Beyond Material

Digital Tectonics of Fabric and Concrete

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Fabric formwork, known as the casting concrete with flexible fabric molds, frees the nature of the material, which is fluidity; hence, its tectonics. This paper examines the tectonics of concrete and fabric through computational design and analog methods. During this examination, fabrigami technique is used to foresee the intuitive act of concrete within the fabric mold concerning the computational model. Fabrigami use in fabric formwork allows the emergence of a dynamic fabric mold system revealing form variations.

Keywords: *fabric formwork, fabrigami, folding, dynamic mold*

INTRODUCTION

Concrete, one of the most widely used materials of architecture, has become a material that produces repetitive architectural tectonics squeezed into wooden molds in general. Although there are flexibility and fluidity in the essence of concrete, the limits determined by conventional formwork methods with concrete material are generally far from being flexible. Fabric formwork, known as the casting concrete with flexible fabric molds, frees the nature of the material hence its tectonics. Researchers and designers have been investigating the structural and artistic performance of the fabric form concrete on the architectural elements and design products by using both analog and digital methods since the 19th century (Veenendaal et al., 2011, Veenendaal, 2016). Conventional concrete casting methods have started to be questioned, starting with the integration of fabric formwork to design, especially throughout the technological developments. As one of the pioneers of the fabric formwork field and the founder of Centre of Architectural Structures and Technology (CAST)(2002) at the University of Manitoba, Winnipeg, Mark West underlines that this integration defines a new periphery for the entire "tree" of concrete architecture. West approaches to concrete material as an entity that does not have any idea about its form in the end. According to him, the flexibility of mold enables an ongoing relationship with responsive concrete material where the plasticity and weight determine and define the final form (West, 2016).

The definition of the form in fabric formwork has a grammar constructed upon gravity, flexibility, material amount/weight, and supports/hinges. All these elements can also be called as the vocabulary of the grammar of the generated concrete form. Fabric formwork differs from conventional formwork methods with its unpredictable nature. The result of fabric form concrete casting can always differ even with a well-defined or duplicated mold. The use of CAD/-CAM technologies and robotic production methods opened a gate for novel production methods for molds, consequently for fabric formed concrete, especially to foresee the result of the casting and to raise the accuracy of the digital simulation models. Regarding the destructive effects of the age of humans, the research in architecture has focused moreover on material reduction and sustainable methods in construction and design using computational design tools and methods. Fabric formed concrete responses to these needs most, but it could not have been spread around the construction market yet.

While these concerns lead design research, researchers also seek novel form-finding methods via these technologies. Different form variations can be produced with the flexible and fluid-structure of the concrete. The relationship between the digitally designed and applied leads to the continuous feedback loop about the mold and generated form. While the mold evolves during these feedbacks, the form changes from one situation to another. Although these inversion and transformation processes are uncertain in conventional methods, they can be predicted by computational design methods.

CONTENT

Form generation via fabric mold is a production method that will come to the forefront in the future with developing technologies working on mostly material reduction, computation, construction, and sustainability topics. Therefore, the computable behavior of the molds and materials regarding the generated forms should be examined more to discover the potentials of the tectonics of the fabric and concrete in digital realms.

In this paper, digital tectonics of concrete and fabric is investigated through computational design and analog methods. The relationship between the material, mold, and digital model is questioned through the technique of fabrigami (fabric origami) during this investigation. A dynamic fabric mold system is used while seeking for novel tectonics of fabric formed concrete besides. The study has four stages, as listed below.

1. the investigation of fabrigami and its use in design in terms of geometry and form
2. the use of fabrigami as a patterning technique via computational design methods
3. the design of the computational model of the mold
4. the fabrication of the mold and casting the concrete

The experiment stages are compared to elaborate on the behavior of the fabric mold both in analog and digital realms. The reusability of the mold is also questioned.

Fabrigami and Its Use in Design

Fabrigami means folding fabric by using origami techniques. While the primary material is paper in origami, in fabrigami, it is fabric (Stovall, et al., 2013). Origami, which is a combination of two words; ori (originated as oru) meaning "to fold" and kami meaning "paper" in Japanese, is the art of transforming a 2D shaped flat paper through a recipe into a 3D form by using solely fold operations (see figure 1). In this paper's context gami - rendaku sound of the paper (Kubozono, 2008)- does not represent a material. On the contrary, it represents the folding act. In this case, gami is used as a morpheme and fabric, and gami unites the word Fabrigami which can be defined as the act of folding 2D fabric with a step by step procedure to generate a 3D form. While the geometrical result of origami is predictable, the geometrical result of fabrigami can both be predictable or unpredictable.

