

CAPTURING THE (IN)FINITE

Bottom Up CAD-CAM Technology for Regenerative Architecture

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Abstract. In most design practices there is a division between the generation of information to describe buildings and the production of information to construct them. Today architects are in charge of the design of the building (aesthetics) while the contractor is accountable for the means of construction (tectonics). The advent of digital technologies within the field of architecture however has begun to cause and will continue to cause fundamental changes within the AEC industry.

The Paper describes a possible scenario where a Bottom – Up, part to whole approach to architecture can be adopted using the freedom afforded by Parametric Design within the CAD-CAM environment. This approach is explored through the design of a smart block in concrete that is integrated into a wall system.

1. Looking Back to move forward

In *The Four Elements of Architecture*, published in 1851, German architect Gottfried Semper argues that architecture has historically evolved from and responded to four different industrial arts, namely ceramics, carpentry, masonry and weaving.

He argued that the central hearth derived its forms from the heat and fire associated with ceramics and metalwork, while the enclosure drew on the fundamentals of weaving, the roof from skills of carpentry and the terrace or mound from masonry. In fact, he is most famous for his speculation that weaving and wickerwork were crucial skills for the primary architectural gesture of enclosure, namely the wall.

During the early 15th century, the great architect Filippo Brunelleschi was formerly a goldsmith before he was commissioned to design and build the dome of the Cathedral in Florence. Working with clocks, wheels, gears and weights, developed his exceptional skills that would help him construct some of the greatest pieces of architecture in Renaissance history. He was given a title of master builder due to his knowledge of machinery as well as his engineering prowess combined with a keen interest in mathematics. More recently, the architectural movement of Modernism resulted from the influence of the industrial machine age on the arts. Modernist buildings are essentially unembellished, functional machinery for living or working; oftentimes with their operational elements exposed to view. The works of Mies van der Rohe and Le Corbusier are among the most notable examples.

While history is replete with examples of influences from other trades the later part of the 20th century saw an increasingly inflexible building industry where the desire for efficiency, need for growth and profitability shifted the focus from collaboration to specialization. By allowing architecture to become reduced to the current degree and by relinquishing responsibility for assembly, product development, and materials science to specialists, the architect has allowed the means and methods of building to move outside the sphere of architecture. (Timberlake, 2004)

With the advent of digital technologies and mass customization that has been successfully adopted in the car and airplane manufacturing industries architects are beginning to change the way they practice primarily through collaboration and technology transfer.

2. Concerns

The broad concerns that this proposal hopes to address are listed as under.

2.1. SUSTAINABILITY

The construction and maintenance of buildings within the United States uses 40% of energy and 30% of wood and raw materials. The situation in India is also grave and fast reaching similar unsustainable levels due to prodigious economic growth. The project will address this issue by using concrete that is far more sustainable due to its lifespan and use of recycled materials like fly ash and slag.

2.2 MASS CUSTOMIZATION

Mass Customization is the use of flexible computer-aided manufacturing systems to produce custom output. Those systems combine the low unit costs of mass production processes with the flexibility of individual customization. The use of this technology within the field of architecture is gaining momentum.

2.3 AFFORDABLE HOUSING.

The lack of Affordable Housing is a growing concern. In order to make housing more affordable the use of technologies and innovative materials needs to be incorporated. There is a need to collaboration with industry and incorporate available research into existing models. Thus far the industry is fragmented and a collaborative approach needs to be adopted in order to provide much needed solutions.

3. Case Studies

"A world view of a culture is limited by the structure of the language which that culture uses." (Sapir and Whorf Hypothesis)

The case studies below are an attempt to link the developments in manufacturing and the cultural effects it produces within the field of architecture. The language of expression in each of these projects is clearly influenced by developments in industry and thus represents the spirit of the age in which they were built.

3.1. STORER HOUSE: MODULARITY / TEXTILE BLOCK CONSTRUCTION

The Storer house in the Hollywood Hills displays the heavy Mayan influence the architect was enamoured with during the 1920s. This house was the second of four houses that Frank Lloyd Wright built out of textile block in California. Typically Wrightian is the joining of the structure to its site by a series of terraces that reach out into and reorder the landscape, making it an integral part of the architect's vision. For the first time the architect could exploit his grid system vertically as well as horizontally: in Wright's own words, 'Standardization was the soul of the machine, and here I was the weaver ... crocheting with it a free masonry fabric ... great in architectural beauty.'

Wright intended that this type of construction would come to represent a new way of building homes in America. Though this did not achieve its goal the Storer House is a forerunner of his Usonian homes that became very popular in the 1950's.

3.2. TURBULENCE HOUSE: PARAMETRIC DESIGN / STRESSED SKIN

The Turbulence House designed by Steven Holl was an opportunity to respond to the bareness and harshness of the desert landscape of New Mexico with the least conventional design. This was also an invitation to use digital means to realize an architectural project. The house is designed with a passageway that allows gusts of summer wind to pass through the middle of the house. It is relatively cool when the temperature outside is extremely high. Its curved horseshoe plan and arched section look set to withstand the wind.

