THE INSTANT HOUSE

Design and digital fabrication of housing for developing environments.

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Abstract:
Through a novel method, it is possible to provide mass customized, designed housing to emergency and poverty stricken locations. A definitive need exists for a system that is rapidly deployable and scalable while fostering individuality within the larger rebuilt community. This paper describes the relationship of digital fabrication to materials and design rules by example. The paper ends with different iterations of the *Instant house* and an explanation of its construction method and execution.

1. Introduction

We aim to present a novel design and prefabrication process for mass customized emergency, transitional and developing contexts. The process aims to give agency to the end user, utilizing generative computational methods and Computer Numerically Controlled (CNC) fabrication techniques to accommodate for design customization in this previously monotonous genre. The Instant House product ships as an all inclusive flat packed structure, ready for immediate implementation.

Davies (2005) opens his seminal prefabrication publication with a quote: *"When I was younger, it was plain to see, I must make something of myself. Older now, I walk back streets, admiring the houses, of the very poor,"* from William Carlos Williams. Customized housing within these social contexts, is not intended as paradoxical, but acknowledges the personalization and customization already rife in communities from Levittown to Soweto.

The process lends itself to customization, embodying principles of lean production (Pine, 1993a), flexible computer-integrated manufacturing strategies and reduced cycle times; all effecting rapid response times. A direct instantaneous (Pine, 1993b) link can be established between generative design and fabrication and evaluation system. The end user can participate in this decision process, without incurring cost beyond the initial technological infrastructure. A generative system that mechanizes the interaction between user, designer and fabrication, attempts to effectively deploy customized dwellings without incurring a cost premium. It is not intended that the process proliferates cosmetic change (Chin, 2005), but more importantly structural and spatial variation.

Initially the process utilizes the end user exclusively for assembly purposes, but taking a page from Gershenfeld's (2005) Fablab and given sufficient local resources, the Instant House system could ship as an autonomous factory, capitalizing on the availability of local labor, minimizing logistical costs and circumventing political lethargy while symbiotically paring with prevailing development concepts in micro-financing and marketing.

2. Background

The research in this paper explores two issues in design systems: computation and prefabrication. First consideration is new criteria for low cost design systems that allow for design variation as part of the generative process. These processes are evaluated quantitatively on preset performance criteria (Stiny, 1980; Fuhrman, 2006)

Past examples of generative methods using shape grammars (Stiny 1980) have produced house designs as spaces and forms only (Flemming 1986, Koning 1981, Duarte 2005). The *Instant house* combines concepts of prefabricated low cost design systems with those based on shape and a system for Digital Fabrication.

Relevant examples of prefabricated emergency housing include Shigeru Ban's Paper Log House, The Global Village Structure and the Ha-Ori Shelter by Joerg Student. (Antonelli, 2005). Ban developed a paper log house assembly system successfully deployed in Kobe Japan, 1995. The same construction system was adapted to suit earthquake shelters in Kaynasli, Turkey. Ban's shape variation was driven by family size and stock material availability, with no real experimentation in complex and varying geometries. Partially prefabricated, the paper log house requires 8-10 hours of on-site assembly. Most of these options offer variation of floor plan and not shape, allowing limited three-dimensional variation.

Japanese prefabricators have assimilated CNC manufacturing and customized lean production processes into their plants as standard, where human intervention is minimized to providing oversight only. Their core competency is up market single family detached houses for the local market.

3.0 Method

The *Instant house* process produces a customized, habitable mono-material plywood structure, assembled manually with rubber mallets and crowbars. The materials are connected with a limited number of joint types [Figure 1] that sustain their assembly through friction, such that nails, screws or glue are not needed during assembly.

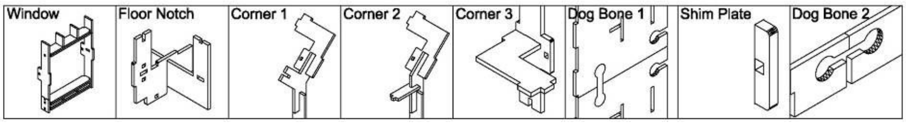

Figure 1: Joint Taxonomy

The process proposes the development of an automated generative system, first for shape design and secondly for fabrication through a generative subdivision based on the Wood Frame Grammar (Sass, 2005). With the design informed by a predefined construction system, it allows the two processes to coexist, setting a framework for customization.

The process is divided into five stages, namely shape design, design development, evaluation, fabrication and construction. The initial prototype testing was performed manually, mapping the process for future automation.