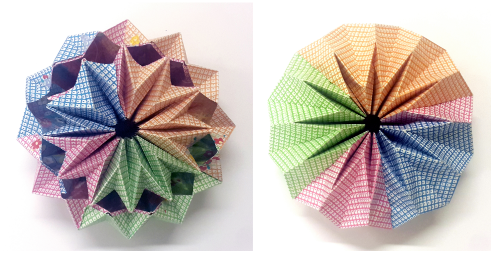


Figure 1
An origami form generated through a waterbomb base pattern produced by the author

The static nature of a flat sheet of fabric turns into a dynamic form through a mathematical recipe, through an algorithm as in origami. However, the algorithm of the origami needs to change in terms of operations for fabrigami, especially in actualization phase. While origami depends on solely folding, fabrigami needs more hinge-like operations according to the use purpose (see figure 2).

Figure 2
Fabrigami forms generated through the waterbomb base pattern by Dennis van Rijsbergen, the folding is generated with dashed laser cut lines.

Fabrigami and its use in design in terms of geometry and form depend on origami folding operations. Origami is widely used in architecture and design for form-finding, shell, and plate design and structural design areas. It offers opportunities to explore various generative, kinetic, and deployable structural behaviors as well as esthetic qualities with its from simple to complex mathematical relations with form (Sorguç et al., 2009, Coar, et al., 2016). As origami techniques base upon transforming a 2D rigid sheet or plate into a 3D rigid form, fabrigami uses anchor points/edges and hinges as in tensile structures or supporters like in deployable structures (see figure 3).

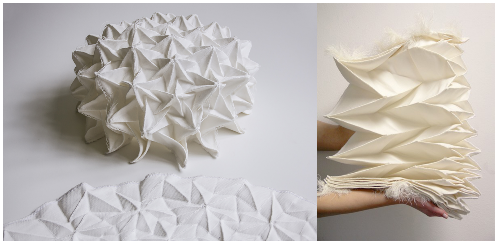


Figure 3
Studio Samira Boon's woven self-supported origami used fabrics

Figure 4
Fabrigami Project by L. Coar, C. Mueller, L. De Laet, J. Hare, K. Wiese, S. Oberlin, Winnipeg, Canada. 2016

While Samira Boon focuses on using fabrigami by digital weaving techniques, Lancelot Coar et al. 's Fabrigami named project is an accurate and contemporary example of tensile structure typology. The study is also the only research that uses the word Fabrigami in the architecture field. The designers use origami both for form generation and structural performance. It is a temporary warming hut project in Winnipeg, using flexible fabric material. An ice shell is created by wetting the fabric with water and then by making it freeze to achieve a rigid structure (see figure 4).

Fabrigami as a Patterning Technique via Computational Design Methods

Fabrigami uses origami techniques in terms of pattern generation. It uses the same grammar grounded on a crease pattern, which is an unfolded diagram of the form. In other words, it is a generative 2D design representation working as a reference for the folding lines. A crease pattern references two types of folding acts called mountain and valley as illustrated in figure 5. Origami form emerges by folding the crease pattern according to mountain and valley traces. These traces structure spine of the form (Lang, 2011).

The fabric should be strengthened in fabrigami to achieve a self-supporting form. There are multiple techniques to strengthen the fabric, such as 3D printing the crease pattern on the fabric, digital weaving, using tensile and deployable bar structure typologies, and material studies like creating a hybrid fabric combined of textile and plastic. The subject matter is selected as the waterbomb base pattern to understand the essence of the origami geometry and fabrigami pattern generation. Waterbomb base is a fundamental pattern that can produce complex geometries with its tessellations. The parameters of the waterbomb base are mountain, valley, edge anchor points, center anchor point, mountain orbit, valley orbit.(see figure 5) The generated unit from the waterbomb base can act as the unit of a modular system. One of the variations of the waterbomb base tessellation can be seen in figure 6.

