Numeric Instructions for Construction

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In 1798 Eli Whitney addressed the U.S. Congress and asked for funding for a proposal to mass-produce rifles with interchangeable parts. That innovation marked a significant shift in the history of making. Up until this point, most objects were custom-made by skilled craftspeople. Whitney's initial proposal included three mass produced prototypes that were actually produced by hand; it was not until 1808 that Whitney delivered the proposed 10,000 rifles.[1] Henry Ford extended these ideas of production with his concept for automobile manufacturing. In 1909, Ford produced 10,000 automobiles; in 1920, 940,000.[2]

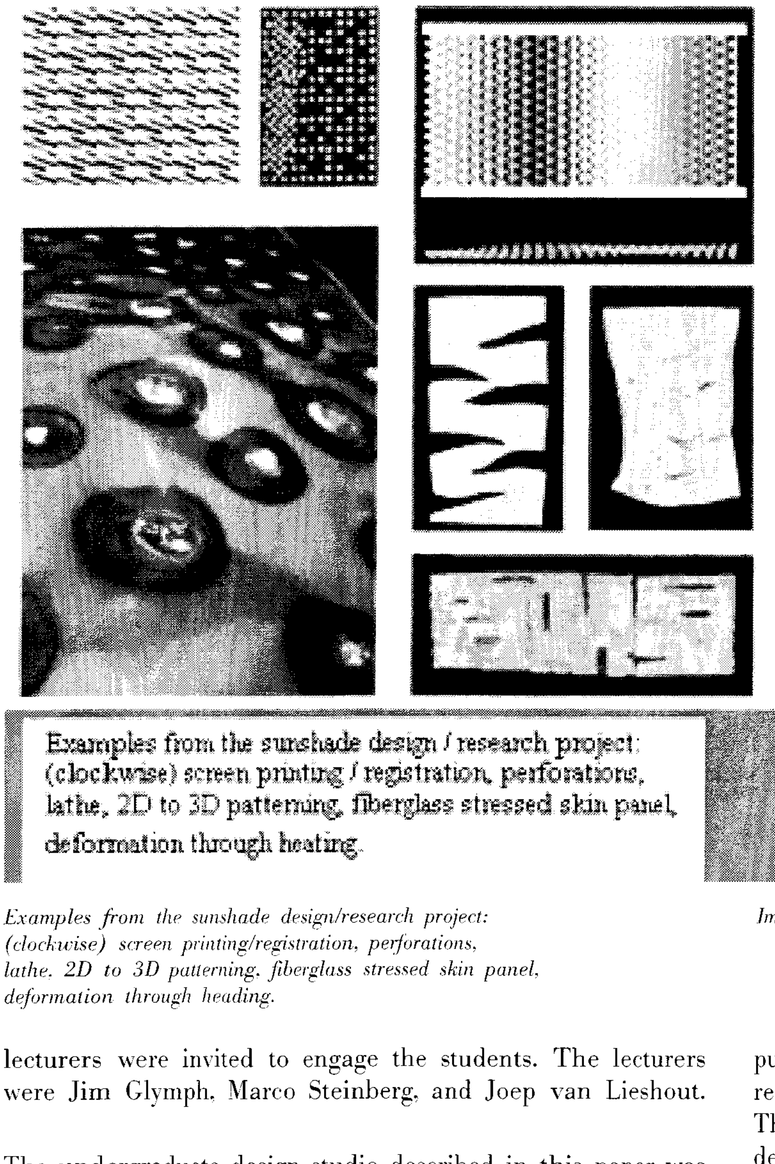
Custom and crafted items were pushed aside for cheaper and reliable items in the hands of the masses. Craft-oriented culture was eventually displaced by mass production, and it was not until the early 1990s that a new paradigm began to emerge, one of infinite customer-driven flexibility. Mass-customization continues to promise a flexible and efficient mode of production for custom parts or services at low costs. The catalyst for such a revolution has been computer-aided design and computer-controlled manufacturing.

