Abstract

With a certain budget and limited access to a Computer-Numerically-Controlled mill, fourth year architecture students were charged with the problem of designing full scale architectural space that could be assembled and re-assembled in various contexts and configurations. As the constraints for the design studio, an economy of capital ($150 per student) and an economy of means were developed to create and produce over 600 units of a flexible architectural component, and many variations, into a building system that could be assembled to create multiple formal and spatial configurations pushing the concept of Mass-Customization towards MASS-Appeal.

After choosing a unit-multiple method as the most practical parti for designing a space which can disassembled and reassembled in multiple configurations and contexts, the students developed the economy of their block unit based on a maximization of blocks per sheet of 4’x 4’ Medium Density Fiberboard. 4’ x 4’ was the maximum size that could be cut on the CNC mill at the school of architecture. The cut sheet was developed such that less than 3% of the board would go to waste. The exploration of assembly with these components produced multiple block types and multiple connection types that gave flexibility to the designed system.

1 Introduction + Hypothesis

“Our real hope is that (technology and architecture) will grow together, that some day the one will be the expression of the other. Only then will we have an architecture worthy of its name: architecture that is a true symbol of our time.” – (Mies van der Rohe 1953)

The primary impetus of this research is its importance as education for students who look to be future architects, and to give those students an opportunity to actualize some of the virtual design that is generated in architectural studios. To begin the students needed to learn & familiarize themselves with different types of CNC + Computer Aided Design/Computer Aided Manufacturing technologies. It was important that the students understood that these technologies came from industries beyond the strictly architectural and are only now being developed for use in architectural design. These technologies were developed for and have applications in automotive, product, and furniture design and fabrication.

The students’ research of these technologies introduced the idea of Mass-Customization to the studio (Figure 1). The idea applied both to the theory and the design segments of
the studio. The theory being that Mass-Customization had beginnings as a business model and could influence the economics of architectural models and projects. As a business model, rapid-prototyping and Mass-Customization is demonstrated as an open and flexible system for product research and development to find the optimized design solution for manufacturing and marketing. In the studio, the students were instructed to find and adapt a similar process for developing a full-scale architectural space.

Figure 1. Perspective Photograph of STL Project Facade.

1.1 Variable Entropy, Mass-Customization, and MASS-Appeal

There is a market strategy behind mass-customization. That fascinating group of products that promise to meet our needs as individuals, the products that are made special for the individual, like a snowflake, no two being the same. These products are customized for each person, who buys them, by each person who buys them. These are the products that fall into the buzz category of being mass customized. Marketing buzz aside, when speaking to students about the idea of mass-customization and in turn MASS-Appeal in relation to architecture it is important to define the terms.

- Mass: When thinking of architecture, Mass refers to the overall, solidness of the building. It could be defined in terms of development, "massing" scale and the building blocks of the structure. Mass could also be defined per the project as a type of blankness, or repetition. In other words, a regularity was required that structured the project before the appeal component appears.
• Appeal: The Appeal of a project acts as a counter weight to the massive nature required to support it. Appeal could redefine the idea of customization; expanding it beyond the strictly architectural.

Architects have shifted/exchanged the term custom with design in contemporary design. This exchange has decreased the pool of design possibilities within projects to “limits” or “choices”. On the other hand, project parameters can be used to develop a flexible matrix within which Appeal is revealed. A nickname for this condition would be "Hyper-local". The "Hyper-local" is tailored to a specific and often very small area in which the customization or design can impact the standard archetype or standard architectural component. In the case of the studio where these concepts were studied, the students developed a product called ‘STL Blocks’ that create a standard component, the block. Variations on that component and in its assembly create an opportunity for local areas of appeal in an otherwise regular system. These variations give the product an innumerable series of opportunities for working with and replacing existing systems as well as using the block archetype for creating a landscape in new applications.

The combination of Mass & Appeal involves both production and customization. As a type of business model, factors of "made to stock" and "to order" come to mind for Mass Appeal. The Appeal can also be thought of as an injection of ‘other’ open and variable information into the Mass, an organized but closed, non-variable system. Appeal injects randomness or disorder into the ordered Mass; raising the systems entropy raises its appeal.

