PARAMETRIC MODULATIONS IN MASONRY

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Abstract. The focus of the research presented in this paper asks how a designer can create a flexible system of physical making which can accommodate multiple programmatic functions within a smooth whole, rather than creating an a priori singular formal object. This adaptable system of construction works through the development of an intelligent CAD model that can be mapped to a flexible manufacturing mechanism, i.e. a reconfigurable mold. This system of manufacturing can be used to cast totally unique solid modules without creating a unique mold for each part by manipulating the topological structure of the system. This approach takes the notion of mass-customization beyond the expensive and unsustainable one-offs that the design world has seen recently, and into a new paradigm of a sustainable, economically viable world of mass-customizable form and space.

Keywords: Parametrics, Variability, Reconfigurability, UHPC, Topology, Molding, Casting.

1. The Problem of Non-Standard Building Systems

In between the abstraction of ***Idea Space*** and the reality of materialized ***Body Space*** is the space of potentialities. This space can be considered the Solution Space, or as we call it, the ***Formation Space***. Contemporary architectural practice is increasingly focused on how advanced digital representations can interact with CNC [Computer Numerical Control] fabrication equipment and various material logics to expand this Formation Space and push design forward towards systematized, bottom-up constructs that are informed and directed through **materiality, technique, and variable systems of construction**.

Within the context of digital space making and formal variation the design world has seen a significant shift over the past two decades from standardization to customization. Standardized building components became one of the driving forces of Modern Architecture throughout the 20th century due to their economic advantages and their ability to conform to quality control and design standards. Today non-standard building components have the potential to become normalized within the AEC industry in order to give designers more control of both local and global conditions of design.

This attempt to create unique parts for the production of buildings has most notably been researched through the use of CNC fabrication equipment such as routers, water jet cutters, and robotic arms. While these techniques have the ability to create a tremendous amount of variation through 2D profile cutting and 3D subtractive sculpting, they are still inefficient both in terms of cost, time, and material expenditures relative to conventional means of mass production. Due to these limitations, the promise of non-standard architectural design has not been widely deployed throughout the AEC industry. These inefficiencies are found both in the representational and constructive processes. Unique formal conditions at the local scale of the building component can be excessively time consuming to digitally model by hand without the use of parametrically driven software, and the production of each of these components through completely unique fabricational operations is neither economically feasible nor environmentally responsible.

The research here proposes a new approach to non-standard construction through the development of a continuously variable cast concrete system working with topologically defined reconfigurable molds that can be mapped to and driven by flexible parametric models.

This parametrically modulated approach has been researched thoroughly in recent years with most of the focus centered on the parametric representation more so than the actual fabricated construct. In many cases the fabrication research ends with a stereolithography prototype or a milled mockup. One project that goes beyond the digital representation is Urban A+O's *Bone Wall* Exhibition at New York's Storefront for Art and Architecture (figure 1). This installation is an excellent example of previous research in the area of topologically defined modulations where a global configuration is used to modulate locally defined components. Larry Sass of the MIT Digital Design Fabrication Group has produced an algorithmically driven interlocking masonry system, currently in the prototyping phase, called *A Physical Grammar* that deploys stereolithography as an analog to full scale 3D printed modules (http://ddf.mit.edu/projects/PHYS_GRAMM/index.html). One additional example of this method can be found in the *Topological Deformations* installation by the Ventulett Chair at Georgia Tech in 2006 (figure 2). The project is conceptualized as a construct built from a single topologically invariant, geometrically transformable polymeric brick which can transform from a dense stacked condition, to a hollow stacked box beam, to a woven spatial truss system, to a folded corrugation without breaking the underlying topological definition (figure 3). In this installation the material behavior is crucial to both the conceptual underpinnings and the final constructability of the piece. Polycarbonate sheet was used for its high strength and low modulus of elasticity in order to achieve a twisted and woven construct made from cold formed flat stock that is capable of performing in long span conditions.

