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AIA Pavilion, a flexible system of cellular building blocks

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Figure 1. Exterior and interior.

Introduction

The AIA Pavilion combines research about new materials for architecture with parameterization techniques and digital design and manufacturing processes. The pavilion was developed at the "Digital Design Build Studio", that I direct at the Georgia Institute of Technology. With this studio I am researching the possibilities of digital design and fabrication in order to develop new construction methods for environmentally friendly materials. The AIA Pavilion in New Orleans allowed me to show how plastic can be used to build a new kind of lightweight structure that is affordable and environmentally friendly.

Figure 2. AIA Pavilion in use.

The project was selected for realization at an annual AIA call of entries that asked for interventions to bring to life the historic city of New Orleans. My project suggests a series of pavilions sited within usually hidden, often private courtyards. With the city's webpage announcing different events at their locations the forgotten places turn into new public destinations. The pavilions are reactivating the city's fabric by reversing it - what was a private space during the day becomes a public space for concerts, performances, and other events at night.

In the evening, the pavilions dramatically modulate the host environment, bringing attention to the city's romantic and mysterious spaces, typically located deep in the block, away from the street. The first pavilion was realized in a courtyard, located on Orleans Street, close to North Rampart. From the street you can only see glimpses of the alien-like, bright glowing object. For curious residents and visitors, brave enough to enter the courtyard through an existing long narrow alleyway the strange object is revealed to be a beacon, an event space of open possibilities.

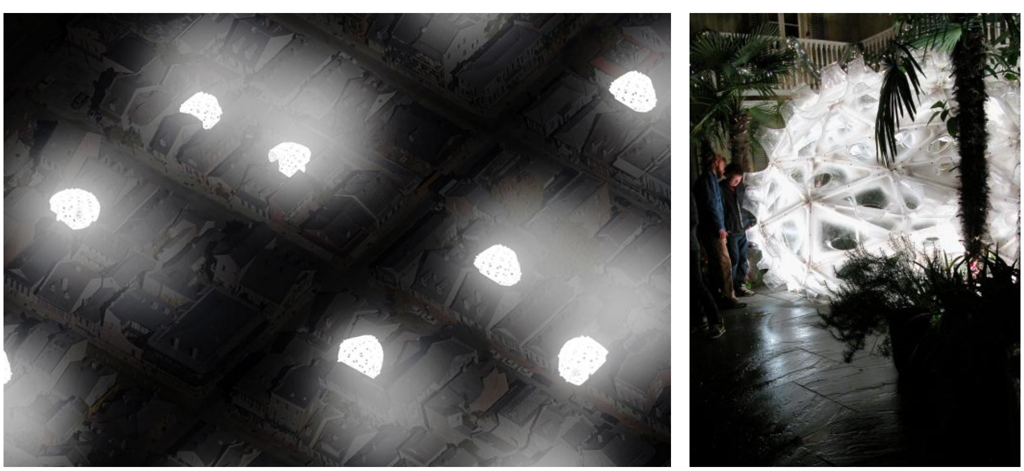

Figure 3. Pavilion at night.

Designing Flexible Systems

Architects should design systems instead of buildings. Generative modeling tools such as Grasshopper, a graphical algorithm editor, allowed me to define form as generative systems that respond to unique requirements and contexts. Using such tools form "emerges" from the definition of rules. With this method of working I am bypassing constrains of typical architectural typology. During the design process of the AIA Pavilion different geometric methods such as nurb, polygon and subdivision were tested to develop new "digital typologies". The resulting building blocks or "cells" that had been developed were tested against architectural functions, structural performance and materiality.