Perhaps a nice succinct definition of entropy would be Humpty Dumpty. 
‘Humpty Dumpty sat on a wall, Humpty Dumpty had a great fall, all the king's horses and all the king's men couldn't put Humpty Dumpty back together again.’ There is a tendency to treat a closed system in such a way. You have a closed system, which eventually deteriorates and starts to break apart and there's no way that you can really piece it back together again. – (Robert Smithson 1979)

Unlike the Humpty Dumpty example, STL blocks display an open system for the following reasons. Some intentions of Mass-Appeal look towards the emerging systems inherit to the model at play. The STL model is clearly a field condition, characterized by precise and simple local organizations. Because the rules of the organization are determined locally, changes are not catastrophic to the whole. Flexibility in the modeling environment is accommodated by fluid adjustments. A small group of STL blocks or a large group of STL blocks displays fundamentally the same structure. As different combinations of STL blocks are used a pattern emerges (Figure 2). Without repeating exactly, the blocks display tendencies toward roughly similar configurations, not a static type, but as the associative result of localized behavior patterns. The associative results account for the Mass-Appeal of the systems in STL blocks continually interact.

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A shift in model types, additive to subtractive, was also taken into consideration with the STL blocks. During the semester, both additive and subtractive systems were investigated throughout to test and develop block types. After the semester, a change to subtractive models was employed to parallel material possibilities that had not yet been explored. The subtractive models developed an idea of casting verses cutting in which new connection types emerged. The new primary connection type was stacking. In other words, the STL system demonstrated flexibility capable of accommodating multiple local changes that can be smoothly incorporated.

Figure 2. Drawing of STL Block Pattern.

2 Organization

“Quickly and continuously converting new product ideas into crude mock-ups and working models turns traditional perceptions of the innovation cycle inside out: instead of using the innovation process to come up with finished prototypes, the prototypes themselves drive the innovation process.” – (Michael Schrage 2000)

As in any business, the students found that organization of human resources into branches of project development would be the most efficient use of time and labor. This organization took time create, but as its efficiency was found the process of developing design ideas was not only accelerated, but evaluated on multiple levels simultaneously. Each student began designing as individuals as they do in most architectural studios. Common design ideas then served to form design committees. Eventually only the strongest design committees would remain, while others would reform to serve other important functions such as a research committee, drawing committee, and budget committee. These committees would be adapting design ideas based on specific constraints at the same time that design was being conceptualized. Each committee
would evaluate those constraints in a parallel fashion before the prototype model would be machined. This organization would serve to be the success of the studio as, the use of computer-numerically-controlled technologies provided many constraints for the students to overcome and optimize on their way to a final design.

2.1 Budget Committee

The budget committee was in charge of the economy of financial resources, physical materials, and time required to fabricate a full design. Often evaluating designs in the digital model and small-scale model phases, the budget committee would hypothesize about what materials were possible for each design. This required the budget committee to have a great level of tectonic understanding for each design, and to analyze that tectonic understanding relative to the economy of its material potentials. Certain designs desired the qualities of texture that plywood would bring to the project, but would need to be fabricated from medium density fiberboard because the time it took to cut plywood was 15% greater for plywood than MDF.

The constraints evaluated by the budget committee required them to be the most outreaching committee on the project. Realizing the number of units that would eventually need to be produced in the amount of time given to produce them would require outsourcing some of the fabrication. Outsourcing to other educational facilities would be relatively inexpensive, but not very temporally efficient. Outsourcing to industrial facilities would greatly speed up production, but would be financially prohibitive. This required the budget committee to serve as a true business or marketing group to obtain as much financial support, materials, and machining time as the community would be willing to donate.

2.2 Research Committee

The research committee was in charge of finding and examining existing modes of production, alternatives for materials, and alternatives for designs relative to case studies in contemporary design practices. Often evaluating designs in the full-scale phases, the research committee heavily involved in interdisciplinary research for how to solve construction and assembly problems. The clamps and slots developed for connecting the units came, in conjunction with the drawing committee, primarily from this group of students who would evaluate the forces acting on each connection type and the strengths of test materials to design and size adequate elements for each solution.

The research group would also push the boundaries of designs by questioning if some units could connect in multiple ways and suggesting how some clamps designed for multiple connection types. This served to generate ideas from the design committees about larger scale connections of wall elements, roof elements, floor elements, benches and other programs. It is here that the non-linear process becomes key; the researchers challenge the designers, who generate designs that open up more research.
2.3 Drawing Committee

The drawing committee were responsible not only for preparing final drawings and models for conversion to fabrication files, but they were also in charge of evolving and developing designs from diagrammatic or schematic to efficient and technically sound components. Often vacillating between three-dimensional digital models and two-dimensional drawings, the drawing committee would shift and change configurations to challenge the designs to achieve more connections and find new directions. They would then bring drawings to an ultimate precision of 1/256\textsuperscript{th} of an inch, taking the CNC mill bit width and radii into account to develop an interface with the Computer Numerically Controlled output.

