Flexible Systems

Flexible Design, Material and Fabrication: The AIA pavilion as a case study

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Abstract. This paper is about the fabrication process of the DesCours pavilion, a project that was realized in the context of a graduate design studio in the Fall Semester of 2010. The assembly and construction process of the pavilion will be used to show how parametric software, such as Grasshopper can inform fabrication and material systems.

The paper will explain the fabrication process of a pavilion in detail and make an argument for plastic as a material that not only responds to the malleable characteristic of digital tools but also to environmental issues.

Keywords. Design Build, Grasshopper, CNC, Parametric Design, Digital Fabrication, Plastic

DESIGNING FLEXIBLE SYSTEMS

Buildings that respond to definite problems with specific, unique and unrepeatable responses are usually configured as rigid systems that can hardly be replicated with success anywhere else. Architecture has a long history of rule-based spatial systems that relate to “Zeitgeist “ new materials and specific architects. From Viruvius “Nine Square Grid“ to Le Corbusier’s “Five points“ or Mies van der Rohe’s “skin and bones“ systems. These systems have defined styles and have influenced architecture more than individual key projects. An important aspect why these systems were as influential might be related to their flexibility and adaptability for different programs and scales.

Continuity, smoothness and variability are some of the keywords that describe the outcome of today’s architecture. Still a closer look reveals their fallback into a modernist separation of architectural systems such as envelop, structure that is still intact.

The studio started with a research in complex geometry, subdivision geometry in particular. It then speculated how geometry organizations of a high degree of complexity might allow re-combining programmatic, functional and contextual needs in radical ways. As modernist architecture clearly was about separation, this studio was all about integration. This temporary liquidation of types lead to more flexible “types“ or systems that could adapt to different needs. A single system could for instance be sometimes more skin like and sometimes more column like by changing in configurations.

The AIA pavilion was designed as an efficient lightweight shell structure that allows for easy transportation and rapid assembly and disassembly. The base geometry of a sphere was transformed to adapt to specific site conditions and solar orientation. It was optimized relative to size and location of apertures, floor surface, program and structure. The geometry was then tessellated into 320 unique triangular proto-cells that were transformed into cells of different attributes.
Figure 1
Possible variations of modules

Figure 2
Map of different networked modules.
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. Each cell adapted further to different functions: windows; seating; foundation; brackets for an electrical lighting system; a day lighting system; containers for plants; and water collectors. The process of informing and transforming each proto-cell based on specific functions was entirely scripted. Therefore, each function had to be articulated as rules that informed the cells geometric transformations.

The degree of unpredictability in form increased with the number of sets of information that operated on the same geometry. Scripting became the primary design tool and was not just to automate an existing design. The final overall form and spatial qualities of the pavilion in turn emerged from the cells variations. By scripting the entire pavilion in this manner, we dramatically increased continuity between digital design and fabrication. Engraved instructions that helped to connect the different cells, plus numbering of all edges and details that changed with each cell could be added easily to the script as additional information.

To minimize the amount of material used for the envelope and to create a lightweight structure, the envelope generates wormholes that act brace- and column-like and increase the surface tension. The formation of wormholes within the surface allowed for the lightweight structure to be as light as 123 kg.

**FLEXIBLE MATERIAL SYSTEMS**

The highly malleable nature of plastic made it suitable to the digitally derived form of the pavilion and its complex geometry and cell variations. The material is light, impact resistant and easy to fabricate. This contributed to rapid assembly, disassembly and transportation. The material choice also responded to sustainability and environmental concerns.

The question of sustainability and ecological performance has spawned the studio’s research in bioplastics. The three Bio derived plastics are: Bio-derived Polyethylene (Bio-PETG), Polylactic acid (PLA) plastics, and Plastarch (PLM) starch based plastics.

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 the leading researcher and manufacturer of Bio-PETG in the world [1]. According to a 2004 study by the Carbon Dioxide Information Analysis Center in Brazil, “Over 1.5 billion pounds of CO2 will be annually removed from the atmosphere, which is equivalent to the fossil emission of 1,400,000 Brazilian citizens”[1].
Brazilian chemicals group Braskem claims that using its route from sugar cane ethanol to produce one tonne of polyethylene captures (removes from the environment) 2.5 tonnes of carbon dioxide while the traditional petrochemical route results in emissions of close to 3.5 tonnes [2][3]. This product is virtually identical to regular fossil fuel based PETG, with its exceptional thermal and recyclable characteristics. Although Bio-PETG can be recycled, it is not biodegradable.