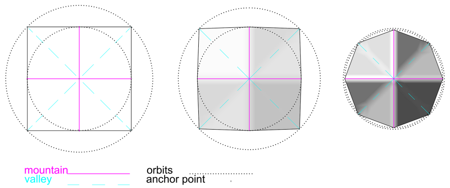


Figure 5
The parameters of the waterbomb base

The Design of the Computational Model of the Mold

All these parameters can be controlled dynamically through a computational model, and the variations can be determined accordingly. To understand the dynamic nature of folding, the waterbomb base pattern folding motion kept symmetrical in the generated computational model. There is a spherical kinematic where all the action is determined through a single input, which is the folding angle shown in YZ coordinate direction in figure 7 (Hanna et al., 2014). As the angle differs, the anchor points move along the mountain and valley orbits, and the generated form closes and opens dynamically. This folding act opens a gate towards a dynamic mold system that can be computed. Through one waterbomb base pattern, many variations can be produced. Till to this stage, the fabric plates are considered as flat sheets. Hence the results of the folding act are predictable.

While the computational model of the mold is generated with RhinoCeros software and Grasshopper plugin, the simulation of fabric formwork is conducted with the Kangaroo plugin. Kangaroo enables the physical simulations, but the accuracy of the computed models is questionable in this study in terms of material quality and behavior. According to that, two computational models are generated regarding the control tolerance. In the first model, the anchor points all along the fabric edge have been rigid as like a rib structure, and the folded mountains and valleys are considered as a hinge-like spine (see figure 8). The first simulation created a controlled behavior that can be observed through the folding angle variations, as seen in figure 9. It also enables the creation of a two-way fold modular design unit, as shown in figure 10.

In the second definition, the anchor points determined as the corner vertices of the fabric, and the crease pattern is considered as a hinge-like spine (see figure 11). The results are unpredictable, and control tolerance and the simulation accuracy is low. Therefore, to foresee the unpredictable acts, the second model definition is selected to produce the mold for casting the concrete.

Fabrication of the Mold and Casting the Concrete

Regarding the findings from the computational model, a trial mold is designed in the home environment. The primary materials of the mold are felt for fabric, metal bars as spines, cement, water, ropes, and wood for the structure (see figure 13). The planned dynamic mold could not be actualized due to material limitations. However, the static mold works as an exploration medium to understand control tolerances, and it sheds light on the dynamic mold generation. It has been realized that the symmetrical kinetic system of fabrigami is unstable due to fabric

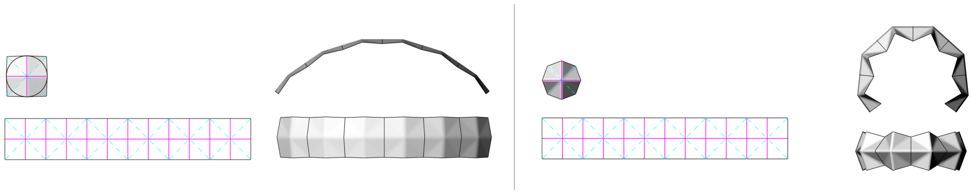
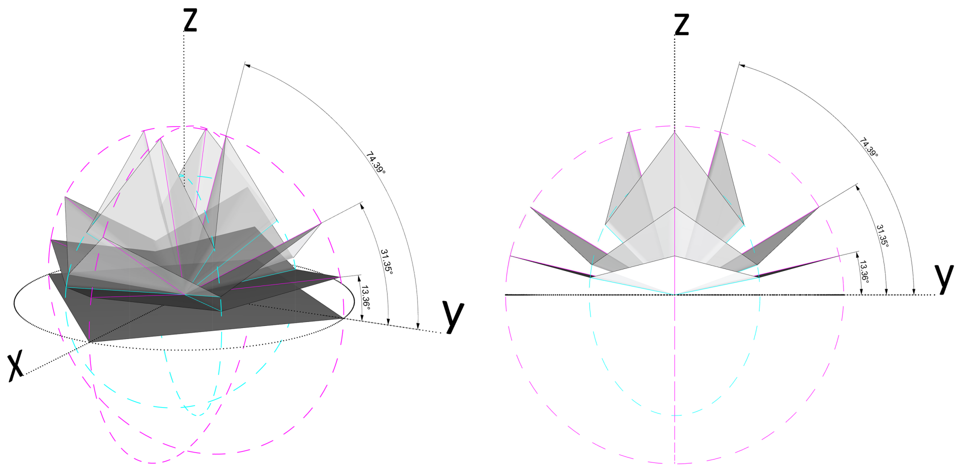


Figure 6
The waterbomb base tessellation variations and their crease pattern

Figure 7
The dynamic folding variations of waterbomb base pattern through the angular changes in ZY and XZ directions



quality. As a result, the control points symmetry of the fabric mold was not accurate, as in the computational model. More fabric types need to be tested to understand this situation, and the mold construction needs to be more precise in terms of fabrigami and fabric formwork parameters.

