Representation and Realizing: a hybrid process of immaterial and material

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The disconnected relationship between representation and construction

Three-dimensional modeling technology has been extensively developed in the past twenty years. Today, architects are using various algorithms, scripting, and simulated physics to generate complex forms that move beyond the traditional shaper operations such as topological, geometric, transformative, and Boolean operations. Powerful modeling tools allow designers to directly manipulate freeform models without considering the constraints of the building process. Therefore, we are left with designs that are often not able to be realized in the physical world.

“It has been argued that architects make drawings not buildings….The conventional drawing has comprised one of the essential protocols that separate the maker from the architects, a device of status and demarcation.” (Callicott. 2005) The disconnection between immaterial representation methods and the real tectonic assembling principles intensified with the rapid development of digital computation in the past decade. The freedom in the digital form-making can easily violet the reality of material culture. Yehuda described this disconnection as a failure in representing architecture as a code for communication “since arbitrary codes abide by a different set of rules and constraints than physical entities do, it is possible-in fact it is rather easy- to apply changes to an arbitrary-coded representation in a manner that violates some premise of the represented object ” (Yehuda, 2004)

The distinction and relation between developing building information and the act of making itself has been discussed for decades. This conversation has accelerated due to the new wave of Building Information Modeling (BIM) and Integrated Project Delivery (IPD). The conventional CAD based communication among architects, engineers, contractors, fabricators yields a large amount of digital waste. The redundant and repeated work of design documentation is reduced and replaced by a single shared database. This database is used for design, structure analysis, and building operation. By promoting an integrated database and BIM, the digital waste issues have been partially solved. These types of processes have been wildly adopted in the practice.

Within an IPD process digital representation, such as construction drawings and three-dimension modeling, are extracted and driven by the central database. Valuable information is stored or released within each of the media. Realizing the building information in the physical world develops new situations where information is no longer just represented but now processed through various pipelines that differ from one another. This difference is the major contributor in difficulties found in educating students about the digital fabrication process that utilize information to build the physical landscape.

The deficiency of digital fabrication in the current design process

Parametric thinking and CAM tools have yield a significant renovation for designers to explore digital fabrication and material processing techniques. Laser cutting, CNC milling, and 3D printing have been introduced to students as tools that can assist in realizing complex virtual models. “The onset of CAD/CAM interfaces that allow designers to design directly for manufacture has placed production potentially back in the hands of the architects” (Castle. 2005). And do we ask, is digital fabrication an appropriate solution to reconnect immaterial and material world in its design/ build process?

Realizing the importance of materiality and tangible-form provokes a question that is vital to the field of architectural education; how does one teach beginning design students the difference of immaterial and material design while providing them an immediate experience and hands-on knowledge of materials and construction? To answer this question, several design courses have been developed and discussed among faculty at University of Cincinnati, University of North Carolina Greensboro and Southern Illinois University Carbondale. This discourse has developed several different strategies which investigate the building representation (immaterial process) and fabrication (material) process. The fabrication process is summarized into two distinct paths:

- *physical representation*: end product as scaled model for realizing immaterial form physically
- *physical prototyping*: material and tectonic driven design process.

These strategies were introduced to students as a series of projects investigating design pipelines and platforms that focus on the making of architecture through scaled models, simulated construction, and material experimentations. Digital representation (immaterial process) and fabrication (material process) are considered as hybrid activities where students engaged in a non-linear pipeline that digitally produces building information by exploring the processes which focus on representing materiality.

Physical Representation

In the *physical representation* process, conceptual models were generated with advanced freeform modeling software. The freeform model is virtually created without the consideration of tectonic quality and material property. These models were realized in the physical realm by students using waffling, paneling, slicing, and contouring techniques to produce two dimensional fabrication drawings for CNC production. The result of the fabrication process is a scaled model which can be classified as a physical representation. For instance, a customized rib system was extracted from curved mass and cut as 1/20 scale in chipboard following their unique profiles. A large amount of boards is left as the wasted material (Figure 1).

Figure 1. These two projects are physical representations with limited material investigation. Students tested the spatial and aesthetic qualities rather than the tectonic procedural. There is a disconnection between forms and material property[i].