Polylactic Acid (PLA) plastic is a transparent plastic made from many different renewable resources, such as corn (United States), tapioca (Asia), or sugarcane (rest of the world). Although PLA plastic is very similar in appearance to both PETG and Bio-PETG, it is biodegradable and recyclable through a “Cradle-2-Cradle” certified process of Thermal Depolymerization [4]. Through this process, “a highly purified lactic acid is extracted and can be considered as raw material for the manufacturing of virgin PLA with no loss of original properties”. This is the only material of the three that can be truly recycled and reproduced without losing any of its original characteristics. One disadvantage to PLA is that the cost is presently very high. This can be attributed to the fact that PLA is a fairly young product. PLA plastic’s connection to corn ethanol research in the automotive industry might be promising. If biofuel derived from corn starch becomes a standard in the future, one could see PLA plastics being in very high demand. A disadvantage still is the uncontrolled biodegradability of the material. Currently, one could imagine PLA as a temporary building product.

The final bioplastic material is Plastarch (PSM) starch-based plastic. PSM plastic is generated from thermoplastic starch from the likes of potatoes and corn, combined with other biodegradable materials, such as sorbitol, glycerin, polyester, cellulose, and polyvinyl alcohols. A plastic blend therefore consists of two phases – the continuous and hydrophobic polymer phase and the dispersed and hydrophilic starch phase. In the hot, anhydrous smelt in the extruder, the water-soluble, dispersed starch phase is mixed with the water-insoluble, continuous plastic phase to form a water-resistant starch plastic [4]. By having different composites and “starch-blends” of PSM plastic, one can adjust different additives to tailor the material for a given application [4]. The customizability of this material is a major advantage. For example, if one would like to increase the overall strength of the PSM material, one would increase the ratio of cellulose to the existing mix in order to add strength, or add different polymers to decrease its water absorption, making it more waterproof [4].

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Figure 5
Interior view of the pavilion.

Figure 7
The pavilion at night
FLEXIBLE FABRICATION SYSTEMS:
The research in complex geometry and material was paired from the very beginning of the studio with a research in different digital fabrication techniques. Geometric principals were related to material characteristics. Using short exercises, the students were introduced to different materials and fabrication techniques such as CNC, plasma cutting and thermoforming. While testing new materials and different fabrication techniques, the studio was speculating about what materials' characteristic best fit the fabrication needs. The main criteria for this speculation were function, structural performance, weight, weather resistance, sustainability and cost.

Flexibility in manufacturing usually means the ability for one machine to produce different
products or parts, vary an assembly process and sequence, and 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.

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 our needs. We then had to adjust the boundary condition of our system to the boundary conditions of our fabrication method.

The 300 modules of the pavilion were all different but part of the same family. Each was a different size and proportion, but shared the same base geometry of triangles. The section of each module was different but each could be developed 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. The studio investigated 3 Thermoforming techniques; Draping, Drape-forming, and Vacuum Forming, and programmatic advantages associated with each option. The studio responded to a parametric digital model with a flexible system to fabricate the cells. Entirely scripted, the model could update to fabrication constraints at any time. A continuous feedback loop was created between digital modeling and fabrication. A flexible mold was developed that could adapt to different triangular geometries: 3 molds were tested:

Figure 10
View of the pavilion in the courtyard
Spring mold: Is a mold that consists of different tube segments that are held together by a system of springs. The tubes are cut at 2” intervals. All triangles could be produced with 36 interchangeable tube segments. Advantages were that very little material was consumed for the formwork, and the spring itself produced interesting surface effects on the material. The disadvantage was that it was time consuming and created round corners that weakened the structural performance of the module.

Block mold: Is a mold that is assembled from woodblocks of different shapes. The advantage is an easy way to assemble the different forms; the disadvantage was a large amount of parts to generate a satisfying precision of the individual triangles.

Steel Frame Mold: Is a mold that consists of Steel Strips in increments of 2” and flexible hinges that can be adjusted to make up for that 2” tolerance. The Steel Frame Mold was selected as a final mold since it was the most precise and the mold that used the least amount of material. The disadvantage of this mold is that it’s a time consuming process to assemble, which ideally would be automated.

CONCLUSION
Using scripting to design the pavilion and using a flexible mold to thermoform each cell allowed us to customize each cell according to different functions and context in a highly cost effective way.

The project responds to the chemical industry that is currently changing it’s production of plastic from fossil-fuel based products to bio-plastic which might make plastic the building material for the 21st century.

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REFERENCES