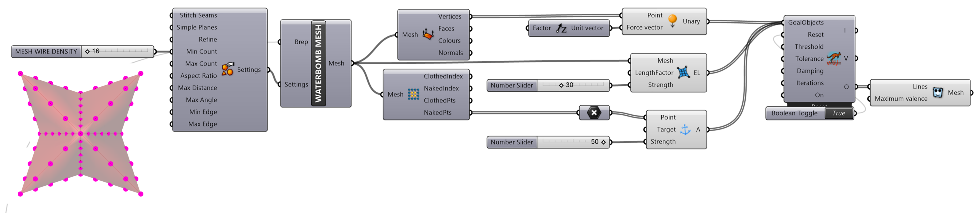
The final fabric formwork has proved the unpredictable act of the fabric (see figure 14). As West pointed out, the concrete has no idea about its shape. Hence this situation can be interpreted as a creative shift in the design process. According to that, the computational model can be reevaluated.

The metal bars as a spine technique also needs to be elaborated, and more variations need to be tested by using multiple techniques to strengthen the fabric. 3D printing the crease pattern on the fabric, digital weaving, using tensile and deployable bar structure typologies, and material studies like creating a hybrid fabric combined of textile and plastic should be researched and tested on a fabric form concrete casting.

CONCLUSION

In this study, the intuitive act of concrete within the fabric mold is explored by using fabrigami techniques for form-finding and mold generation concerning the computational model. The relationship between the computationally designed and materialized creates a continuous feedback loop about the mold and generated form in a fabric formwork. This

Figure 8
The initial computational model in which the anchor points defined all along the fabric edge



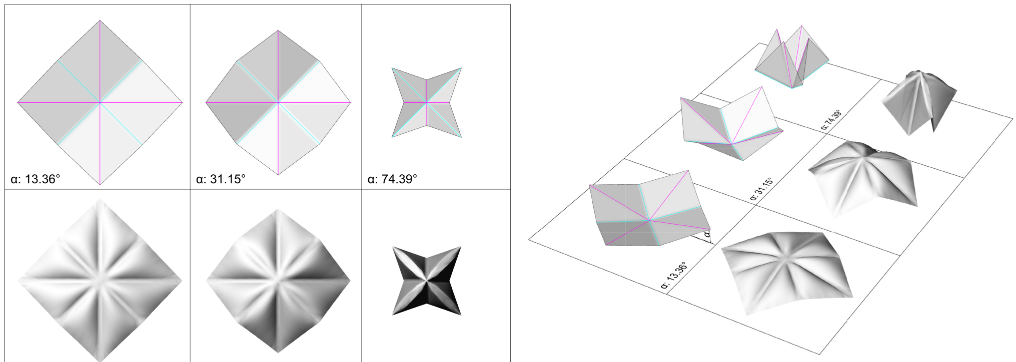


Figure 9
The variations of the generated form, initial parameters are folding angle and material force amount

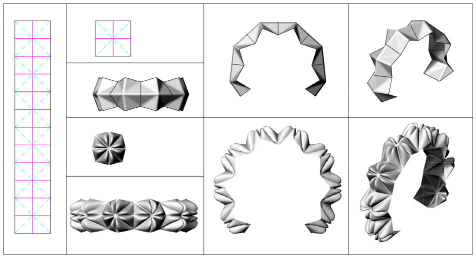


Figure 10
Waterbomb base pattern as the unit of the modular designed arche

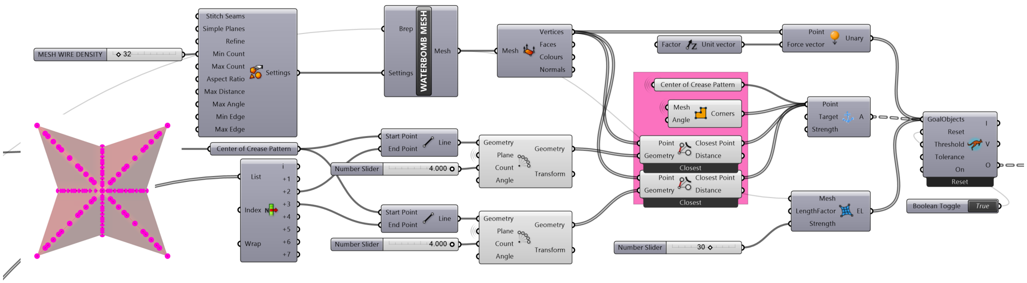


Figure 11
The second definition, the anchor points determined as the corner vertices of the fabric, and the crease pattern is considered as a hinge-like spine.