Within these very clear paradigms, hybrid strategies have emerged that challenge and compete with the pure approaches. General Motors began outselling Ford by offering different color and model automobiles in 1924 when Alfred Sloan articulated GM's product strategy of "A car for every purse and purpose"[3] but these cars were still mass-produced. A more recent hybrid approach to manufacturing is typified in the U.S. Department of Defense's Joint Strike Fighter program, which began in 1996 with both Lockheed-Martin and Boeing. Both contractors were retained to develop working concept demonstration planes illustrating the teams' vision for the plane and manufacturing process. The JSF program began with a logical but radical proposition: instead of creating three different airplanes for three different users, one design approach would be used to build a single family of aircraft. This plane would need to achieve economies of scale in production and support while responding to performance requirements. The contractors were required, because of a "tight budget" to employ the most innovative design and manufacturing techniques to build the best product for the lowest cost. The three users were the Navy, Air Force, and Marines. The family of aircraft designed shared 90% of the same parts, yet their performance remained incredibly varied. Both Lockheed-Martin and Boeing satisfied the requirements of their contracts because of their efforts in research, computation, and advanced manufacturing techniques. The Joint Strike Fighter was digitally designed, built, and flown before a single piece of metal was cut.[4]

Such innovations in manufacturing, both pure and hybrid have always influenced the making of buildings, usually many years later. The materials that are available, the methods of erection, and the pool of labor constructing buildings evolve based on the paradigmatic shifts in the culture of making. These issues consequently influence every aspect of building, from the interaction permitted between designer and fabricator to the format of instructions and specifications issued for the purpose of making. Although mass customization is feasible for manufacturing (typically at small dimensional scales) it is still not fully available for the construction of buildings. We are still not at a point where pilots fly custom fighter-jets made to their personal specifications. Computer-driven manufacturing has affected high-end buildings, making difficult things possible, but the promise of high variability for low cost is still not truly attainable for a typical building budget.

DESIGN STUDIO

Each year during the winter term, the senior undergraduate students begin a semester long design competition. The studio instructors develop a theme around which the work will be juried. In the winter term of 2003, the charge was to explore craft, technology, and production resulting in the theme "Instructions of Construction". Each instructor proposed a studio to engage issues of making, and the students balloted for their studio options. In conjunction with the theme, three



Examples from the sunshade design/research project: (clockwise) screen printing/registration, perforations, lathe. 2D to 3D patterning. fiberglass stressed skin panel, deformation through heading.

