An Exploration on Transformable Shading Systems

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Abstract

Adaptability is one primary advantage of considering motion in architecture. As a dynamic filter between interiors and exteriors, an adaptable building interprets movements - either to affect a desired change of use, or to rapidly adapt to ambient conditions through self-alteration. [2] In concert with systems that allow the filtering of light, views, sounds, or smells, motion can also enhance aesthetic experiences in architecture. [3] Despite the fact that adaptive architecture is expected to deliver a high level of flexibility, there has been insufficient attention in architectural education to its dynamic potential. [1] In the spring 2015, a transformable design studio called tranSTUDIO at Texas A&M University was offered to fourth year architecture students to address the principles of transformable design. In this paper, we present a transformable shading system (Figure 1) proposed for the façade of the Museum of Fine Arts in Houston developed in tranSTUDIO[1]. Rows of tetrahedrons rotate autonomously along the x-axis. As alternating rows rotate upwards and downwards towards each other, the quality of light and shadow is readapted for the space. As the forms separate from each other, light peaks through the gaps revealing the interior space.

Figure 1 : *A transformable shading system proposed for the Museum of Fine Arts in Houston*.

1. Introduction

In order to seek new solutions to mediate between internal and external conditions of buildings, the design of building envelopes are gradually shifting from static to dynamic. Adaptable shading systems not only optimize environmental performance but also add aesthetic intrigue. Designers now have the tools to

[1] This project was a collaborative project with Matthew Michalak in tranSTUDIO 2015, in the department of architecture at Texas A&M.

experiment with transformable solutions that utilize environmental factors to accommodate the needs of the occupants before fabrication. Parametric design can propagate new standards in building envelopes. Furthermore, transformable building envelopes can further mass customizations of geometry and shading.