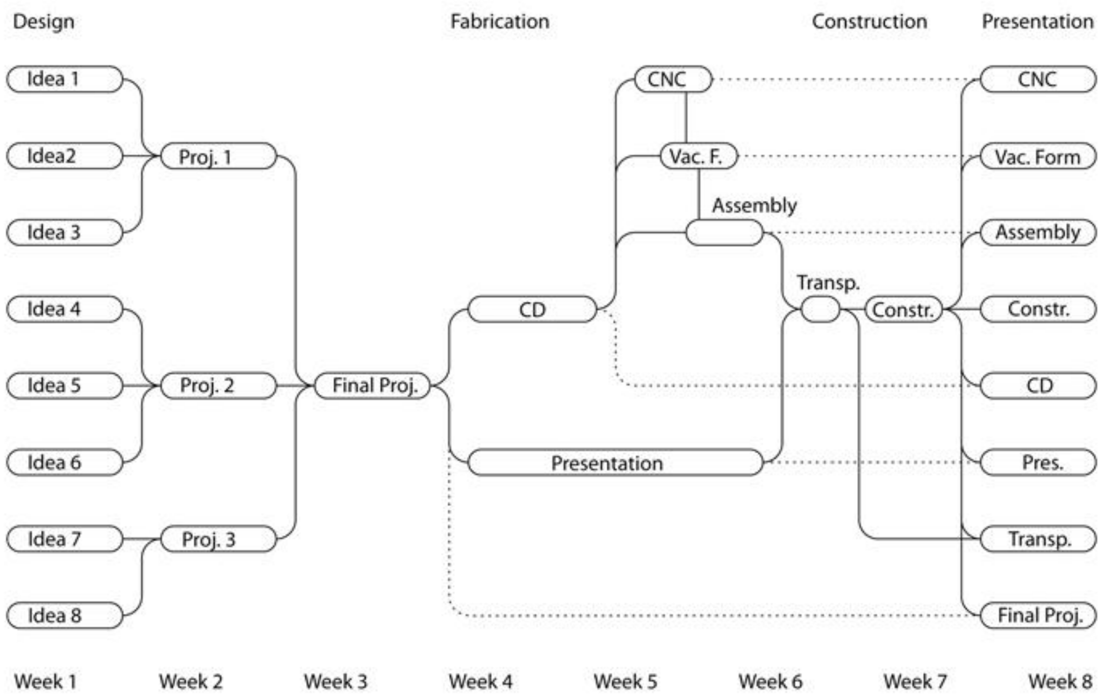

Figure 4. AIA Pavilion Workflow Diagram.

This liquidation of conventional types lead to more flexible systems, new combinations of functions, unexpected hybrid situations, new forms of interactions between natural and artificial systems and systems that can adapt to different needs. The cell during the design process developed from a primitive to a complex state. This higher level of complexity within the initial cell proved to be essential in allowing for the integration of programmatic, functional and contextual needs. In biology this behavior is called Chemotaxis, a directional movement with respect to an external chemical gradient (Hanczyc, et al., 2007).

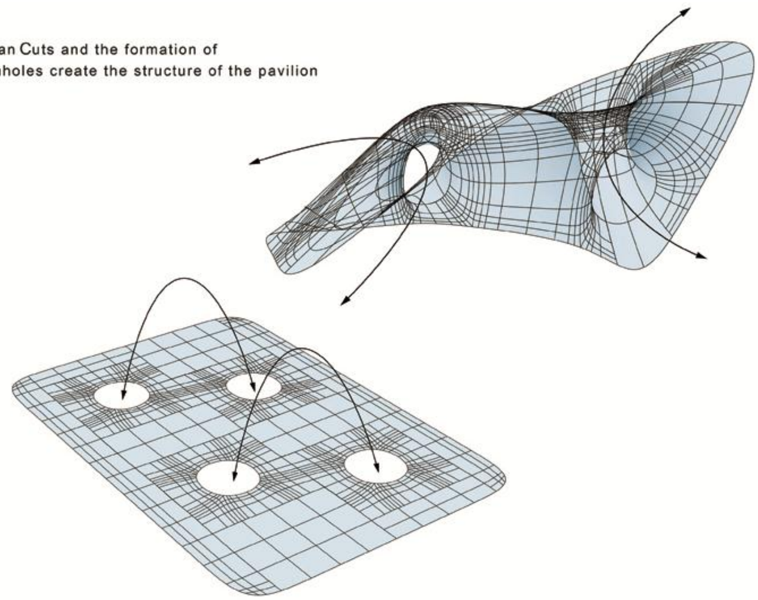

Figure 5. Structural diagram.

The final base geometry of the pavilion's cell was a triangle, which transformed into 320 unique variations based on different sets of attributes. Depending on its position, the edges of each cell were folded differently to provide stiffness within the cell and to make up the overall structure. A single cell for instance could sometimes act more skin like and sometimes column like by changing in shape and configuration. Each cell could adapt further to different functions such as windows, seating, foundation, brackets for an electrical lighting system, a day lighting system, containers for plants, and water collectors.