This high degree of accuracy, together with the demands of the budget committee would lead to developing an efficient and economical prototyping process in which sheets of material would be maximized for their potential of component fabrication. Distances between components would coincide with the width of the mill bit open areas on the material sheets created from the geometry of the components would be optimally filled with clamp connectors.

The organization of committees was a horizontal/non-hierarchical distribution of students all feeding each other with constraints and ideas while also all feeding the final, full-scale product (Figure 3). By working in a parallel fashion designs would be developed and evaluated for their aesthetics, economics, tectonics, and applicability at the same time, which would serve to influence each committee to move together towards a common solution.

![Diagram of Committee Organization](image)

Figure 3. Diagram of Committee Organization.

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3 Design Process

“There is a beautiful process in the making of a cedar strip canoe called lofting. Lofting in generic terms is used to describe the full-scale drawing of the curves associated in the building of a boat hull or an airplane wing. It is similar to “setting out”, a process that has been practiced by stone carvers for centuries. Setting out involved the full scale drawing of templates onto zinc plates. These zinc “molds” were cut out and used in the carving process much like a tailor uses a pattern. The science of stereotomy, the art of drawing and cutting solids precisely, was practiced by carvers as early as the 13th century. Using the developing science of descriptive geometry, carvers projected the shape of a three-dimensional stone, onto a two-dimensional zinc plate. Contemporary three-dimensional computer modeling programs are a direct descendent of this tradition that bridged science and art...

The drawing is built.” – (Bruce Lindsey 2001)

3.1 1:1 or Full Scale

Beyond the impetus of technology and collaboration in education of architecture students, lies the importance of designing at full scale. Now more than ever the importance of understanding the spatial implications of design is deemed lost in architectural education. Some would argue that this is a product of technology, or architecture designed in the computer. Models built in a computer don’t have a fixed scale, and scale is integral to understanding space. Digital technology, however, is developing as a way to bring architecture designed in the computer out of the computer into physical fabrication, into full-scale. Building a design at full-scale is the best way to experience it spatially. Perhaps one day, it will be the only acceptable way to experience it spatially.

The studio that would later produce STL Blocks was always a studio designing towards a unit-multiple scheme, but the move towards the stereotomic was the result of prototyping, testing, and design cross-fertilization. In the beginning the students were most comfortable designing a whole space, (as is done in most architectural studios) but had no real understanding of how the space would be broken down and constructed from fabricated components (Figure 4). When charged to work in reverse, the students would begin to design components without strong ideas of how those components would create space. Bridging this disparity between the unit and the whole required a non-linear process where the hypothetical could be explored digitally and the practical could be explored physically with ideas and understanding synthesized in fabricated prototypes.
3.2 Digital Process

“The parts have fairly complex definitions that take into account elements such as the diameter of the machining tool and the fact that we cannot have concave angles with a radius smaller than the tool’s diameter... Everything in the assembly is very closely fitted. But as nothing in the ‘real’ reality is truly exact, and as the software is fully exact, we had to also define small gaps to account for ‘errors’ in the production and assembly... There is a considerable degree of complexity built into the connecting parts.” – (Bernard Cache 2003)

Perhaps the most important aspect of the digital process in the studio was the non-linear approach and its integration with the physical process. Cache’s account of the complexity in his work is important, because too often the rigor of a digital process is not seen, and therefore is not considered. Many softwares of multiple types were used to (re)evaluate each design of the STL Blocks before it would make it to physical output from the CNC mill. Drawing and modeling softwares were used not only to prepare the units for cutting, but also for digitally building the prototypes for each unit and conceptualizing its many potential (re)configurations.

Digital models gave the students the potential to model ideas that constraints like money, time, and the laws of physics prohibited physically. The students could propose designs made entirely of materials such as transparent orange acrylic, which they could not afford to do in reality. They could multiply designs to 10,000 units, which they would not have
time to fabricate in reality. They could assemble units into configurations and place them into contexts that they would have access to in reality. These digital hypotheses would serve to impact design decisions that could not be made without digital exploration.