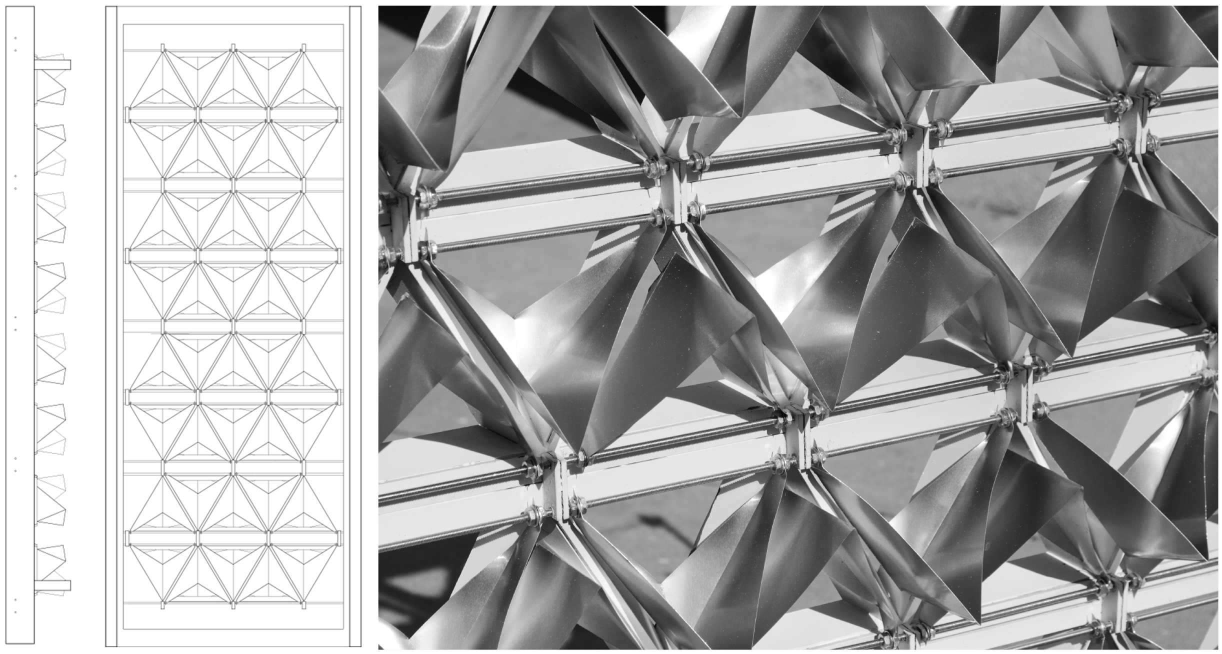


Figure 2 : *Triangular tessellation*

2. Initial Design Development

The transformable shading system is to be applied onto the Cullinan Hall, an addition to the Museum of Fine Arts in Houston, designed by Mies van der Rohe. The most prominent feature is the curving glass front to imply the freedom of free-flowing open space throughout the interior volume. Preserving the interplay between the exhibitions within and the street view, the shading system must complement Mies van der Rohe's minimalist, modular design yet introduces alternate pattern configurations. Thus, it is essential to design a system that would fit into an iconic architectural style but also could be transposed on multiple typologies.

Our solution fulfills this objective by allowing simple modules with complex movement to create gradient patterns while modulating between transparency and opaqueness. Due to the transformability, the system balances aesthetics and mechanics. The system would be managed mechanically but also could offer a high level of complexity in the visual sense. Furthermore, the shading device should appear light in terms of weight and movement without the bulky view of the mechanical components. The interior condition should be valued equally to the exterior.

In order to achieve the aforementioned qualities, the shading system must consist of modules that have the capability for tessellation. In terms of two-dimensionality, only triangles, squares, and hexagons can be replicated infinitely to fill a plane without any gaps. Triangles were chosen because they are a minimalist shape that when multiplied create a myriad of patterns. Furthermore, they can promise an interesting interplay of light and shadows (Figure 2). Shifting from two to three dimensions, the triangular pattern inherently transitions into a series of tetrahedrons that will serve as a base for sculpting the geometry. In order to create variability of daylight filtering through the design, two systems were created: the solid and the frame. By maintaining a static frame and moving the solid tetrahedron along the frame's edge, the play of light within the frame is a unique experience as shown in Figure 3 and 4.

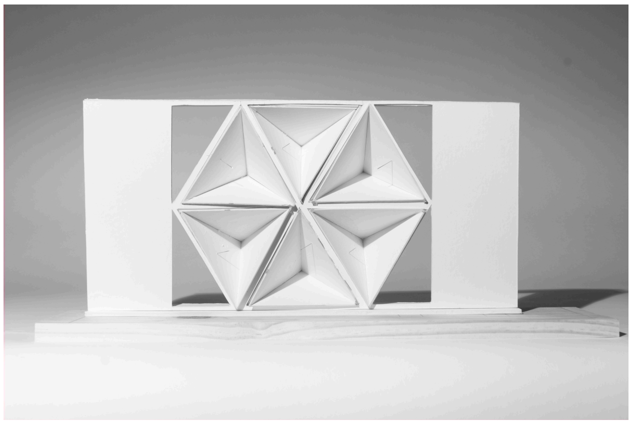
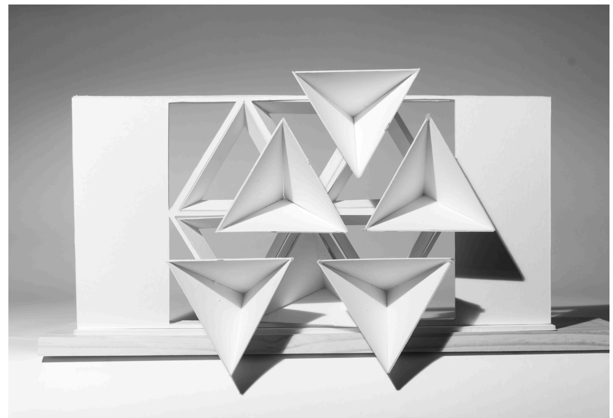