3.1 Shape Design

The shape design commences with the structuring of a morphological box (Grant). Parameters are defined based on regional criteria, with a set number of variations assigned to each parameter. Parameters include climate, location, spatial constraint, vernacular influence and stylistic variation. A unique morphology is generated by combining variation sets. This is done in either a random or preferential manner, with a shape variation developed for each morphology and the results in turn mapped to design taxonomy [Figure 3].The taxonomy serves as the first evaluation platform, allowing for comparative analysis of the entire matrix of generated designs.

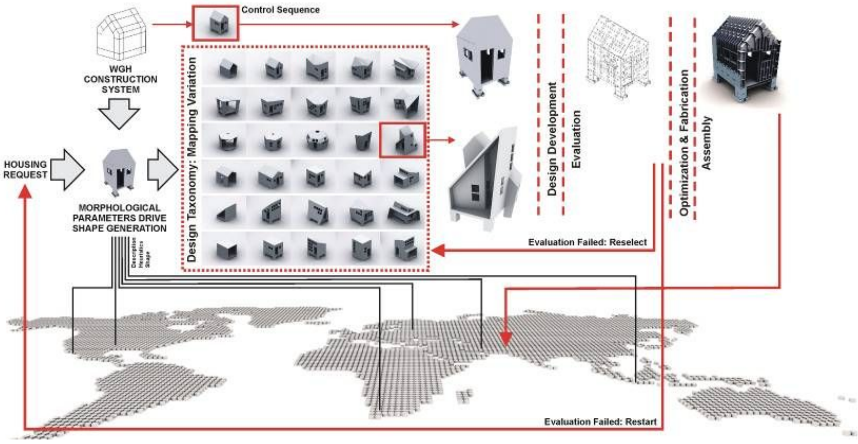

Figure 2: The proposed stages for generative design and fabrication process

The first prototype built, served as a control sample of the process. A new design was selected from the taxonomy and the chosen shape design serves as the first iteration for the design development model. Parameterization of this process allows for custom site and client specific variations, controlled algorithmically to evaluate potential designs.

The process of shape selection borrows from contemporary product development process simplifying the architectural enclosure to one macro object comprising of a discreet combination assemblies constructed from both custom and generic parts, each assembly respecting tolerance, friction and its sequential hierarchy similar to a Building Information Modelling process. In the second design iteration [Figure 3], variations were chosen to produce a single space, four person house, suitable for a hot arid climate. The shape design uses cross ventilation, vertical heat stacks, slanted walls and algorithmically defined window orientation to counter solar heat gain and allow passive cooling.

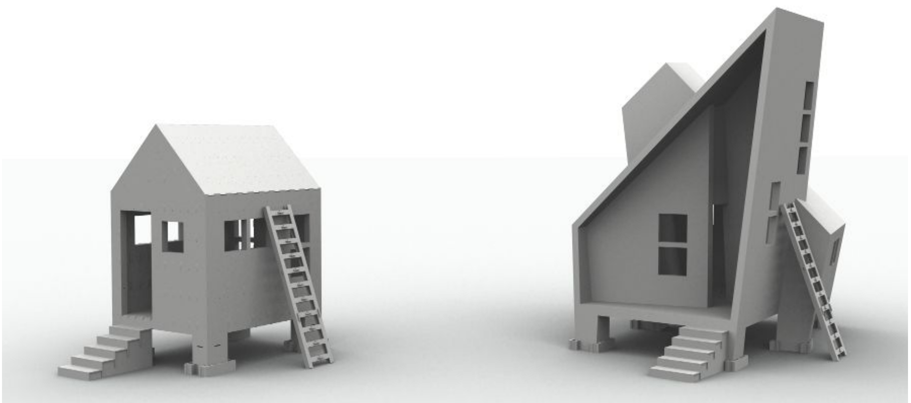

Figure 3: The second prototype iteration, shown on the right alongside the control sample

3.2 Design Development

In order to establish a datum between the design and fabrication processes, we referenced the generative subdivision grammar: The Wood Frame Grammar (Sass, 2005). [Figure 4]

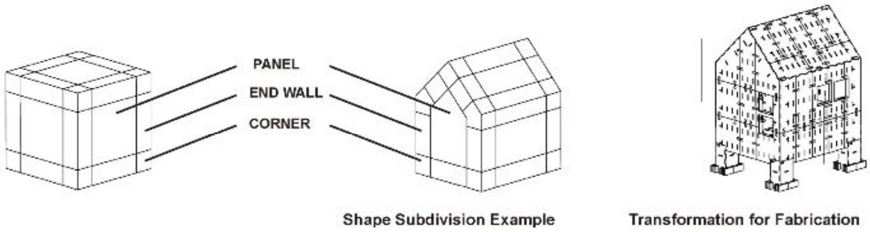

Figure 4: The Wood Frame Grammar (Sass, 2005) and the subdivision CAD model

The system starts with a design shape as a surface model in CAD; secondly rules of construction based on ¾" plywood transform surfaces to 3D solid objects with interlocking components .The grammar utilizes a basic subdivision grammar to define three non traditional timber construction subdivision categories: End walls, Corners and Infill Panels. "Corners" define the absolute coordinates of multiple plane connections, while the "end wall" translates the structural geometry turning from one plane to a second adjacent plane. The "infill panels" serves as interconnecting membranes for the first two geometers. The corner and end wall geometry underpins the novelty of the system as it redefines the nature of corner conditions for timber frame construction.