It was in this digital process that many of the design ideas would be proposed. The digital vacillation from 2D to 3D generated the first idea about clamp-like connections was generated. The physical testing would then require design modifications that would have to be evaluated digitally for fabricating. In the digital process goals for design problems were also frequently visualized. By assembling units in different ways, vicissitudes such as the viewing hole were found that would solve design issues such as mass-void imbalances in the ideas.

The ability to mass-produce irregular building components with the same facility as standardized parts introduced the notion of mass-customization into building design and production; it can be just as easy and cost-effective to produce 1000 unique objects as to produce 1000 identical objects (Figure 5).

Figure 5. Photograph of Several Units at Night in Wall and Beam Configuration.
3.3 **Physical Process**

“The model/series structure is not endemic to all categories of mass-produced objects and certainly not for objects that remain models... As we live among serialized objects, from computers to clothing, our urge to personalize becomes dependent on the options available to us in the field of commodities... Architecture might be the perfect example of the medium where there is *always* and *never* the model. Unlike the series object, architecture is never fully prototyped to scale and it is rarely completely crafted and assembled in an industrial process.” – (Neil Denari 1999)

In a way the STL Blocks moved from physical to digital, back to physical; and in its continued research it has begun to complete the loop again. Denari’s discussion of architecture as a medium neither prototypical, nor industrial is strong in theory, but perhaps a bit naïve to reality. The industrialization of structures is a growing field, only a field that is perpetuated by non-architects, and the STL project along with others is a move toward fully prototyping architecture to scale.

The physical process is one that must work at multiple scales; both multiple scales of modeling and multiple scales of analyzing the project. 1:12 units of each design were modeled and assembled physically by design committee members, as a way to think about how the units could be assembled to make space. Full-scale physical prototypes were made simultaneously by the research committee as a way to maximize the potential variations of each unit and optimize the connections of units.

Physical testing by the design committee was also occurring regarding the full-scale units and how their assemblies would create multiple spatial configurations, while those full-scale units were simultaneously being evaluated by the budget committee and drawing committee for the strength and optimization of their connection points.

It was in the physical process of building and reconfiguring the design that the project came to life. Members of each committee would come together to build the full-scale project and communication between these students in a construction atmosphere created a whole new nomenclature for a project already composed of ‘straights’, ‘tapers’, and ‘leaners’ (Figure 6). The webs and flanges of the blocks became ‘wedges’ and ‘faces’. Standard edge-to-edge clamps became ‘staples’ for their connection style. Rotational clamps, which would connect units face-to-face and counter shear forces in edge-to-edge conditions, were named ‘Honda’ for their similarity to the car manufacturers logo. One clamp, which allowed for flexibility between units, was even called a ‘dream clamp,’ named for its revelation to one student in his sleep. The one design feature that most deserved a nickname never got one. That was the slots on the faces of the units that brought the whole project together. It was the element that underwent the most rigorous evaluation and optimization.
4 Optimization + Continued Research

"Versioning here is instrumental in allowing the practice of architecture and design to return to a vertical organizational structure similar to the ‘master builder’ of the Renaissance. Their invention of new forms is closer to Brunelleschi’s systems of variable brick models than it is to the image-generating machines of the architects of the ‘dot-blob-bust’. When building the Duomo in Florence, Brunelleschi modeled multiple brick shapes and sizes using wooden moulds constructed from versioned templates to respond to specific loading conditions when assembled in different combinations.” – (SHoP/Sharples Holden Pasquarelli 2002)

Similar to the SHoP idea of Versioning, the STL Blocks went through many iterations. Beyond just the number of schematic designs presented by the many students in the studio, a number of design modification and optimizations had to be made to the STL Block after it was chosen as the design to develop. The catalysts for these design changes dealt with optimizing the economy of the system, strengthening and maximizing the connection types, and introducing variation into the system.

4.1 Connections + The Slot

Optimizing the connections was a design intention from early in the studio. As the projects became more developed the connections and possibilities multiplied. Beyond
the number of clamps developed, the real engineering came in the slot that allowed the clamps to hold the units together. Standard edge-to-edge conditions came first, in a similar connection to typical masonry units. For flexibility purposes, the clamps here would replace mortar in standard masonry. Face-to-face stacking came next and the adjustment in thickness of material and forces would generate another clamp type. This clamp type however would also work to counter shear forces in certain edge-to-edge conditions, which resulted in a modification of the slot. As an angled connection was later introduced as a way to create other archetypes such as arches and beams, an angle connection was introduced, also modifying the slot (Figure 7). This slot truly embodies ‘form follows function’ as its necessary edition to the STL blocks generates the texture and filtered light effect of the final product.