The integration of the frame with the skin is perhaps the greatest leap forward in digital fabrication thus far. The architect's 3-d drawings were used by Zahner to develop a set of digitized drawings that broke the building into 4 compound-curved panels, 10" thick, with aluminum-zinc exterior, two waterproof membranes and integral metal ribs. Once fabricated the panels were shipped to site, tilted up and bolted into place on a concrete slab foundation. The interior of the house is kept simple and local skilled labor is employed to complete the traditional plaster work using a quarried mix that has a soft pink hue.

3.3. BIG BELT HOUSE: CNC MILLING / CAST IN PLACE CONCRETE RIBS

The Big Belt house was built using CNC milled EPS formwork and supported on scaffolding. Threaded rods acted as concrete ties. After concrete was cast in place the EPS forms were stripped away. PVC pipes were then laid lengthwise over the ribs. Insulating foam was sprayed over the pipes and sanded smooth to form a monolithic enclosure. The surface was then sealed with polyurea and finished with diagonal strips of wood siding.

The working files generated from the 3d model replace traditional working drawings. Each shape of the rib is derived from digital section profiles, subdivided into interlocking parts and nested onto standard panel dimensions for CNC milling. Holes for reinforcing were located in the panels. Bill Massie's design build practice opened up the possibility of experimenting during the construction process, developing design at full scale and merging design with the craft of making.

3.4. LOBLOLLY HOUSE: COMPONENT BASED DESIGN

More recently the Loblolly house is an attempt by architects Kieran Timberlake to focus on building supply chains, prefabrication processes, and rediscovering the role of the architect as master builder. The architects credit the advances made in digital parametric modelling for enabling the project to move forward. They depart almost entirely from the traditional prefab models to a component based design in which the number of parts are minimised. (Fortmeyer, 2006)

The entire House would fit on two tractor trailers for delivery to the site. The architects reformulated typical house design into larger elements that combine a variety of CSI building materials into simple units such as floor cartridges that could easily be installed in the field.

3.5. TROPICAL HOUSE: PREFABRICATION

Another relevant study was Jean Prouvé's tropical house. Prouvé began his lifelong engagement with the industrialization of architecture, particularly its application to mass housing. Prouvé designed the Tropical House in 1949 as a prototype for inexpensive, readily assembled housing that could be easily transported to France's African colonies. Fabricated in Prouvé's French workshops, the components for the house were completed in 1951 and were flown disassembled to Africa in the cargo hold of an airplane. The house was erected in the town of Brazzaville, Congo, where it remained for nearly 50 years. In 1999, the Tropical House was disassembled and shipped back to France for restoration. (UCLA, 2006)

3.6. DYMAXION HOUSE: EASE OF ASSEMBLY / INDUSTRIAL PRODUCTION

In 1945 Buckminster Fuller decided to manufacture the machine for living in that he had proposed in 1928. The visionary inventor whose mantra was more with less formed an alliance with the Beech Aircraft Company to produce steel ribbed aluminum houses at the rate of 200 per day. At a stroke he would solve the housing crisis and revolutionize the construction business just as Henry Ford's had done for the automobile industry. Unfortunately the ambitious project did not see its fruition, only two prototypes were built.

The impossibility of testing and perfecting all the novel features and moving parts in a few months with scant funds and skeletal crew eventually caused Fuller to shelve the project. It still remains however a brave attempt at solving the acute shortage of affordable housing that is faced even today.

4. From part to whole: The Parametric Smart Block

Architecture requires control, deep control, not merely of an idea but also the stuff we use to give form to the idea. (Timberlake, 2004)

Parametric Design (sometimes referred to as associative geometry) allows the designer to treat a design as one large database adventure where design process decisions are published as histories embedded in the representation of the design in any given instance of its development. (Kolarevic, 2003). This is one way of regaining control over a fragmented process.

The Project explores the use of Parametric Design to design a smart block that includes the following constraints:

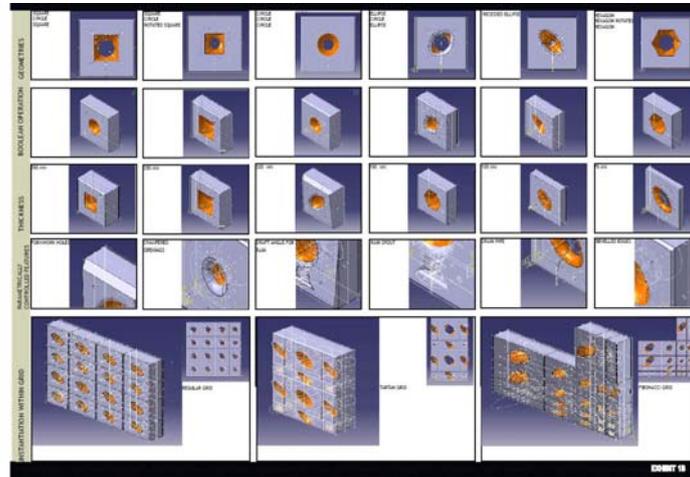
- Geometric sets for various shapes that determine porosity.
- Thickness that varies according to requirement linked to design table.
- Features like edge filleting and formwork holes.