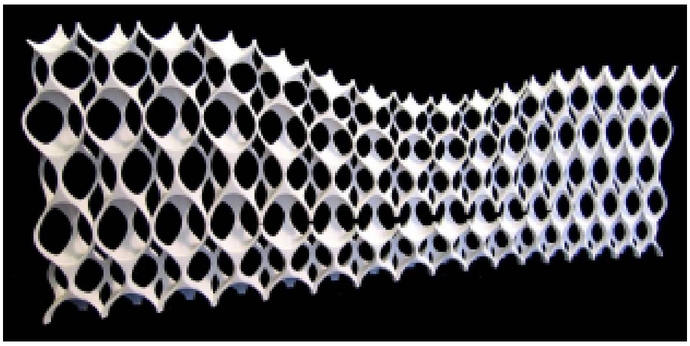

Figure 1. Bone Wall | Urban A+O | Storefront for Art and Architecture.

Figure 2. Topological Deformations | 2006 Ventulett Chair | Georgia Tech.

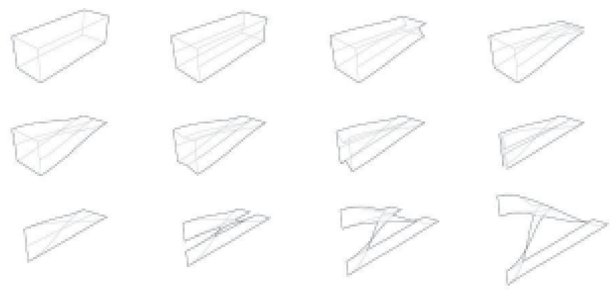

Figure3. Topological Deformations | Module Transformation Diagram.

2. The Proposition

The work presented in this paper is the result of a graduate research seminar at Georgia Tech in the spring of 2007 entitled *Parametric Modulations in Masonry*. The research focused on issues of modular variation in Ultra-High Performance Concrete which led the students to the development of two variable systems of construction, *'Curva'* and *'S-Concrete'* (figures 5 & 6). Each system is based on an invariant topological model that can be directly translated to a congruent topological mold. These systems allow for the production of continuous geometric variations from a single reconfigurable mold, thus reducing the amount of time, material, and energy consumption required to produce unique components. The internal logic of each system gives way to the final design deployment through a bottom up approach to design. This exercise tests a variety of configurations in which the system can be deployed in order to commodiously adapt to a particular context, including physical, social, and aesthetic issues.

Ultra-High Performance Steel Fiber Reinforced Concrete was selected as a material for investigation due to its ability to be easily cast into complex molds without traditional steel reinforcing. This material has the potential to form very thin structural sections of both synclastic and anticlastic doubly curved surfaces in a very economical mode, leading the way to the ubiquitous production of geometric complexity without high material/energy costs.

3. System Representational Methods – Parametric Modeling

By using the concept of a parametric curve, or B-Spline curve (figure 4), the team was able to develop a parametrically defined local module that could be mapped to an overall global form, or adaptable rig. Through this mapping every adaptation of the overall global geometry produced updated variations of each unique module. By extracting only the 'control points' of the B-Spline that were the underlying definition of the each module the team was able to greatly simplify the amount of data transfer necessary from the representation to the physical molding mechanism. This system allows one to quickly study many different variations of the design system while maintaining an assurance of constructability due to the direct mapping of the model geometry to the mold.

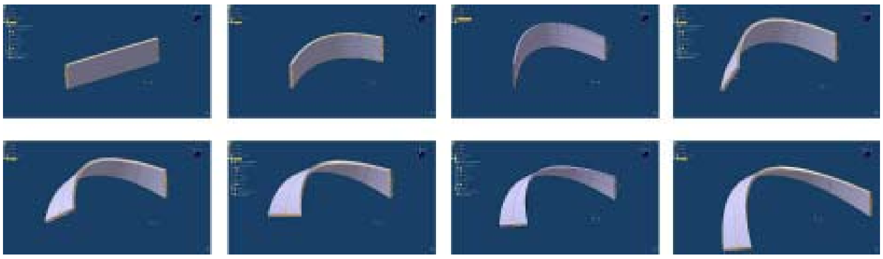

Figure 4. Variable module based on B-Spline Curve, modelled in Digital Project.