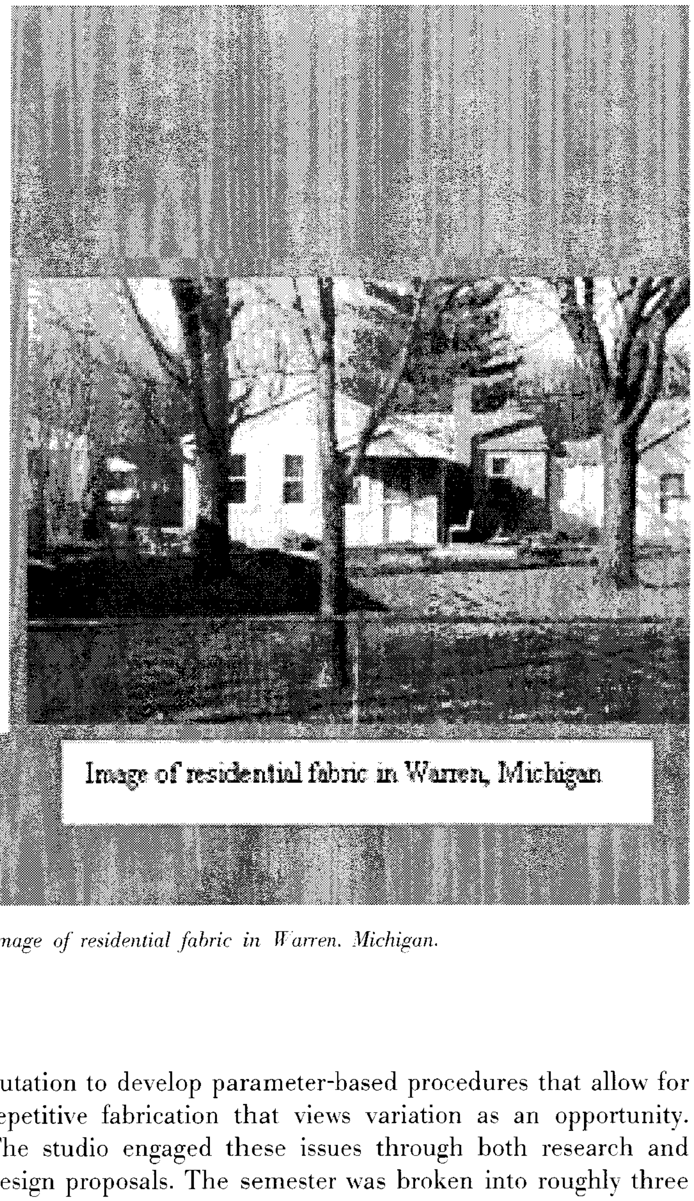


Image of residential fabric in Warren. Michigan.

lecturers were invited to engage the students. The lecturers were Jim Glymph, Marco Steinberg, and Joep van Lieshout.

The undergraduate design studio described in this paper was set up to explore the architectural potential of manufacturing strategies. In many cases, the studio employed high-end manufacturing techniques and applied them to low-cost applications. In the manufacturing examples previously mentioned the techniques were employed to lower costs or make something more efficient. While cost is always an issue for architects, the technology was exploited to test spatial and material ideas and effects.

A hybrid model of making that emerged from the work of the studio was that of "mass crafting" which freely employs strategies of the three production models mentioned (craftspeople, mass production, and mass customization). The studio investigated and revived ideas of craft defined as a skilled artisan working in direct contact with a tool and material. The students allowed their work to be informed by the digital design tools, digital fabrication equipment, and new materials.[5] In the mass-crafting model developed, the design process used computation to develop parameter-based procedures that allow for repetitive fabrication that views variation as an opportunity. The studio engaged these issues through both research and design proposals. The semester was broken into roughly three equal parts. The studio began with an open-ended research phase that investigated the history of manufacturing in order to construct a manufacturing timeline and a map of production techniques that were employed throughout the semester. Some of these issues included the results of on site or off site production, smart parts versus smart tools, smart people versus smart components, traditional methods, and the role of unskilled labor, and economies of scale. The second segment of the studio put words into action. The students identified a technique or approach and were asked to develop a full-scale interior partition / sun shading system. The project had a very limited program, which allowed the students to focus on the project as research. This initial test of ideas challenged and prepared the students for the final project that would include more constraints and more complex issues.

The final project was an "affordable" prototype house for Warren, Michigan. The house had a limited program and was to be about 1300 sq. ft. Open lots were identified as possible sites within the residential fabric across from the General Motors Technology Center. The close proximity to the manufacturing hub became a means of amplifying the influences of manufacturing and making. The studio projects would house employees (either blue or white collar) from the automotive industry.projects would house employees (either blue or white collar) from the automotive industry.

Many of the traditional studio concerns needed to be eliminated as a means of forcing the students to use their designs as an extension of their research. This meant removing the dominance of site and program, essentially forcing the students to propose a design agenda that grew out of their sunshade project techniques. The students were also pressured to explore more complex formal propositions, so they could not fall back on "business as usual" strategies for making an affordable house. Much like the case of the X-Fighter, the students were required to rethink the production techniques as a means of solving the problem. The final project explored how the instructions for construction could be translated from 1's and 0's into built matter (digital to physical). The solutions sought repeatable processes / techniques with variation. The module was an obsolete concept from an economic perspective. Square parts and free-form parts are cut using the same process (one is not more expensive than the other, but the material waste might be). The students were also urged to think serially; rather than develop one project, they were expected to use iterations to test possible technique results. Certain restrictions did exist. Flat sheets, material dimensions, software parameters, CNC bed sizes were all possible limitations and / or opportunities to be inscribed on their final product.

The following are three projects that represent the range of ideas that emerged from the studio. The projects fell into three loose categories: construction sequencing, material innovations, and design process techniques.