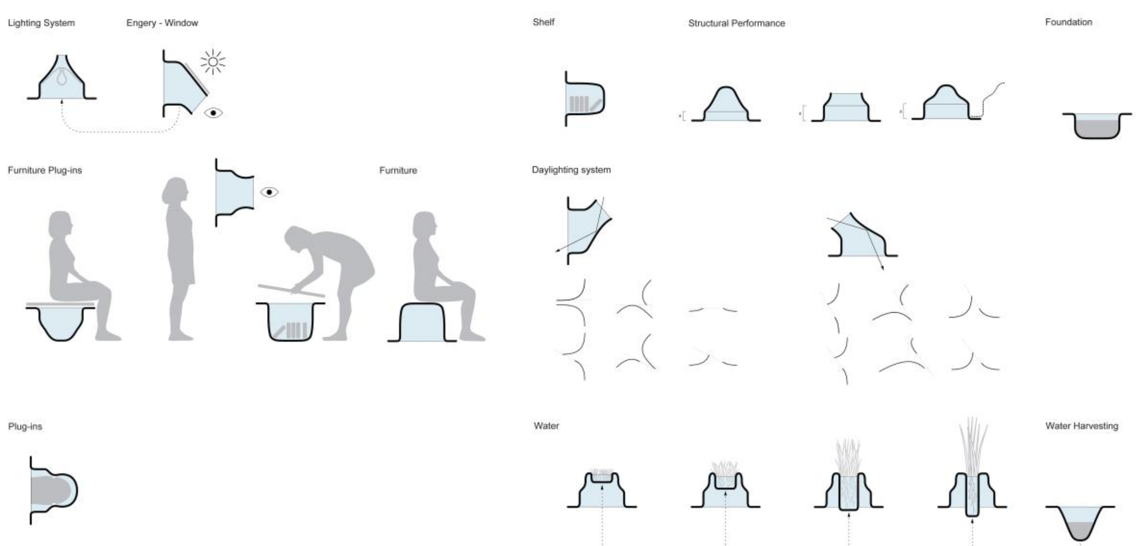

Figure 6. Transformation of a single cell.

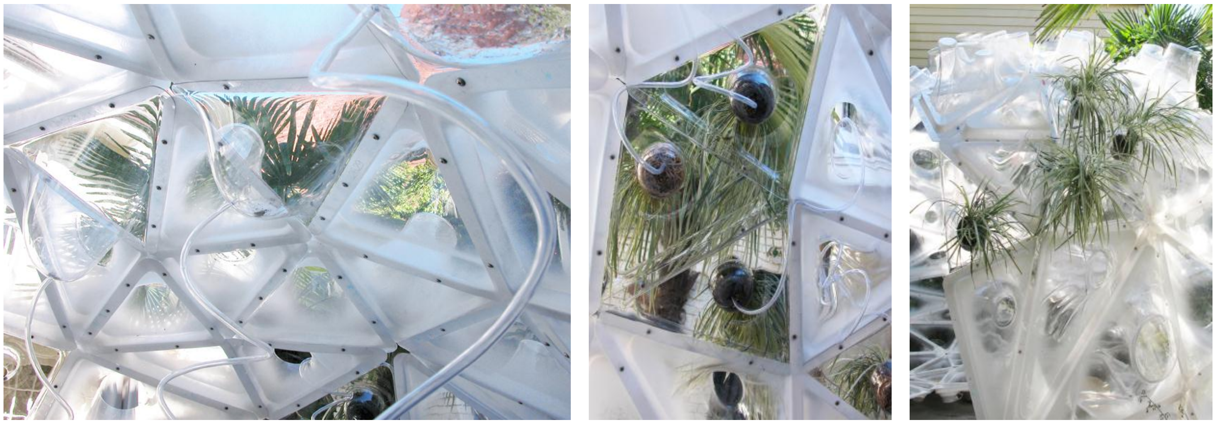

Figure 7. Water collectors and plants inhabiting the envelop.