Figure 3 : *Closed*

Figure 4 : *Opened*

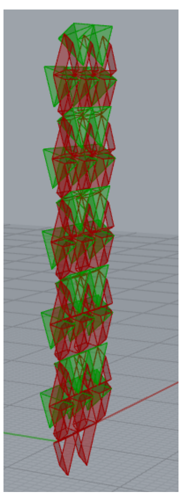
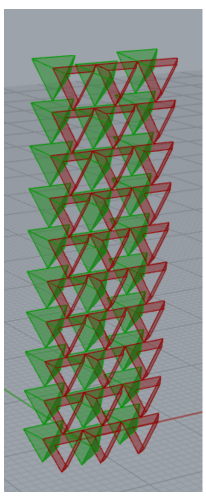
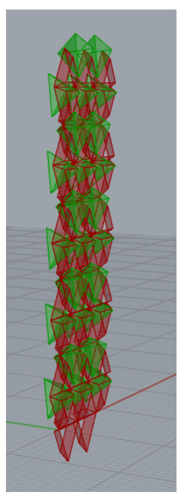
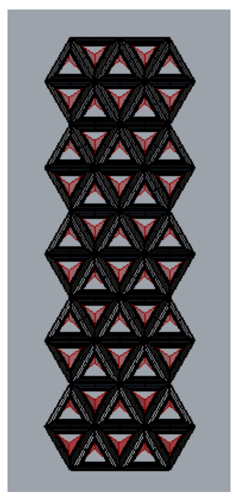
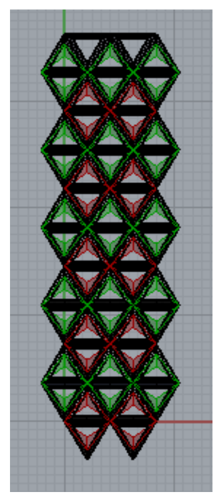
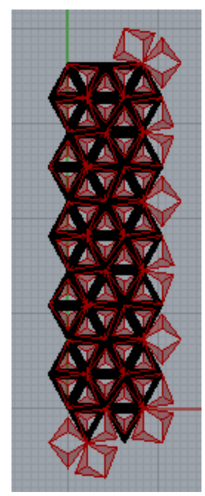







Figure 5 **Figure 6** **Figure 7** **Figure 8** **Figure 9** **Figure 10**

3. Digital Iterations: Exploration Focusing on Movement

Explorations during the iterative process were focused mainly on movement. Pattern making through parametric design software, such as Rhino and Grasshopper simulations, was tested to recognize different configurations. Grasshopper is a visual scripting plug in for Rhino that allows designers to specify a sequence of relationships and operations to generate complex geometries (See Figure 11). In this application, these tools were used to digitally animate various transformations of the shading system. With the first iteration, Figure 5 shows alternating rows slide along the front and the backside of the frame. Front pieces move along the right edge while the back pieces translate along the left edge. In the second arrangement, all pieces uniformly translate along the left edge of the frame as shown in Figure 6. Figure 7 shows a similar configuration as the first iteration, but this one rotates 60 degrees as the pieces slide along the edges. The movement is really intriguing; however, the modules awkwardly hit the frames as the tetrahedrons are rotating. With the next variation, the tetrahedrons have one face subtracted from the geometry, which are termed “fins”, in order to allow light to penetrate through as the pieces rotate like a hinge along the edge of the frame. With this movement, there is no conflict of overlapping modules. Furthermore, this configuration filters the light to create more interesting patterns (See Figure 8). Figure 9 displays an option similar to the last arrangement except that all the pieces rotate 90 degrees along the horizontal edge and alternating rows close up in the back. The last arrangement plays with the previous iteration by rotating pieces along multiple edges (See Figure 10). This appears visually overloaded and couldn't achieve the desired effect for the shadows.

All of the iterations were cross-referenced with two conditions. Daylight simulations in Grasshopper and Rhino were utilized to test shading effectiveness. Moreover, by analyzing which of the iterations is physically plausible to construct the mechanism within a time constraint, the possibilities are ultimately narrowed down Iteration 5, which showcases interesting shadows and simple movement that can provide flexible configurations.