The whole however is intended to be more than the sum of its parts through strategic repetition and positioning and use. (see Drawing 1)

5. Design Method

The software platform used was CATIA V5 and the particular function incorporated was the power copy. The smart block was instantiated within the grid. Various alternatives of the grid were tried from the regular square grid, to the tartan grid and the Fibonacci grid. (See Table 1)

TABLE 1. CATIA snapshots of design method



Symmetrical Grid

Tartan Grid

Fibonacci Grid

The smart block populated the grid and the subsequent panel of 12' by 12' was 3d printed for testing. Various iterations of the panel were tried and in each case experiments with porosity were carried out. The panels could function as slabs as well with the use of steel reinforcement much like the woff and weave system of Wright's Textile concrete blocks. Thus an entire system may be designed based on a single smart unit.

The design table below displays the possible alternative panel thicknesses that may be used. Column A describes the thickness in front of the selected geometric plane and Column B describes the wall thickness behind it. The third column has the overall thickness.

6. Plug Design

The design of the plug is crucial to the finished block. The material used for the plug design is mdf. This is milled on a CNC router and is built in layers not more than $\frac{3}{4}$ " thick. The layers are then assembled and bolted together before placing them within the wooden formwork for casting.

After the concrete has set, the plug is disassembled and removed for use in the next block. This plug is intended to be used repeatedly till the construction is complete.

6.1. PLUG FOR APERTURES

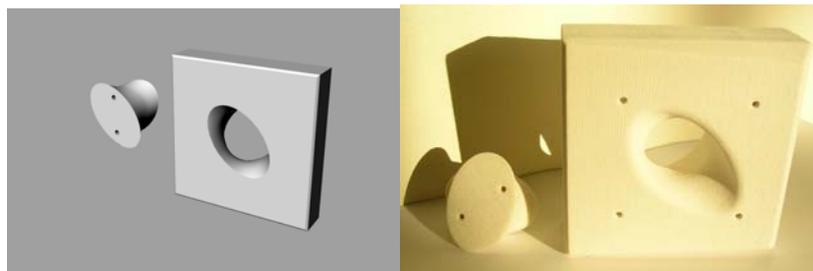


Figure 1. Block showing corresponding plug. Image at right is a 3D Printed version using ZCorp.

Each size of opening will have a corresponding parametrically designed plug that can be used multiple times as shown in the Figure above. The aperture thus modulates the light and can be oriented to control the quality of light entering into the space.

7. Capturing the Infinite: A concrete panel system

The Digital Realm is located precisely at the frontier where the coded and the abstract meet the concrete and the immediately accessible. The challenge today is to redefine materiality in the articulation of formerly opposite characteristics like abstraction and concreteness, control and freedom, or computation and sensation. (Picon, Fall 2007).

Today there is a sense however, that with the tools currently available, we are closer to capturing the essence of the virtual within a tactile tangible framework. In a sense **Capturing the Infinite**.....

These relationships between geometry and mathematics, nature and built form have intrigued architects for generations. One such attempt at reconciling these two fields was the Modulor system of measurement as proposed by Le Corbusier. He described it as a "range of harmonious measurements to suit the human scale, universally applicable to architecture and to mechanical things." (Corbusier, 1955)

This project uses the ubiquitous grid based on the Fibonacci series to begin to explore the relationships between the organic and the inorganic. The system thus developed combined with idea of porosity and modulation of the surface will generate infinite possibilities by using a controlled palette.

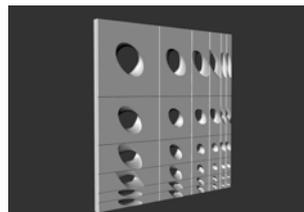


Figure 3. Concrete Wall Panel tilted up after plugs have been removed for reuse.

8. Where do we go from here.....

The goal of the design research is to illustrate the success of part to whole design process using Parametric Design within the CAD / CAM environment. By maintaining control over the smallest component of the building (in this case the block) the project illustrates how the architect can establish his authorship of the design through the construction phase of the project.

In order for the architect to be instrumental in dealing with the pressing concerns sighted earlier he must be empowered to take crucial decisions from concept to implementation of a project. The authorship of digital drawings and the elimination of the shop drawing process is one such way of

regaining this control. The reduction of the building into its constituent elements and crafting them individually can create more opportunities using simple even meager means. This kind of Bottom –Up approach can be instrumental in regenerating the AEC industry by providing architectural solutions that represent a symbiotic relationship between precise industrial process and intuitive local expertise.

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