Parametrics, Performance and (Pre) Fabrication

Luis Eduardo Boza
Catholic University of America

Abstract

This paper will present the current work of a graduate design/build studio at a nationally accredited school of architecture. The studio examined how digital design, simulation and fabrication technologies can be assimilated into a more relevant architectural discourse in order to question their roles in the design and production of a *sustainably* (pre)fabricated architecture.

In doing so, the studio sought to extend sustainable design principles into the digital and analog environments via the notions of Parametrics, Performance and Prefabrication. The studio required that quantitative and qualitative criteria be considered in tandem with the tools and technologies utilized during the design and fabrication processes as a means of generating an intelligent logic and methodology to address sustainable design principles. As a result, the notion of sustainability turns away from merely the application of high technologies and the specification of green materials to the fundamental process of identifying new opportunities that generate a wider spectrum of variations and performative values for prefabricated architecture.

Introduction

Prefabrication, as a method of production, can be traced as far back as the Mesopotamian civilization, where the burnt clay brick was developed and the craft was standardized. Early examples of the use of prefabrication in the construction of architecture date back to 1624 when the English brought with them to Cape Ann in the form of a panelized house of wood for use by their fishing fleet. The house was disassembled, moved and reassembled several times as fleets moved around the coastal regions. [1]

Since then, the promise and challenge of prefabrication has teased and tormented architects, engineers and builders. For almost two centuries, designers have struggled to harness the power of industry to produce beautiful, functional, and efficient architecture.

Numerous value-added benefits afforded by prefabrication are enticing to architects, engineers and builders. One such benefit is a reduction in project delivery times. Prefabrication allows construction times to be reduced because tasks are completed simultaneously rather than sequentially. Site built items (infrastructure, foundation, electrical, plumbing) are being accomplished at the same time that shop built items (prefabricated modules) are being completed in the factory. If correctly scheduled and project managed, the entire process can reduce the average construction time by 80 to 90%; from 24 months to 90 days.

Another attractive aspect for architects and builders is that prefabrication offers the opportunity to extend the reach of the knowledge gained during the design and production processes. This suggests that one "gets more bang for the buck" — an approach where design decisions extend beyond "one-off" solutions to "more-of" solutions. Conceivably, the value gained from the efficiencies of both time and money can be passed either to the consumer and/or dedicated towards higher quality materials or higher end home technologies.

Nonetheless, the term "prefabrication" often still rings skeptical in the ears of potential homebuyers/owners due to a few critical shortcomings of the current approaches.

Lack of Specificity

Historically, one of the major issues with prefabrication/mass-produced architecture is its lack of specificity to the local conditions of a chosen site. Physical characteristics of the site (view, terrain, vernacular traditions, etc.) and environmental considerations (solar orientation, wind direction, annual rainfall, etc.) rarely, if at all, can alter the design or layout of a prefabricated structure as most these responses are "built-in," generic and static —

unable to be customized. This approach often leads to un-oriented, a-climatic, and non-contextual structures.[2]

Minimal Levels of Customization

More often than not, the "lack of specificity" to the local conditions is a result of the minimal level of customization built into the design scheme. User customization is relegated merely to the selection (or upgrade) of interior/exterior materials (granite vs. laminate, wood vs. carpet, siding vs. masonry) and appliances (GE vs. Sub-Zero). Although, these decisions are often important to potential buyers, they do not address the ability of the home or structure to perform more effectively or efficiently in its context or functionally for its user.

Lack of Attention to Sustainable Design

There are few options available to homebuyers interested in purchasing a sustainable prefabricated home. Attentiveness to the need for environmentally conscious decision making is affecting the consumer's mindset as their concerns about global warming; rising fuel and energy costs and unfavorable health conditions resulting from sick building syndrome continue to escalate. Sustainable design thinking is most often kept to the obvious and inherent benefits that prefabrication offers — reduction of construction waste, both on and off-site, and a reduced impact or disturbance to the construction site — and rarely becomes the driver of industry innovation.