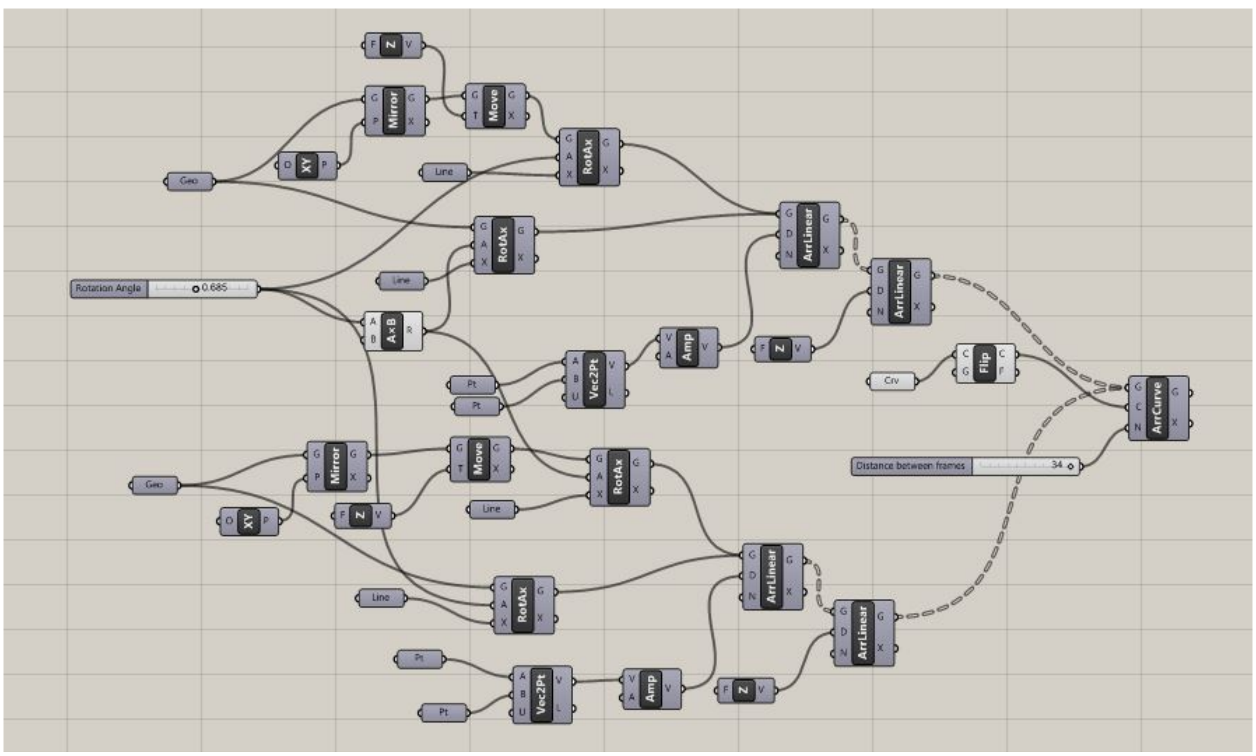


Figure 11: *Grasshopper definition of Iteration 5*

4. Physical Iterations: Exploration Focusing on Mechanics

While physically realizing the shading system, a few technical issues were also recognized. In Figure 12, the fins were not catching onto the rod. In order for this system to work properly, the fins must be completely fixed to the rod. Also, while building the frame, only the edges are touching thus not providing much structural stability.

Taking these technicalities into consideration, a new model with the realistic materials was constructed and even more challenges were encountered as shown in Figure 13. A threaded rod was utilized to hold all of the fins together and fixed the fins in its position relative to the rod by compressing the fins' corners between two nuts. This worked well until the nuts began loosening. Therefore, a jig was built to temporarily support the frame. Furthermore, with all of the fins threaded through, the rod bowed in the middle, which made it difficult to rotate the fins without hitting the frame. Another issue was the precision needed for constructing the frames. The assembled frame created a slightly smaller gateway for the fin to pass through.