Physical representation process of architectural imaging and representation tends to dominant our design process with only the end product in mind.. We can consider this as an immaterial form where a virtual model carries all the design information from the conceptual design to the two-dimension shop drawings for fabrication. In many cases digital fabrication has been used as a communication tool, a physical "representation" media as a scaled model, rather than a simulated construction process which is driven by various tectonic principles.

In the physical representation process, there is no pressure to consider the economic factors during fabrication. The waste from the cutting process is treated as a process of making a scale model. Students were asked to consider this waste in a sustainable manner where they do not simply excuse the material waste because it does not reflect the real manufacturing process.

Physical Prototyping

Physical prototyping simulates the construction process and considers all economic factors associated with the act of making. By simulating manufacturing processes, the waste, cutting time and material property has to be carefully studied. Students developed several projects that carefully address some of these economic issues. Student projects focused on the folding, bending and manipulation of material after a careful investigation on its property constrains (figure 2). Students concluded that the physical prototyping achieved a higher level of material usage than the *physical representation* approach.

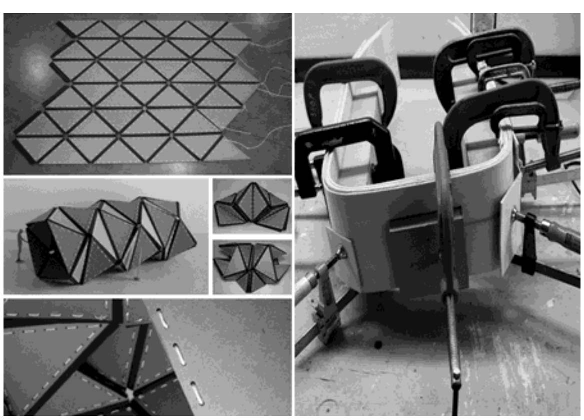

Figure 2: Left: Folded house[ii]; Right: Bending Plywood to create a suit case[iii].

Based on this distinction, many students fabrication projects belong to the category of *physical representation* rather than *physical prototyping*. Immaterial and intangible digital forms have been easily developed by students, and eventually fabricated with CNC and 3D printing technology. Unfortunately, the majority of these projects went without considering the real manufacturing process and material constrains.

The priority of *physical representation* is driven by the top-down principles such as form and order. Regardless of the size, these artifacts should be described as scale models or immaterial forms, rather than tectonic prototypes of simulation. In another words, the majority of these designs are generated without a reference to the origins of craftsmanship or the real manufacturing process. As the result, points, lines, and surfaces in CAD/CAM programs are the immaterial representation of form, but not relate to the material and process of making the form.

Is material waste inevitable?

Fabrication can be classified into either additive or subtractive manufacturing. Additive manufacturing is a process of joining materials with layers upon layers, such as fused deposition modeling (FDM). Like 3D powder print, this process generally does not produce much waste or left over material. Subtractive manufacturing process generates larger quantities of waste. For example, the left over pieces from laser cutting or CNC milling. Material size, thickness, geometry (vector or raster), strength, and pricing are among the parameters that beginning design students should learn in order to make an efficient use of flat-stock materials.

There is software, such as Rhinonest, to optimize the cutting pattern and layout in order to reduce waste. Is it the student's responsibility to optimize the material usage? Should economy be considered as a factor during the design- build process?

To answer these questions we can look at the process of manufacturing timber. Production of lumber begins with the transportation of logs to a sawmill. Since this process is separated from the design, architects generally do not participate in this process. Each log is stripped of its bark and then passed repeatedly through a large saw to reduce the log to untrimmed slabs of lumber. The purpose of this method is dividing the log and producing the maximum yield of useful material and therefore the greatest economy (Figure 4).

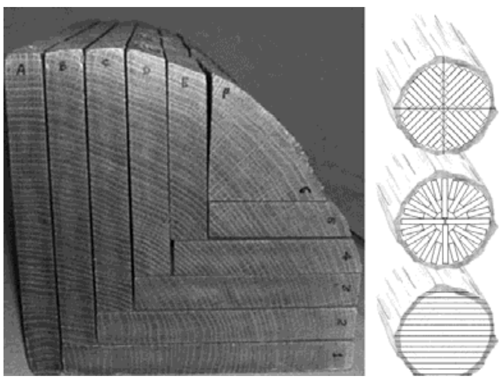

Figure 3. Manufacturing process of lumber showcasing minimum waste.