Parameters Performance & Fabrication

Given recent advancements in design and production technologies of design, analysis and production, coupled with recent cultural and economic shifts, a renewed interest in the processes involved with prefabrication is occurring. At the same time, advancements in the use of digital design, simulation and computer numerically controlled (CNC) fabrication machineries have revolutionized the automotive, aerospace and shipbuilding industries, and is at the cusp of transforming the building industry.

Parametric and Building Information Modeling (BIM) software tools have provided designers with fluid modeling environments where constraints and variables can quickly adapt and reconfigure geometries. [3] Designers are now able to embed "information" into a virtual model, creating an "intelligence" which can be utilized to understand and evaluate the quantitative and qualitative performance-based aspects of their work through simulation and analysis software.[4]

Parametrics

It is important to note here how the parametric model operates in order to understand the fundamental shift from the modeling of a designed "object" to modeling of the design's "logic."

Parametric design makes use of parameters to define a form through the interplay of relations and constraints. For example, in the case of architecture elements, they can be grouped into "families" of elements—floors, stairs, walls, doors, and windows. They can be further grouped by their hierarchical relations—handrails occur on stairs, stairs occur in floor openings, floor openings occur in floors. In order to describe any of these pieces, two items are required; a geometrical description of the object and the relations, or associations, they maintain with each other. Constraints are relations that limit and control the behavior of an entity or a group of entities.[5] The parametric/associative links between entities in essence constructs (fabricates) a virtual database of information where design decisions are recorded and published as a "history" or "logic" of any given geometrical variation.

By modeling the logic of a geometric entity, it also becomes possible to embed rule-based variants. Rule-based variants are variables that can be described by a series of facts relating to the geometry and the constraints between them.[6] Thus geometry can be described by a series of rules, each of which may relate to one or more constraints, through information that is input via a database, user or other associations built into the model. Rules can be numerically based (mathematical equations), text based (yes/no, true/false), or both (if/then).

Performance

The rule-based, parametric/associative modeling techniques require that data be input into the logic that subsequently drives the geometrical model. Performance-based modeling places performance based priorities above form-making and utilizes the data to offer a comprehensive solution to the given problem. The information that drives the performative

response can be many things including technical (structure, acoustical, thermal), spatial (width, length, height) or financial (budgetary). Most important in this particular project is that the design for prefabrication can be performatively modeled utilizing data from site conditions as a means of customizing each particular variation to its location. For example, data may come in the form of the site's longitude and latitude (numerical), which in turn can link to data describing average rainfall, predominant wind directions, and hours of daylight. Data may also describe the preferred orientation at a chosen site (text based—north, south, east, west), which could also correspond with a predominant/desired view. As the generic, un-optimized logic (parametric model) is subjected to various data sets, the range of possible performative possibilities or optimized solutions emerges. Acceptable solutions can be selected at any stage to satisfy other non-quantifiable criteria. [7]

(Pre)Fabrication

Branko Kolarevic states that "a digital convergence of representation and production processes represents an opportunity for a profound transformation of the profession and, by extension, the entire building industry." [8] We need only to look towards other industries (automotive, aerospace, marine/shipbuilding) to see how the connections between design and production have innovated and transformed the way they operate. Common in all these cases was the ability to convert virtual geometries into (and onto) physical materials. Central to this process is a fully coordinated, three-dimensional information model — a virtually "pre" fabricated construct. Prefabrication, by definition, involves fabrication or construction beforehand as means of standardizing/customizing parts or sections for quick assembly and erection. This definition holds true in the case of a fully developed BIM model, especially when the data contained within it is used to run machines, which fabrication the physical manifestation of it.

Computer Numerically Controlled (CNC) technologies have fostered an integrated and collaborative relationship between the process of design and the act of making. As architects and designers become more familiar with available means and methods of digitally driven technologies, they will be able to better collaborate, coordinate and communicate with fabricators (or manufacturers) the control data that ultimately drives the fabrication equipment.