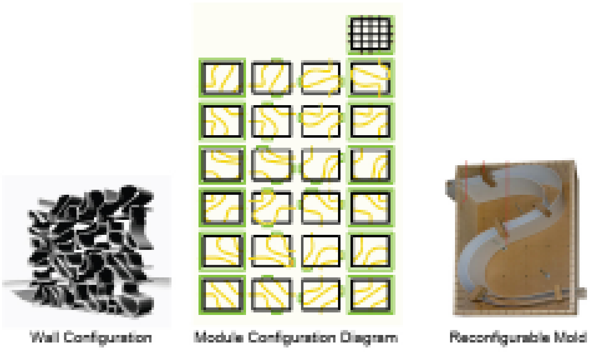

Figure 5. Variable wall system with mold configuration diagrams and mold prototype | 'S-Concrete'.

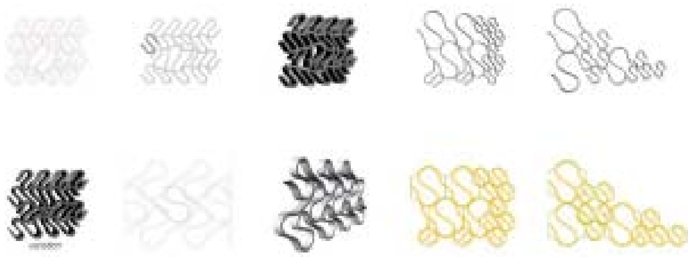

Figure 6. Permutations of variable system | 'S-Concrete'.

Each module is defined as a two, three, four, or five point B-Spline that is extruded, offset, and capped to represent the geometry of the module (figure 7). By controlling the location of the end points of the curve one can assure a high degree of accuracy in the overall system connectivity and tolerances. A special joint was developed to connect the modules by embedding steel angles into the end of each cast module segment (figures 8 & 9).

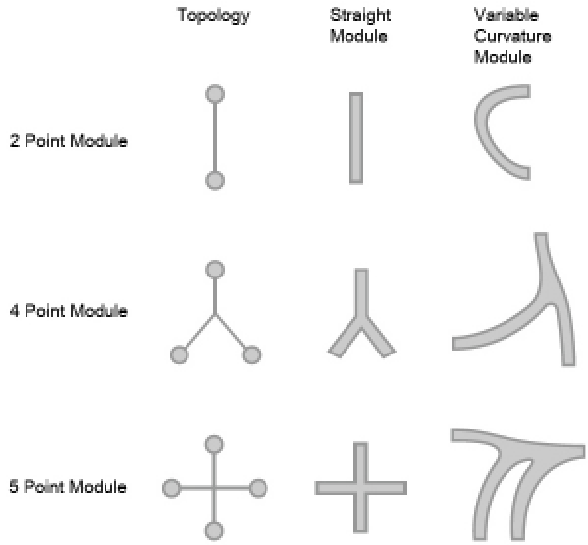

Figure 7. Diagram of topologically defined variable module.

Figure 8. Detail of module and joint in the final prototype.

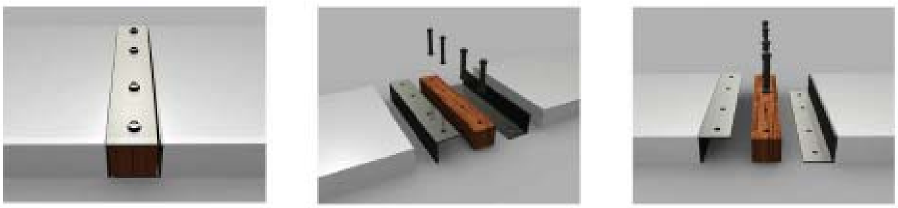

Figure 9. Joints as analog ‘control point’ of B-Spline curve.

4. System Fabrication Methods – Parametric Molding

The major obstacle in the production of variable cast components lies in the production of the mold from which the castings will be made. Again, using the B-Spline logic as an analog for mold making, the team developed a flexible mold using ductile sheets of PETG polymeric material that could produce continuously variable curvatures through the positioning of control point blocking into reusable indexing boards through CNC drilling of the control point locations (figure 10). While the ultimate goal of the project would be to manipulate the physical control points using CNC servos to control location, this low-tech solution proved to be a very effective method for the proof-of-concept prototyping phase.