After resolving earlier problems through a redesigned model, a backing was created for the frame pieces to rest on and devised a joint that will straighten the threaded rod (See Figure 14). A groove was cut into the modular frame to easily slide the frame backing into place. This test model has solved so many problems that were previously discovered; however, there are still a few more conflicts that need to be resolved.

The fins were trimmed so much from its original geometry that it wouldn't be able to shade the building as much. The new fins once installed must have enough tolerance to pass through the frames and significantly shield the users from the sun. In the final model, the geometry was resolved by folding out the flaps on the outer edge of the fins. This not only made the height of the fins smaller but also the shielded from the sunlight more. From an aesthetics perspective, the fins look more fleshed out and dimensional as shown in Figure 15.

Additionally, vise grips were previously exploited as actuators, which worked flawlessly for rotating one row of fins. However, it would be overwhelming to rotate multiple vise grips simultaneously. Therefore, a strong handle must be devised to not only rotate the fins but also actuate multiple rows simultaneously. To operate one row, the handle must be fixed to the rod as well. By giving thickness to the handle and imbedding two nuts into the sides, we have accomplished this. One system can operate every other row, be it all rotating upwards or be it rotating all downwards. Therefore, there are two systems to operating from the same center point in opposing directions. To connect the handles, a dowel is attached to all handles. This connection must have allowance for rotating the handle. (Refer to Figure 16).

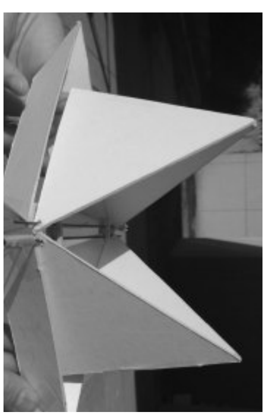


Figure 12

Figure 13

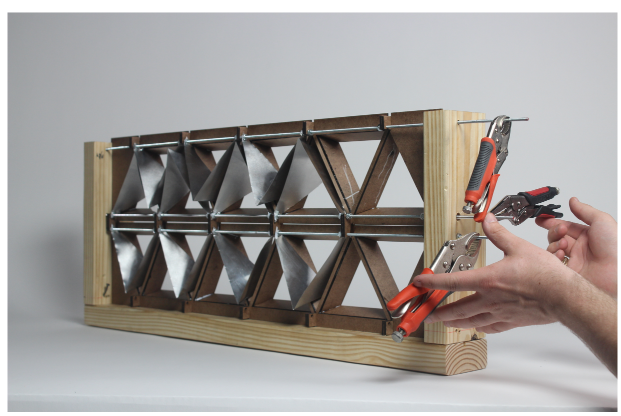
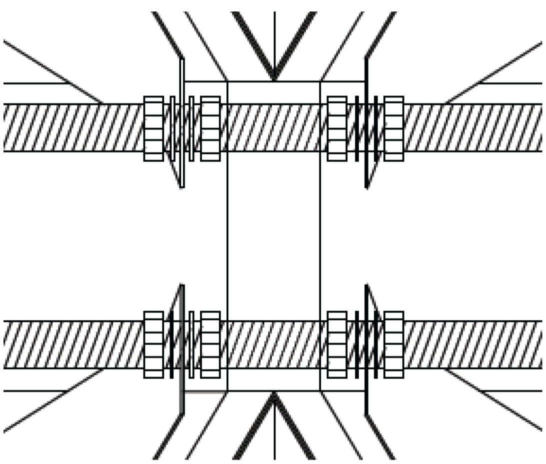


Figure 14

Figure 15 **Figure 16**

Lots of progress has been made while fully realizing the physical module. There were many discrepancies between the digital and physical model that were not accounted for until fabrication began. New solutions had to be generated for joints, tolerance, materiality, and precision. Designing connections was not only essential but fabrication techniques also became essential for precision and efficiency (Figure 17&18). Constructing multiple iterations of fabricated test models eased the transition to assemble the final module.