Digital fabrication in the design/ build process allows the students an opportunity to take a new role as a fabricator or a “sawman”. We are empowering students to consider the economic factors from the point of manufacture. These students actively engage in a sustainable practice were students realize the effects of material and immaterial on a larger scale. But the one questions that still remains is, should economy and usage of material been considered during the fabrication process?

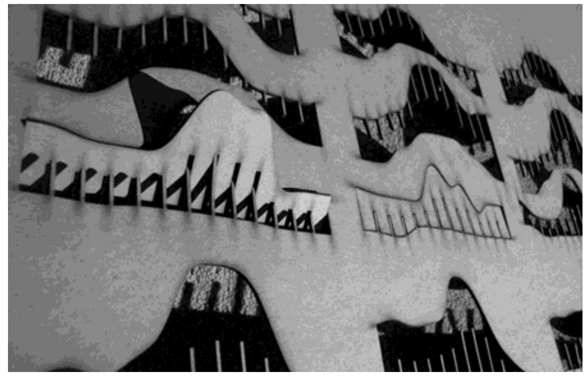

Figure 4. A typical cutting pattern with Laser cutter.

The answer is actually depending on if the fabrication is treated as a physical representation or a physical prototyping. In the first case, the result of fabrication is the representation of an immaterial model, for instance the use of laser cutting sections and stacking material to make a 1/120 skyscraper model, or using 3D printing to fabricate a scaled building model (Figure 5). The economic consideration is welcomed, but the waste is more forgivable because this physical representation is not expected to reflect the real manufacturing and construction process. However, if the outcome is considered physical prototyping or a simulated tectonic assembling, the economy of material usage becomes a very important factor. Like a full scale furniture prototype, the waste and material constraints have to be a priority from the start of the design and manufacturing process. The economy is a design factor which beginning design students must consider during the *physical prototyping* process.

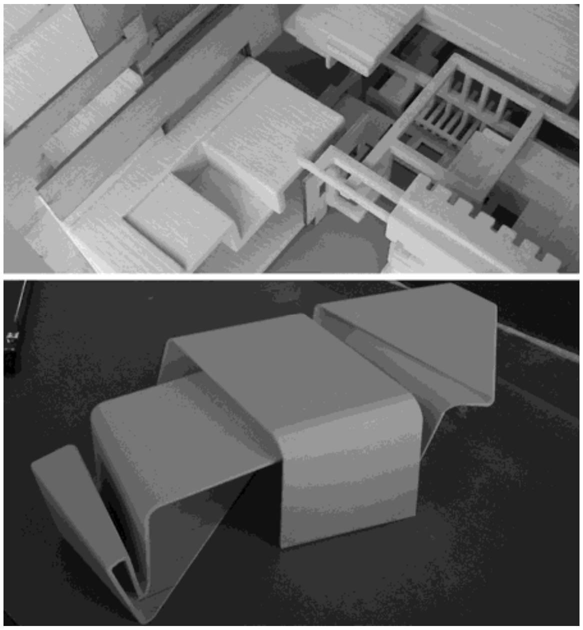

Figure 5. Top. 3D printed scaled building model. Bottom. Coffee Table[iv].

Bottom up vs. top down

Different from the standard 2" by 4" lumber, a customized curved lumber milled by CNC is often the result of a top down design approach. In the top down process, a building form is broken down to tectonic elements which can be easily fabricated. Richard Garber explains that "precise three-dimensional concepts are designed, tested, iterated and optimized in virtual space, they need only to be translated, or actualized, into physical media. A simple example would be a series of panels rationalized on a virtual sheet of plywood to be CNC-cut by a router". (Garber 2009) Using a top-down process, students designed virtual models which would be fabricated. For instance, a blob surface is developed digitally and tessellated into panels. As Lisa Lwamoto described, "digital fabrication is often one of the final stages of this process, and it is very much what sounds is like: a way of making that uses digital data to control a fabrication process" (Iwamoto 2009). The lower priority given to material and tectonic assembling results in more waste produced at the end of the fabrication process.

The bottom up approach is piecing elements together to create a grander system. The elements are usually in a large quantity but less type variation, such as CMU block or glazing panels. Several student projects have addressed the bottom up approach from different viewpoints. The clustering and composition of these elements, as well as the tectonic relationship of each unit became the driver of the entire form. The modular system and the large quantity of repetitive cutting pattern encourage the extra effort to maximize the material usage. In this process, the amount of usage/waste of material has nothing to do with the shape and complexity of the assembled form (figure 6).