Paradigm Shifts: Virtual/Analog (Pre) Fabrication

A possible link between the computational power of parametric design/BIM and the construction technology of CNC and prefabrication suggests a pending paradigm shift for the prefabrication industry. Central to this shift are the notions of Parameters, Performance and (Pre)fabrication. It suggests that a process of production is directly linked to and reliant on the virtual environment and digital model, which itself emerges from a designed logic of relations. The parametric, rule-based, generative nature of the building information model is able to process information about the characteristics of the site/environment and user preferences to automate the creation of design variations. These permutations can then be filtered by specific performance analysis (sustainable design, economics, product lead time, construction schedule, etc.) and driven by additional rules/data added to the model. From this process, a default, variable-rich model is slowly developed from a conceptual model to a detailed design used to drive fabrication machineries. With this process, it becomes possible to mass-customize and manufacture individual structures that respond uniquely to their own site, climate, topography, program and function from one virtually (pre)fabricated construct.

Branko Kolarevic describes this describes this process-based approach as a *digital continuum*. "On-off" architecture has already begun to examine the potential benefits of these technologies. However, the prefabrication industry has yet to exploit the values of these technologies when used in conjunction with each other with the goal of responding to prefabrication's often criticized shortcomings, while maintaining its positive virtues: quality, efficiency, and cost-effectiveness.

Studio Description

In order to investigate these processes, The Graduate Concentration in Design Technologies at The Catholic University of America's School of Architecture and Planning conducted a studio titled *(re)Constructing Sustainability: Digitally-Driven Sustainable Design and Construction Solutions.* This on-going project was initiated during the Spring 2008 semester. During

the spring term, the students were responsible for the initial research into the generative logic and framework with which a site responsive, mass customized architecture could be suggested. In the studio the students conceived of the EnviroNODE: a 400 square foot, sustainable designed and digitally prefabricated modular shelter. Central to the EnviroNODE project were four investigative nodes: Compact/Hybrid Space, Sustainable Strategies and Technologies, Renewable and Recyclable Materials, and Innovative Construction Strategies and Techniques.

The studio questioned if the negative aspects of prefabrication could be addressed by an integrated design, analysis, production and delivery methodology made possible through the use of digital design, simulation and fabrication technologies.

The studio began with three individual exercises aimed at identifying how environmental and programmatic considerations can affect the thinking in the design of architectural structure.

The INside-OUTside Houses

The first exercise was titled the "INside-OUTside" Houses. During this exercise, the students were divided into two groups. The first group designed the "INside-OUT" House. The "INside-OUT" House investigated the relationship of programmatic and functional spaces relative to the external form of the structure and to each other (Adjacency, Overlap, Cluster, Share, Isolate, Embed, Mirror). These students were primarily interested in how the internal environment can "push and pull" a building's program to generate performance and form. To do so, students needed to develop a program and to understand issues related to sequencing of activities, ergonomics and code.

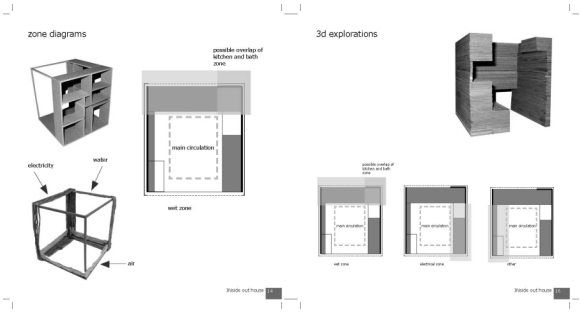

Fig. 2. Image of the INside-OUT House

The "OUTside-IN House"

The second group developed the "OUTside-IN" House. The "OUTside-IN" House investigated the relationship of the building's skin/enclosure to environmental forces (rain, wind, view, cold, heat, etc.), structural requirements (supporting walls, floors, ceilings, transport, etc.), programmatic requirements of the interior spaces (opacity, transparencies, openings). These students were primarily interested in how the external environment can "push and pull" a building's enclosure to generate performance and form. To do so, students needed to understand the variations within various climatic zones, driving environmental consideration as well as building envelope performance.