Figure 12
The variations of the generated form, initial parameters are folding angle and material force amount

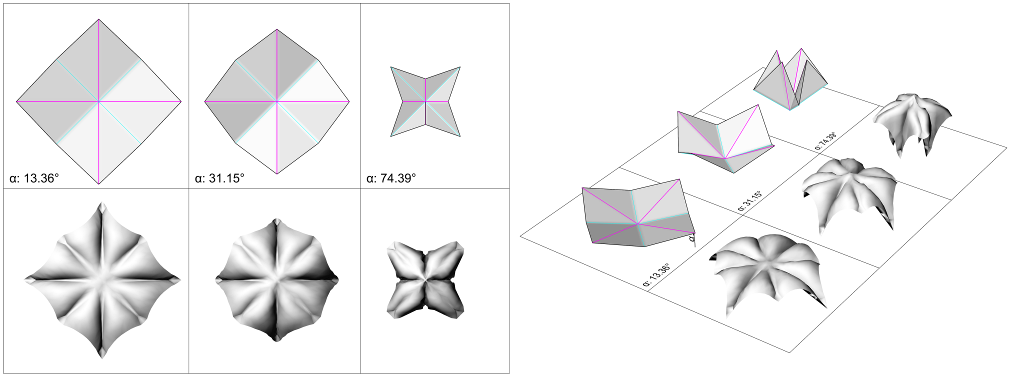


Figure 13
The production steps of the fabric mold from fold to sewing and casting

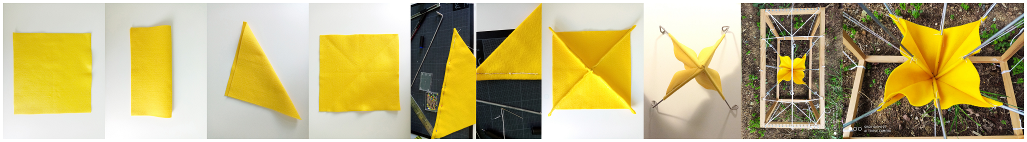
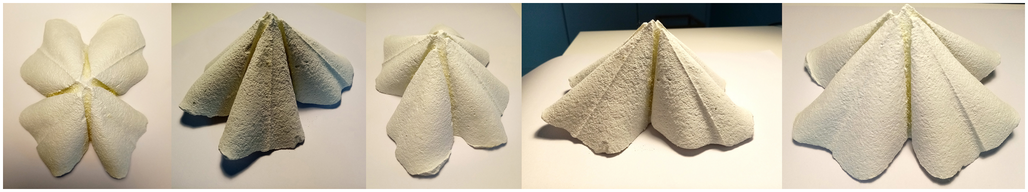


Figure 14
Squences from the final fabric form concrete cast



feedback loop feeds the exploration of potential tectonics of the fabric and concrete in collaboration with the computational model.

This study also proposes the integration of fabrigami generally used in craft making to architectural and structural design as a technique, especially in the field of fabric form concrete. Fabrigami use in fabric formwork has many potentials in terms of both form-finding, structural design, and concrete casting fields regarding its kinetic geometry. Fabrigami and fabric formwork share a common ground in the form generation process by using simple inputs and achieving complex grammars as outputs. Hence, the organic nature of fabric formwork and well-defined procedure of fabrigami also have the potentials to generate a new language of form. This language of form is constructed upon the grammar and vocabulary of fabric formwork and fabrigami, which are linked to crease pattern generation, fabric quality, material, and dynamic mold behavior. Therefore, a comparison of regular-irregular shape use on crease pattern generation and symmetrical-asymmetrical construction of the dynamic mold using different folding angles and fabrics are necessary to explore the possible variations of form-material behavior.

As aforementioned, while the geometrical result of origami is predictable, the geometrical result of fabrigami can both be predictable or unpredictable, as in fabric form concrete casting. The dynamic behavior of fabrigami allows the emergence of a dynamic fabric mold system revealing form variations. The actualization of design representation is problematic due to the accuracy of computational simulation. As technology develops more, the precision of the actualization phase will increase in parallel. The generation of a mechanical dynamic mold for fabric form concrete casting has broad potential in terms of collecting more data on the fluid nature of the concrete. The impact of this can have a reflection on human-computer interaction (Forren, 2019).

Therefore, the results of this study will be used as input first for developing a dynamic mold system and afterward, an intelligent -learning- mold in the future. Also, asymmetrical systems can be tested with robotics to explore design precision and formal irregularity relation.

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