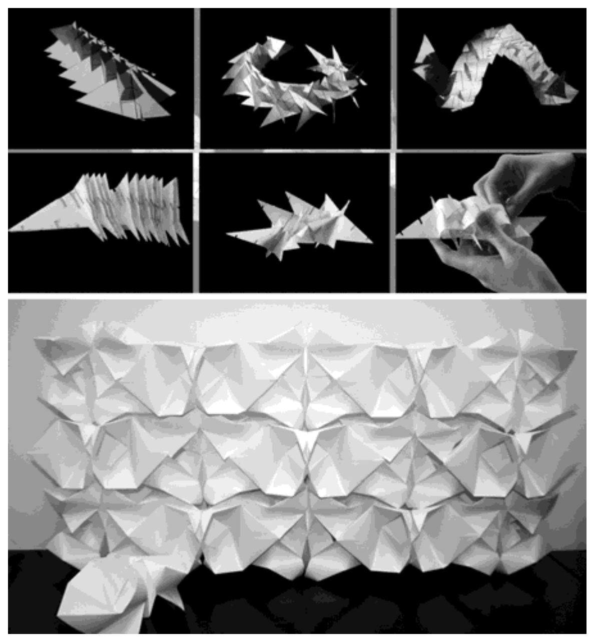

Figure 6: Top: Cellular study of bottom up concept[v]. Bottom: Paper folding using with bottom up approach[vi].

Conclusion

We believe there is a need for the beginning design student to understand the concept of physical representation and physical prototyping. Students need to expand their understanding of the representation skills needed to incorporate digital craft and fabrication process. As Bob Sheil described "digital fabrication implies that making drawings and making buildings are now inseparable entities-their interdependency has become a connected circumstance rather than a negotiable one. Designers, conventionally the maker of drawings and models, have in their grasp the opportunity to relocate to the centre of building with production with a powerful array of tools to convey innovative propositions that are fused with the information to make them." (Sheil, 2005)

As educators, we must fully be aware of the distinction and interconnection of physical representation and physical prototyping. We must encourage economic considerations of material during the fabricating and assembling process. We need to carefully examine the top-down and bottom-up approaches, mass production, and mass customization in terms of economic impact and how it maximizes material usage. "By designing a system that allows for fabrication to be a vital input in the beginning design stage will allow for the architect to speak the computing language. " (Tang, Anderson. 2009)

The essential values of the architectural practice, including but not limited to material properties, constrains of fabrication, assembling process, and economic constraints, need to be prevalent during the conceptual design phase of all beginning design students. The beginning design classes are an optimal place where consideration of fabrication processes should create a feedback loop to the conceptual design. The precaution to the manufacturing process and material issues such as tolerance, strength, flexibility, and cost will encourage students to create design iterations that are derived from bottom up approaches and component-based architecture.

Today, CAM and time-based simulation reveals the sequence of subtraction or addition by which form is realized. Simulated modeling can quickly estimate the amount of material usage and cutting process. As the new CAM tools are becoming more accessible and integrated into the design process it is essential for beginning design students to take on a new role as fabricator and put economy and material in the highest priority. With the ability to visually and numerically quantify the efficacy of fabrication, the results are valued for the process of building, the integration of fabrication, material parameters, and the engagement to the tangible world.

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Note:

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[i] Top: Jonathon Hughes, Katy Johnson. Bottom: Michael Zhao, Andres Santos. ARCH 512, University of Cincinnati, 2010.

[ii] Abigail Buchanan, board composition, IAR201 University of North Carolina Greensboro, 2010.

[iii] Travis Hope. Ryan Ball. & Samantha Scipio, Independent Study, Taught by Peter Chamberlain, Jim Postell, Ming Tang , University of Cincinnati, 2010.

[iv] Tippu Sashi, Independent Study, Taught by Peter Chamberlain, Jim Postell, Ming Tang University of Cincinnati, 2010

[v] Staci Carrier, Michelle Mahoney, Koki Waweru. SAID 294. University of Cincinnati. 2010

[vi] Weston Willard, illustrator and photo composition, IAR201 University of North Carolina Greensboro, 2010.