrinsic and extrinsic properties of textile structures in an effort to achieve an acceptable level of flexibility and rigidity in ways not possible with conventional textiles.

In the interest of exploring how different layers of materials can be laid down to regulate the desired shape changes of building envelope, the authors employed computational and hands-on approaches towards utilizing different additive manufacturing techniques built on algorithmic optimization of complex components along with their material properties, and parameterization of the structural arrangement, location, and orientation of materials within the envelope. Here, by exploiting the opportunities offered by digital fabrication means and methods informed by parametric tools, the authors attempted to epitomize the complex reciprocities among the multiple influencing variables existing amidst form, material, and performance of building envelope.

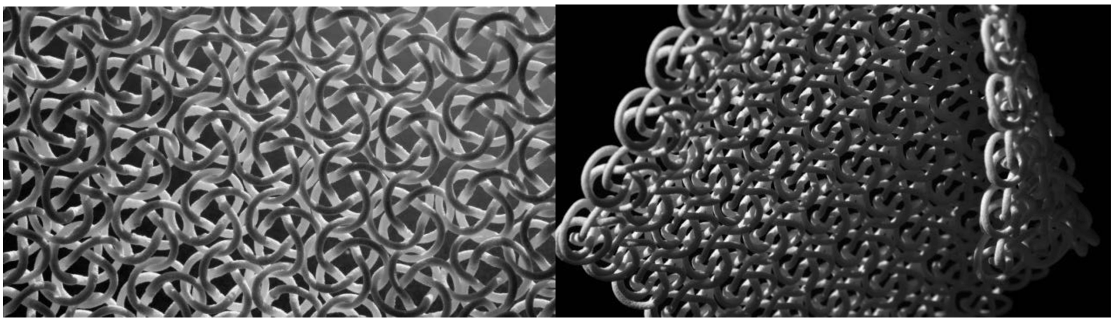

Figure 6. Programmable material explorations

5 CONCLUSION

Flexible Textile Structures search the role of additive manufacturing technologies in design and articulate their potential implications for bio-inspired textiles, according to principals similar to those found in nature.

In the face of technological change, Flexible Textile Structures address opportunities for the integration of engineering in design practice and represent a potential change in the way designers comprehend design challenges. As a consequence of this approach, the authors attempted to develop the possibilities that additive manufacturing might hold for the future of architecture, and translate the technological revolution of our own era into bio-inspired design.

Through underscoring the significance of approaches to inspiring a desire to deepen the relationship between innovative ways of design thinking and ways of making programmable textiles for now and in the future, Flexible Textile Structures aimed to explore new shared territories in the field of design, biology, and technology. Flexible Textile Structures addressed the provision of practical and imaginative insights regarding the principle, logic, or behaviour of nature and their translation into the design of a smarter product.

Flexible Textile Structures, fabrics inspired by nature and created by additive manufacturing techniques, are geared toward helping designers successfully translate their experiences into profound knowledge and insights. By means of this knowledge, Flexible Textile Structures can capture the imagination of both designers and engineers from several disciplines to bring them to life.

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