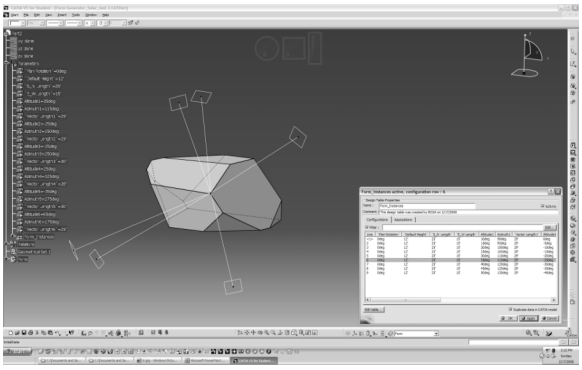

Fig. 3. The "OUTside-IN" House- Variation 1

The "Transfer" Houses

The second exercise was titled the "Transfer" House. Transference is to imprint, impress, or otherwise convey (a drawing, another, to change by means of a transfer from one to another. Here, the students were asked to merge the "OUTside-IN" House with the "INside-OUT" House by transferring the programmatic and performative solutions from one scheme onto the other. Student teams considered the programmatic and performative efficiencies (how the exterior envelope can support/relate to the interior function and vice versa), the structural and infrastructural efficiencies and how they relate to each other.

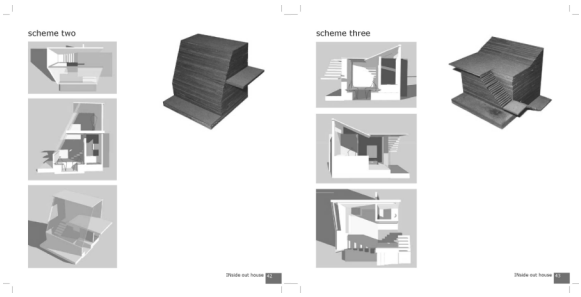

Fig. 5. Image of the Transfer House 1

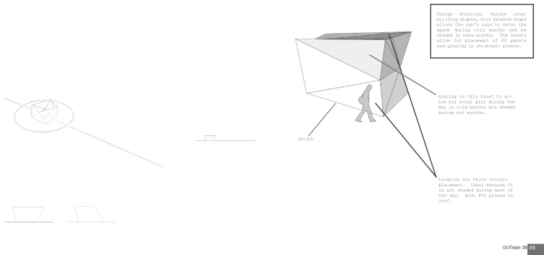

Fig. 6. Images of the Transfer House 2

The (Ex)Change House & EnviroNODE

The last exercise was titled the "(Ex)Change" House. *Exchange* requires that something be given up in receipt of something else—it is a reciprocal act; associations are made, interchanged. It is this house that later came to be known as EnviroNODE As the previous design exercises had produced a taxonomy of forms that were derived from various performance criteria, this exercise posited that, through the use of parametric tools, a unique, mass customized response could be developed to respond to a specific region's environmental forces. Discussions from the previous exercises had begun to question the notion of "modular." Rather than relying on the traditional definition of "modular" as a static, mass-produced, physical component, the designs produced had suggested its digital equivalent; an operative device that when associated with other "digital modules" produced a unique, performance-based, environmentally responsive, "pre-rational" architecture.