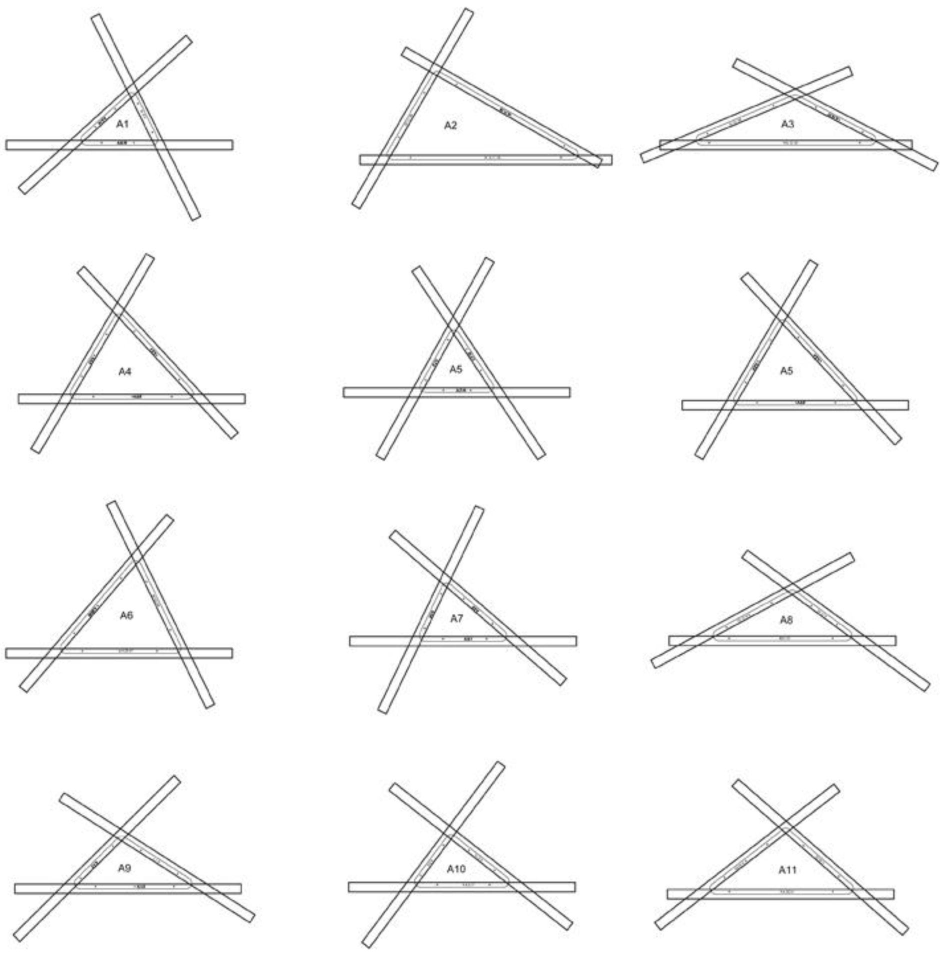

Figure 8. Variations of base geometry.

The process of generating the form of each cell was based on information derived from the context and specific functions. It was a search for mathematical laws that natural and artificial systems might obey a working concept of emergence that is using the mathematics and processes that make it useful to us designers (Weinstock, 2006, p. 273; The Renewable Corporation, n.d.). The process was entirely scripted or in other words articulated as rules that informed the cells geometric transformations. The degree of unpredictability of the final geometry of the cell increased with the increasing complexity of information that operated on the cells geometry. The final overall form and spatial qualities of the pavilion in turn emerged from the cells' variations.