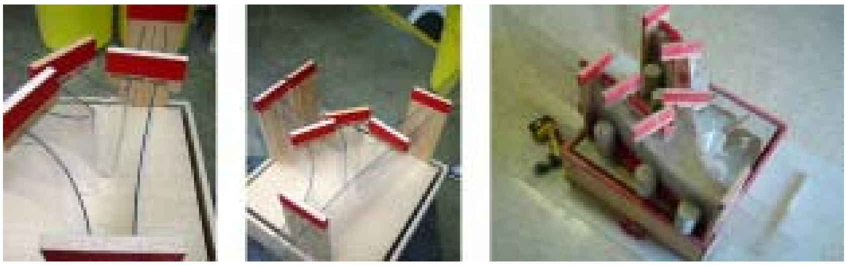

Figure 10. Early mold prototypes: 4-point mold [right] and 5-point mold [left].

5. System Deployment and Exhibition

The two systems were ultimately tested through prototyping, testing, and exhibition at the International Contemporary Furniture Fair in May of 2007 as a method for creating multi-programmed 'smooth' interior furniture systems that could accommodate functions of seating, storage, and exhibition within a singular whole. The prototype was fabricated and assembled by the students over a two week period at the Advanced Wood Products Laboratory at Georgia Tech.

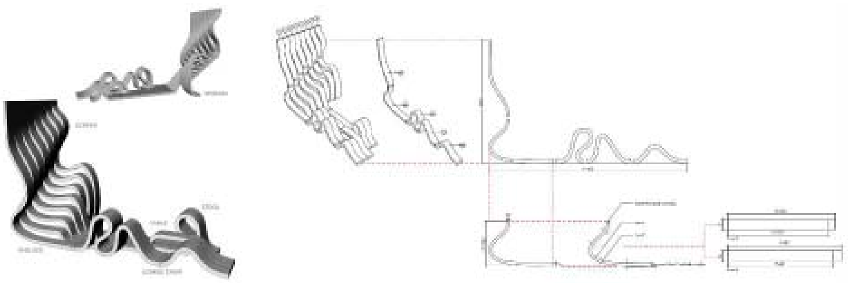

Figure 11. 'S-Concrete' System for the International Contemporary Furniture Fair.

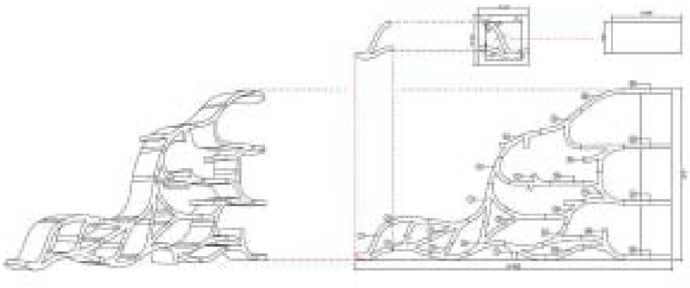

Figure 12. 'Curva' System for the International Contemporary Furniture Fair.

Figure 13. Rendering of 'S-Concrete' [left] and 'Curva' [right] in situ.

Figure 14. Prototype construction and detail.

Figure 15. Final prototypes displayed at the International Contemporary Furniture Fair, 'S-Concrete' [left] and 'Curva' [right].

6. Conclusion and Future Trajectories

In measuring the success of this project we looked at five factors:

- Precision in the relationship between the digital representation and the material artefact
- Degrees of variation possible within the system
- Material and time efficiencies in the production process
- Structural soundness and easy of assembly
- Aesthetic potential

In the first four categories, Precision, Variation, Efficiency, and Structural Performance, the project is considered to be a successful proof of concept experiment. The fifth category, Aesthetics, is still under analysis, and for now will be left to the reader. Future research directions for this project include the introduction of structural analysis as a design modulator using Finite Element Analysis software such as Optistruct and Abaqus. By integrating structural behaviour into the design process model architects will be able to create a more holistic formal solution by expressing material, geometric, and configurational behaviour into a given design solution.