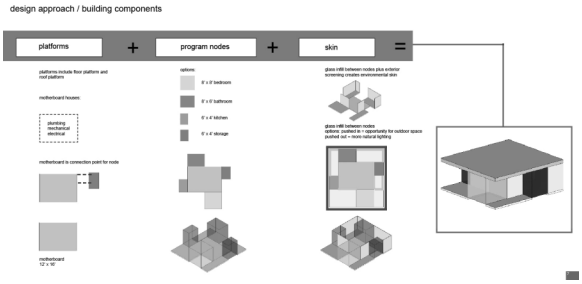

Fig. 7. Components of the (Ex)Change House/EnviroNODE

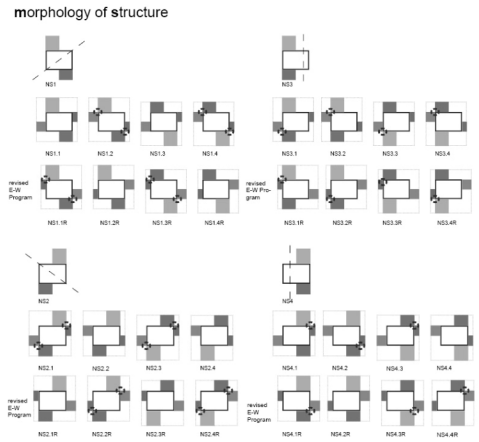

Fig. 8. Parametric Morphology of the (Ex)Change House/EnviroNODE

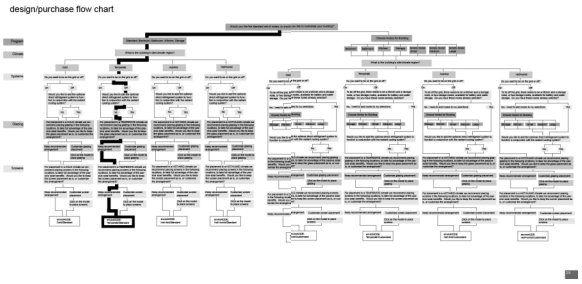

Fig. 9. Mapping of Generative Logic and Parametric Associations.

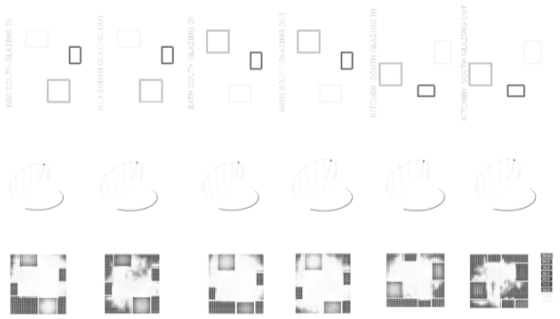

Fig. 10. Images of Performance Analysis in EcoTECT

As the previous exercises had been aimed at understanding the generative formal morphology determined by forces at a specific scales (e.g., environment, program), this assignment required that the design teams "zoom in" to understand how design development could address or supplement a building's performance at the finer scales, including building skins (interior and exterior) and materials. For example, previous design exercises had suggested maximizing façade lengths to maximize or minimize solar gain. In this exercise, design teams considered the specific make-up of the façade (including materials, louvers, transparencies, etc.) to examine its effects on the interior and exterior spaces. Students also considered what the relationships between the various faces of the building were to the environment and to each other. This investigation began to suggest the relational constraints that were present and the possible hierarchical structures of the various geometrical entities. In one such example, various constraints and hierarchical structures suggested that the enclosure be constructed from a homogeneous, continuous, topological "surface" that transforms itself to perform numerous roles (dimensional variation in horizontal/vertical siding allows for opacity, translucency and transparency) rather than enclosure being constructed from various materials, each of which is able to perform their own way.