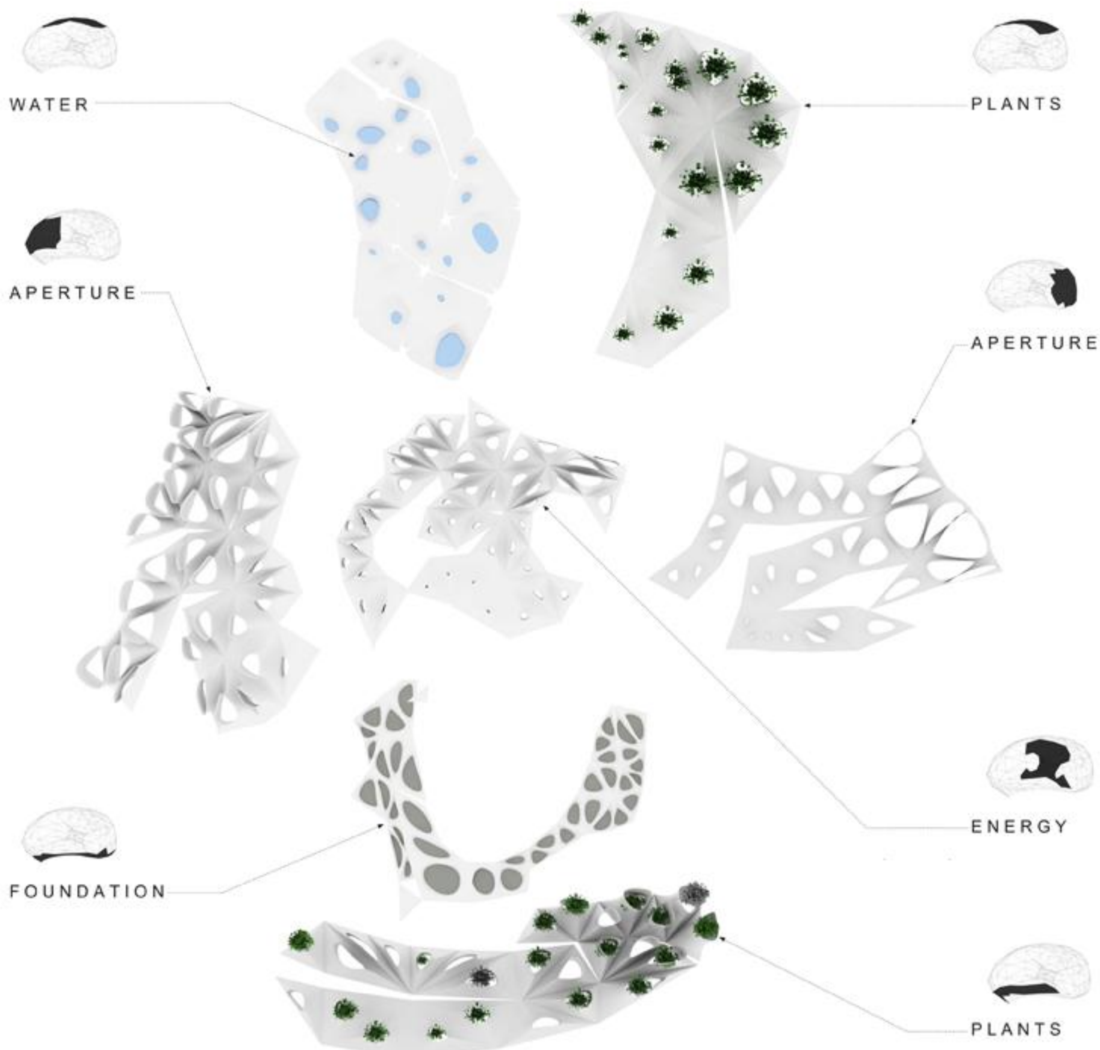

Figure 9. Map of cell variations.

Scripting the entire pavilion in Grasshopper in that fashion also dramatically increased continuity between digital design and fabrication. Numbering of all edges and adding more than 2,000 connection details that varied based on the cells differentiation could be easily added to the script parametrically.

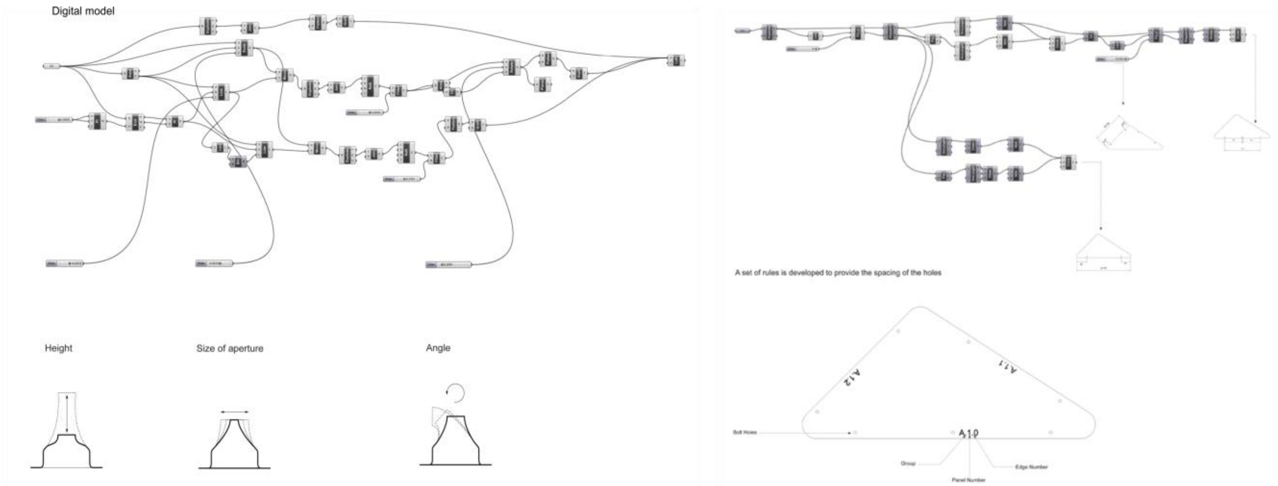

Figure 10. Scripting was used to generate cell variations and to add individual details.

The cell's geometry allowed combining structure and envelope in a single material forming a hybrid exoskeleton system. The edges of each cell were folded differently based on each cells location within the overall structure. This provided stiffness within the cell. Once connected the edges of all cells formed a complex geodesic system. To minimize the amount of material used for the envelope and to create a lightweight structure, the envelope generates wormholes. The formation of wormholes created tension within the surface that allowed minimizing the weight of the structure to 120 kg.

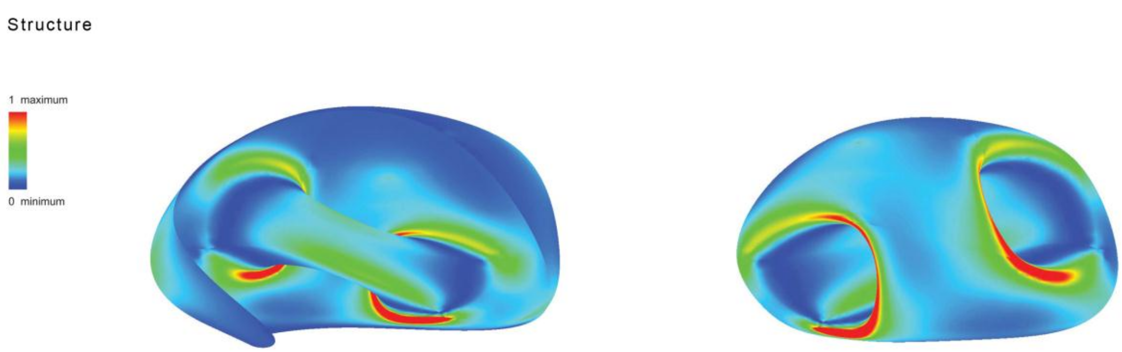

Figure 11. Visualization of the tension within the surface.