The construction sequencing group of projects were concerned with the life of the house from design through use – a multiple year cycle. Concerns included: who would build the house, where it might be built, how it would arrive at the site, and how it might transform over time. The example from this group of projects titled "box-mix" approaches the project with a broad focus and took on the "kit of parts" mentality. The process employed a temporal compression of fabrication. The example used throughout the research was a very detailed comparison between a cake made from scratch and one using a box mix. Many of the ingredients are compressed for easy of use and minimization of shipping space. The house proposal found opportunities not only in the location of fabrication but who the fabricators might be. The technologies, fixtures, products, and surfaces merge to become program. The project is essentially the exterior surface that has been doubly programmed inside and outside. The structural system is informed by the on-site fabrication, and the operability of the users. The project approaches the design like that of a product where the spaces are defined by the objects and these objects can be updated and reconfigured over time. The project never fully developed formally and resisted the lure of the digital fabrication but was a rigorous exploration of using manufacturing processes to inform the architecture.

The second group of projects began with a material technology that was identified during the sunshade project. These materials or material technologies included plywood panels, injection molded plastic, and fiberglass, to name a few. The development of the fiberglass project (seen below) grew from the student's direct interaction with a fabricator from a local fiberglass shop. Sheet Molding Compound (SMC) was identified as an industrial process used primarily in the fabrication of automobile parts. SMC is a fibrous material that is manufactured and distributed in thick sheets. It offers numerous qualities that are found in conventional building materials including durability, structural efficiency, fire resistance, longevity, and thermal and acoustic insulation, all in one thin layer. Its malleable qualities allow it to be shaped and formed with heat to serve any function. The house proposal follows the constraints laid out by the fabricator and are made of three SMC layers: an interior wrapper, a structural layer, and an exterior shell. The structural layer uses a corrugated cross- section to increase its structural capabilities and serves as the formwork for the exterior weatherproof shell. The *inner layer is divided into smaller residential program components. The student employed a mixed approach to custom elements and modular components – a loose fit between the flexible interior parts and the more expensive exterior layers. This was one of the more refined projects formally because the material was exploited spatially, while respecting the constraints of the material and fabrication processes.*

The last group of projects emerged directly from the digital fabrication process. These projects were focused on techniques contingent upon material dimensions, hardware limitations, fabrication concerns, and digital tools. In the following example, material efficiency became the determining parameter that informed the shape and space of the house. The project became more refined and less wasteful of material as the project proceeded. Flattening, folding, and laser cutting were studied as analogous smaller scale representations of sheet metal bending and water-jet cutting. As the flat sheet is spiral cut, the house can be shipped flat and unrolled on site. A series of panels would be manufactured with a similar process to skin and brace the structural spiral. This project is probably the least successful house but the most successful research project that illustrates the impact of material efficiency as a form finding mechanism.

Repetition and modularity are desperately holding on as a means of design rationalization and while it is always cheaper and faster to make the same part, component, or building over *and over again*[6], cheaper is not necessarily better. Through computer-driven manufacturing strategies, the studio identified possibilities for more customization and variation with minimal economic investment. The benefits were seen in relation to quality as opposed to the repetitive quantitative benefits afforded by mass production. For many decades, architects have used their time during design development to standardize the form, dimensions, and materials to fit available parts, products, and methods. Many architects fear mass customization because it offers no perceived resistance, removing the standardization phase of the design process. Without the material resistance provided by current modes of making many see this as an end to thinking about making in a meaningful way. Cost will not based on the complexity of shape but instead the machine time and material cost. The designer will engage the process directly, using the computer file to produce artifacts that take less time to cut, are pre-drilled for assembly, conserve material, and create desired material effects. Resistance and limitations of making exist, but not only are they opportunities for designers to reclaim aspects in the building manufacturing process, but they are ways to more directly engage and transform the process of making.

NOTES

[1] Lux, David S., "The History of American Technology – Small Arms in Revolutionary and Early National Eras", Course taught at Bryant College. See: http://web.bryant.edu/~history/h364material/musket/index.htm

[2] Model T Ford Production (Compiled by R.E. Houston, Ford Production Department. August 3, 1927)

[3] General Motors Corporate History. See: http://www.gm.com/company/corp_info/history/gmhis1920.html

[4] Hoffman, Carl. "The X Wars", Wired Magazine Issue 9.07 July 2001.

[5] McCullough, Malcolm. 1996. Abstracting Craft – The Practiced Digital Hand. Cambridge: MIT Press. 155-190

[6] Glymph, Jim. "Lecture", Dimensions 17 – The University of Michigan, Taubman College of Architecture and Urban Planning 2003. p56.