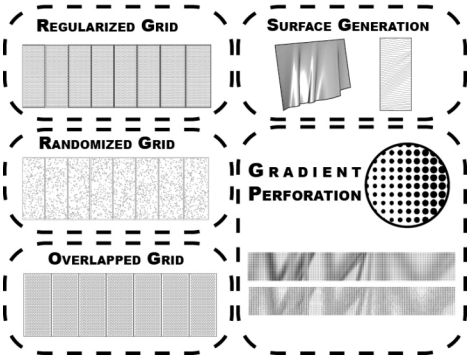

Fig. 11. Envelope Diagrams of EnviroNODE (Gradient Perforated Skin)

In another example, programmatic and spatial relations and constraints suggested the use of "dynamically activated" program entities relative to "statically activated" programmatic entities. Borrowing from Gerrit Rietveld's "Schroeder House," students began to think in terms of movable, "responsive" panels that were hybridic in nature. At any given moment, panels could become enclosing devices, shading devices and/or programmatic devices.

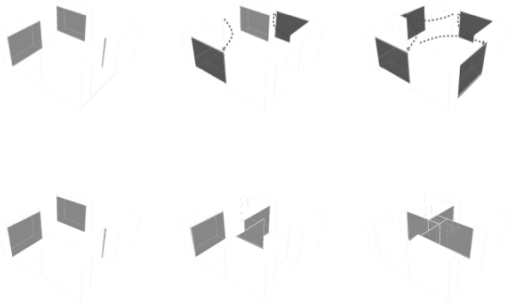

Fig. 12. Diagrams of EnviroNODE Dynamic Panels

Next Steps

At the conclusion of the spring semester studio, a conceptual framework had been developed and was ready for subsequent testing via various software platforms and scripting languages. During the summer of 2008 (the content is yet to be published and/or presented), independent study students worked in two parallel tracks. The first involved the reverse engineering of a prefabricated structure in order to understand possible construction and fabrication techniques and how they may enter into the logical framework and relational constraints. The second group developed the pa-

rametric/informational model with more accuracy and relational data.

We are currently working (Fall 2008 term) collaboratively with a number of consultants including, S/MEP engineers, sustainability experts and fabricators to develop the design and fabrication model/package. During this phase we intend to test the process and create several mock-ups to streamline the transfer of information through the collaborative network.

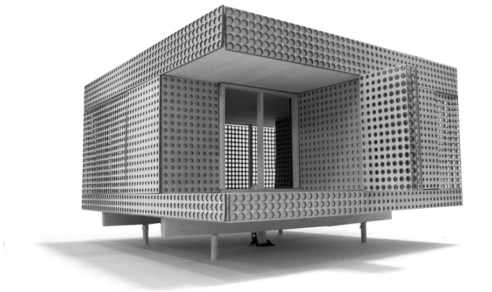

Fig. 13. Model of EnviroNODE

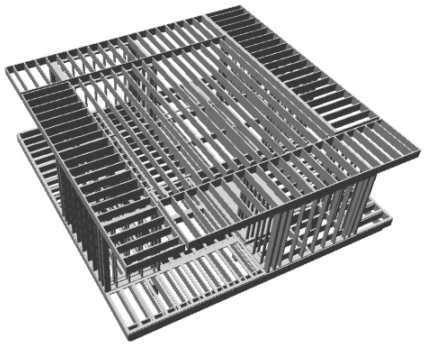

Fig 14 Structural BIM Model of EnviroNODE

Notes

[1] Albert Farwell Bemid and John Burchard, The Evolving House: Vol. III, Rational Design (Cambridge: The Technology Press, 1936).

[2] Kevin Pratt, AIA, Prefabrication and Sustainability, Kieran Timberlake Associates, LLP. www.kierantimberlake.com/research/prefabrication_1.html.

[3] C.Barrios, Thinking Parametric Design: Introducing Parametric Gaudi, Design Studies, Vol 27, No. 3, May 2006

[4] B.Kolarevic, Performative Architecture: Beyond Instrumentality, Routledge; 1 edition (January 21, 2005)

[5] Javier Mondero, Parametric design: A Review and Some Experiences, Automation in Construction 9 (2000, pp. 367-377.

[6] Ibid.

[7] B.Kolarevic, Architecture in the Digital Age, Design and Manufacturing, Spon Press, 2003

[8] Ibid.