A new flexibility within Building Materials

Architects were well accustomed to working within the fixed properties of traditional building materials like stone, clay, wood, concrete, steel and glass. Collaborating with scientists in chemistry allowed us to work at the scale of the molecule and to reorganize the underlying structure of matter in architecture. Plastics can be developed with specific performative properties from the bottom up, rather than shape them from the top down as had been done with other materials. It is further possible to engineer plastics to provide us with a wide range of properties in a single material. This means that we have parametric materials. When chemistry first came up with the innovative use of plastic in the 1960s, plastic was an environmentally problematic material. With the chemical industry currently changing from fuel based to bio plastics, plastics are celebrating a comeback.

Responding to the chemical industry we are investigating new architectural techniques and methods to reintroduce plastics as building materials. At the AIA pavilion we used a glycol-modified polyethylene terephthalate (PETG) that can either be produced from recycled plastic or sugar cane. Using bio-plastic as a single material for a lightweight structure the AIA pavilion is a result of this research.

Bio-PETG is produced from sugarcane, a plant that has been an integral part of the culture and economy of Louisiana for 200 years. The material is manufactured from sugar cane feedstock that is used to produce Ethanol, which after a dehydration process becomes ethylene. Producing PETG from sugarcane has tremendous environmental benefits. Any plant produces oxygen and extracts carbon dioxide from the atmosphere. Due to its large abundance of sugarcane, Brazil is currently the leading researcher and manufacturer of Bio-PETG in the world (Dow Chemical Co, n.d.). According to a 2004 study by the Carbon Dioxide Information Analysis Center in Brazil, "Over 1.5 billion pounds of CO_2 will be annually removed from the atmosphere, which is equivalent to the fossil emission of 1,400,000 Brazilian citizens" (Dow Chemical Co, n.d.). Brazilian chemicals group Braskem claims that using its route from sugar cane ethanol to produce one ton of polyethylene removes 2.5 tons of carbon dioxide while the traditional petrochemical route results in emissions of close to 3.5 tons (Braskem, n.d.; US Department of Energy, n.d.). Bio-PETG is virtually identical to regular fossil fuel based PETG, with its exceptional thermal and recyclable characteristics.

Reintroducing plastics as a building material the project also provides new spatial and aesthetic qualities that are essential if one wants to change our perception of plastic from an environmentally problematic to an environmentally friendly material. Plastics can be light, impact resistant and easy to fabricate. These characteristics were necessary for the pavilions rapid assembly, disassembly and transportation. The highly malleable nature of plastic made plastic a suitable material for the digitally derived form of the pavilion and its complex geometry and cell variations.

Flexible Fabrication Systems

Architecture systems need to be flexible enough to be able to respond to parameters that are unique for each project and each site. Flexibility in manufacturing usually means the ability for one machine to produce different products or parts, a viability of an assembly process and sequence, or the ability to adapt to changes in the design. In industrial design the term "Machine Flexibility" is used for a machine that can manufacture a variety of products. The term "Flexible Manufacturing Systems" or "FMS" is used when several machine tools are linked in a flexible dynamic way.

Design and fabrication are using the same software platforms, which helped to streamline the production process. The connection between digital design and fabrication has become obvious and natural.

Computer-Aided manufacturing (CAM) processes like laser cutting, Computer Numerical Control (CNC) milling, and 3D printing, coupled with Computer Aided Design (CAD) tools and parametric modeling software provided instant feedback in a design process; allowing for speculation with real materials in real time. Integrating production and design processes as active agents in the development of architectural systems allowed me to set up a design process that instead of isolating or separating different issues is driven by the incorporation of all possible parameters at each time and the analysis of the consequences of their interactions. Mainstreaming multiple processes in one took a lot of effort in the first place but paid off in the mass customization and the development of unique variations based on functional and contextual changes for different users and different sites.