![Figure 7. Technical Drawing of Slot in Face of Units and Tool Path for Slot.](image)

### 4.2 Variation + Reconfiguration

In the final three weeks, as the small-scale design moves were finalized and the studio went into full production of units, full-scale mock-ups were built, taken down, and built again in different configurations and different contexts. It was here that the qualitative desire for variation met the quantitative need for variation. Each wall, each wall-type, each archetype needed certain variations to raise the entropy in the system; the appeal needed to be apparent in the system in multiple locations. ‘Tapers’ and ‘leaners’ produced various ‘cracks’ and ‘gaps’ in the system that would allow large floods of light
to augment the dappled light of the slots. The eye of the viewer would begin to read the system of blocks and connections only to be drawn to the areas where the system opens itself to be experienced.

This appeal, now a built phenomenon, would draw ‘passers-by’ and create the intrigue the project would not otherwise have. In the day it would create the breaks that people would peak through. They were the breaks that would eventually invite them into the space. At night, when the space was lit from the inside, the same breaks would act as chasms of light that would magnify the kaleidoscopic lantern like breaks between the canopies of forest. This light quality is perhaps the greatest programmatic accomplishment of the system.

In these configurations, the customized landscape was exhausted by the multiple connections types and archetypes that the system could allow. When built through stacking, somewhat static walls were produced, but when connected edge-to-edge the landscape of wall had no beginning and no end (Figure 8). Both connection types would serve to create beams, trellis-like roofs, and point foundations. The combination of all archetypes created spaces that could open and close at any location within the system and forming thresholds, benches, apertures located specific to the site of construction.

Figure 8. Photograph of Observer Sitting in STL Project Configuration #4.

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4.3 Materials, Collaboration, and Continuation

The success of the studio was greater than expected and has generated follow-up research. The STL project is still being developed as an architectural component that can be utilized for a number of programmatic solutions in everyday use. Medium density fiberboard and similar materials does not lend itself to many outdoor programmatic services, so a parallel research regarding potential casting materials is being analyzed with walls and landscapes (Figure 9). This research requires funding and a larger workforce to become effective and will be explored as a marketable component for future development.

Similar studios will be developed and conducted. These studios could benefit from being interdisciplinary studios including students from the industrial design, interior design, engineering, landscape design, and even business and marketing fields. These will explore similar organizational ideas and similar explorations of technology with a different set of student designers with different goals. These future studios can focus on different architectural components and might bring a different kit-of-parts to this design idea. Future studios will have the STL project to analyze and evaluate as a measure of success and limitation.

Figure 9. Photograph Series of Foam Molds for Casting Research.

5 CONCLUSION

“...I think we need to add to that a real impetus to...education, and if we do that, then everybody gets to be astronauts and not just a few.” – (David H. Levy 2003)

The STL project is perhaps not what one would expect from a digital design studio using 3D modeling and CNC milling to produce an architecture project following prototyping and mass-customization from industrial business models. The resulting design does not look like the research that the students collected, nor does it look like the ‘digital architecture’ of the ‘blob’ era. When charged with the question, neither reviewers nor the students could directly relate it to any contemporary product, project, or practice.

The constraints for the studio were simple; full-scale space focused on mass-customization. In sixteen weeks students with little knowledge of rapid- protototyping and mass-customization, no knowledge of Computer-Numerically-Controlled technology, and little ability to work as a design-production team, organized and designed the STL Block project. They set up and managed the budget. They learned how to use the software and...
hardware. They engineered the ideas into digital manifest and brought those manifests into architectural space.

Perhaps the greatest lesson for the students to learn in the studio is that 1+1 does not always equal 2; the idea that the aggregate can be greater than the sum of its parts. In this case the landscape of blocks produces spatial opportunities that far exceed the qualities of the blocks themselves. In the same respect the aggregate of students, especially when working as a true team to design one project produced much more rigor and a far greater synthesis than any of the designs brought forth by individual students and individual committees.

In a way, the development and ‘versioning’ of the connections between the blocks paralleled the development and fine-tuning of the relationships between committees and between the students. The multi-functionality of the blocks working together as a landscape can be seen as an architectural model of the dynamic flexibility carried out by the students working as a group.

References