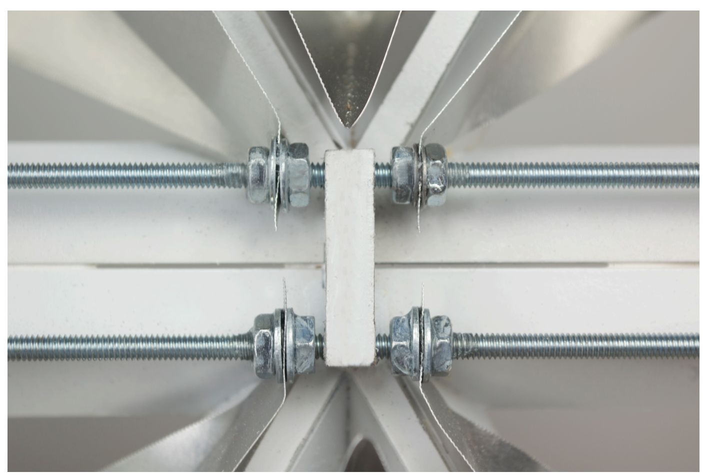


Figure 17 **Figure 18**

5. Conclusion

On a closer inspection, the chosen design has a simple movement with simple geometry. However, the aggregate design appears more complex. Overall, this prototype fits the context of the Museum of Fine

Arts in Houston. This shading prototype offers flexibility in that each module is autonomous and can be manipulated simultaneously. From the perspective of the occupants viewing the module from the interior, the effect with the lighting is beautiful and creates unique shadows. In terms of regulating daylight, Figures 19 and 20 showcases shading performance of our design. Examples of transformable shading systems are already in existence so it is conceivable to implement this design in the near future. Furthermore, the resources to manufacture the modules are readily available. This proposal explores further potential not only in building performance but also in shaping the interior experience. An underlying goal is to encourage future investigation by adapting the digital to physical workflow for shading system designs. Testing parametric variation of the geometry against daylight simulation will introduce unique designs for shading optimization in various climates. As demonstrated, adding movement to the building envelope can generate greater expression to the form and the function.

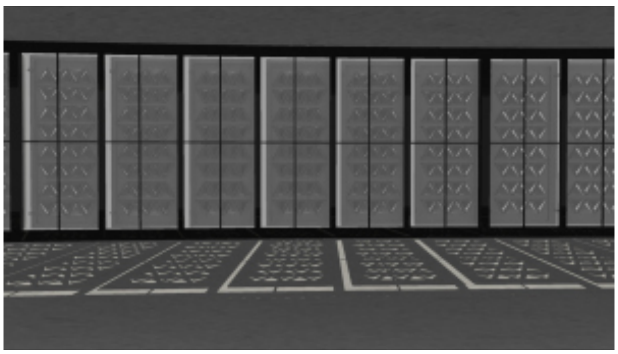


Figure 19

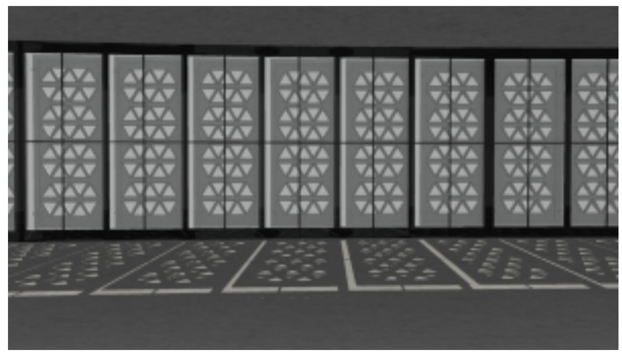


Figure 20

References

[1] Kalantar, and Borhani. 2016a. Starting with Transformation. Paper read at The National Conference on the Beginning Design Students (NCBDS), at University of Cal Poly.

[2] Kalantar, and Borhani. 2016b. "Studio in Transformation: Transformation in Studio." *Journal of Architectural Education (JAE) 70:1* no. 70.

[3] Moloney, Jules. 2011. *Designing kinetics for architectural facades : state change*. Abingdon, Oxon; New York: Routledge.