Developing the cells for the AIA pavilion the studio speculated with manufacturing and assembly processes that can create similar but unique modules. We first developed a flexible manufacturing system that responded to the project's needs. The boundary condition of the system was related to the boundary condition of our fabrication method. The 300 modules of the pavilion were all different but part of a single family. Each was different in size and proportion, but shared the same base geometry of triangles. The section of each module for instance differentiated by extruding the base geometry. Since each module was fabricated from thermoformed plastic sheets, it allowed for different forming techniques due to the programmatic and contextual requirements.

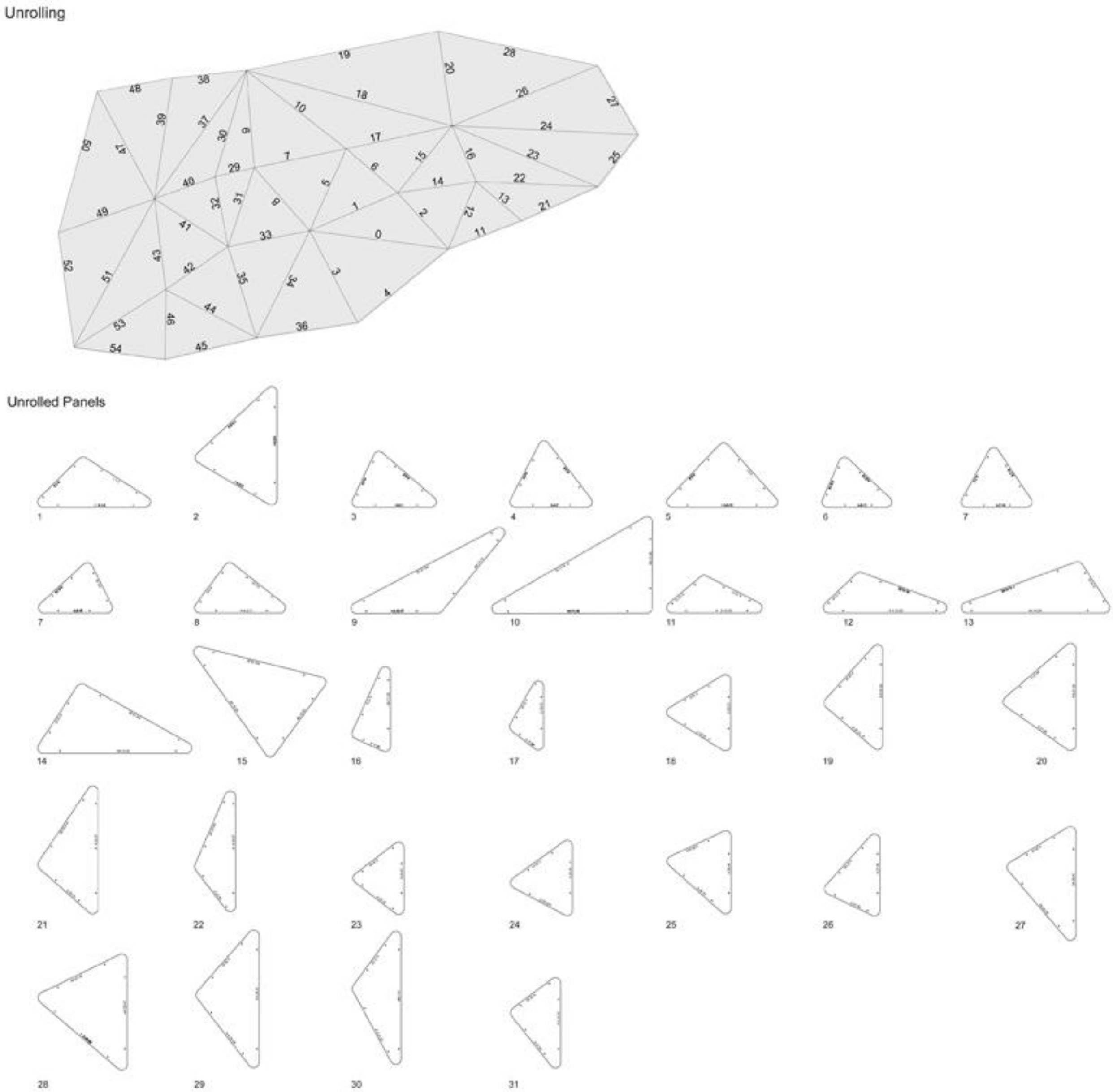

Figure 12. Variations of the cell.

The various triangular outlines of the individual modules were routed from PETG sheets. Each of the triangles was then thermoformed into a three dimensional shape. The parametric model that was entirely scripting allowed linking the project to fabrication parameters and a flexible manufacturing system. A flexible mold was developed that could produce different shapes from different triangles. The mold was constructed from a digitally fabricated kit of parts that combined three different thermoforming techniques: drape forming, vacuum forming and draping.

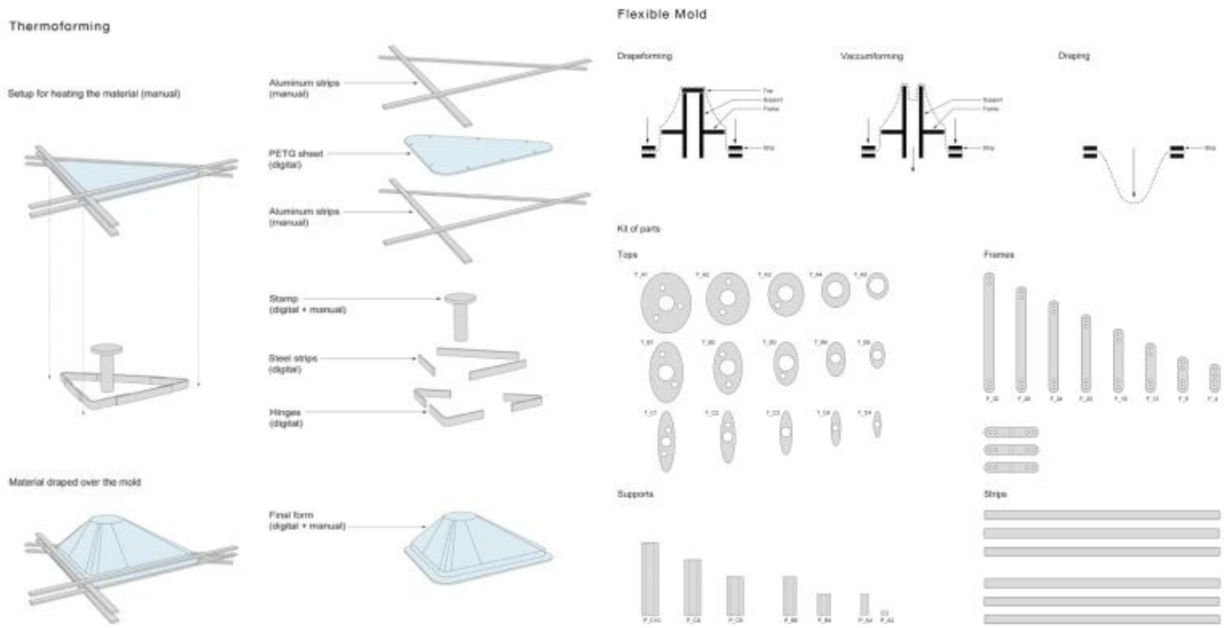

Figure 13. Flexible mold.

This allowed me to respond to a parametric digital model with a flexible system to fabricate the cells. Since the model was entirely scripted it could update to fabrication constraints at any time. A continuous feedback loop was created between digital modeling and fabrication.

Developing our own flexible mold we could prove of using fewer parts and tooling than other molding techniques, which allowed to save material and for a cost and time effective production. It was also very precise, resulting in very small assembly tolerances. After their production all prefabricated cells were assembled into 6 larger components designed to stack and fit compactly into a small truck for transport.

Figure 14. Assembly process.

Figure 15. Groups of cells and exterior view after assembly.

Conclusion

Continuity and variability are some of the keywords that describe the outcome of today's architecture. Still a closer look reveals their fallback into conventional architectural systems such as facade, roof and structure that is still intact. Continuity and variability might suggest a liquidation of type and hybridization between natural and artificial systems. The use of digital design and fabrication methods support these developments of systems that are more flexible and adaptable.

The AIA pavilion promotes an architecture that avoids a typological thinking, suggesting a single system that can be complex and flexible enough to respond to multiple functions and contexts. In that sense the project suggests mass customized building systems and system components that allow for a more intense relationships between architecture and its environment. The project privileges the design of systems rather than buildings which suggests an aesthetic quality that emerges as a consequence of interactions, matter and material behavior.

Coupling a material research with scripting as a design techniques and a flexible manufacturing system allowed customizing each cell according to different functions and contexts in a highly cost effective way.

The pavilion presents a new form of lightweight structure that is saving on building materials. The project also responds to the chemical industry that is currently changing its production of plastic from fossil-fuel based products to bio-plastic suggesting an architecture build from bio-materials that can be recycled.

The project further suggests the manipulation of a material at a micro scale. Applying this idea to architecture might suggest a very different future for architectural matter, an architecture that is responsive to its environment in a much more dynamic way. Buildings might be made from cells that can be manipulated to alter their architectural meaning in searching for the equilibrium between architectural function and different environments. Self-assembling architectural systems might emerge from a tension field constructed from different sets of parameters. Natural and artificial systems might soon become indistinguishable.

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Fabrication: DFL, Digital Fabrication Laboratory at Georgia Institute of Technology.

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