3.2.1 *Design development model*

This chosen shape model is shelled in accordance with the 0.75" stock plywood thickness. The window volumes are subtracted and the structural orientation established, in turn influencing the placement of the primary structural supports. The shell geometry is used to establish the intersection of structure and wall voids. Girder operations modify the studs over the base support at no more than a 7'-10" spacing and notched joints are created for the overlapping Y and X direction studs. Corner bracing studs are added. The window and door volumes are subtracted from the stud frame, followed by a framing procedure for each opening.

3.2.2 *Part Subdivision*

Surface geometries are utilized to create individual panels, with studs subtracted to form plane locator holes, with 1/16" and 1/32" tolerances respectively. Panels are subdivided to conform to the stock size. The subdivision operation breaks down the stud geometry into roughly 4'-0" sections, adding a generic T-brace at every subdivision point. The T-brace adds rigidity and serves as a spacer. For part labeling, *+W1b3*, translates to external (+) wall (W) number one (1), panel located in column b, row three.

3.2.3 *Surface unfolding operation*

Unfolding is conducted on a layer by layer basis. Uniquely numbered parts are realigned to the world UCS and converted to 2D polyline geometry. Generic parts (shims, dog bones and T-braces) are counted, replicated in 2D prior to nesting operation.

3.3 Evaluation

Evaluation regulates the customization process, establishing the Dynamic System Feedback Loop (Pine, 1993). After the design development process produces parts for fabrication, a laser cut model is produced at 1”=1-0’scale, utilizing the same cutting geometry as used for full scale house [FIGURE 5]. This assists with construction sequence confirmation, testing part interconnects and allowing for subjective design evaluation in real space. The process takes sonly a few hours and reproduces a perfect replica, albeit without friction testing. For this purpose, full scale test joints and design details are fabricated.

Figure 5: *The continuous link between evaluation stages.*

Once accepted, the part geometry is output to the CNC router for fabrication out of ¾” plywood sheets. The process is reset prior to full scale fabrication in the event of “failure.” Scripted stop frame digital animation was used to test the assembly sequence.

3.4 Fabrication

Individual cut sheets were exported from CAD to EZcam for G-Code generation. Tool paths were separated into one *Label* scoring, *Hole* and *Part* cutting operations. Cutting stock is represented at full scale, and preset configurations were used to determine spindle and traversing speeds. The G-Code drives the CNC router operation through its proprietary software, TechnoCNC. We were able to enhance the fabrication quality through a traditional router technique referred to as climb cutting, achieved by rotating the bit in the cutting direction. This reduces the need for part finishing before crating and preserves the cutting quality of the router bit.

The stock, 114 ¾” thick 4’x 8’ sheets of CDX plywood were screwed to a spacer sheet of ½” MDF which in turn lays on the router bed. Parts were cut, removed, finished and packed in reverse assembly sequence into one of four crates, while the waste was recycled.

3.5 Construction

This construction typology circumvents expensive paper based design methods requiring multiple layers of skill in order generate, read and translate and construct, while also eliminating mechanical dependency and increasing on-site efficiency. An 8' x 10' room was assembled by two people over three days [Figure 6]. Components are small enough to be carried by one person, eliminating the need for cranes or scaffolding. A ladder comes complete with the house kit.

Figure 6: *Construction sequence as simulated prior to construction.*

A basic cleared site is all that is needed, allowing for the laying out of concrete blocks and the base footings. Layout space for numbered parts is ideal, but not critical. The girders, studs and floor panels are combined to form a rigid waffle slab. Studs are then constructed in a circular motion, creating a rigid structural mesh through the addition of the T-brace elements, followed by the window framing procedure. The Interior panels are located and locked in place with a structural plate and shim. The stud frame serves as temporary scaffolding while mounting elevated exterior panels. Dog bone connectors ensure the effective transfer of shear force across the entire monocoque timber construction.

4.0 Research results

Digital construction methods differ significantly from traditional analog processes. In the case of the *Instant house* unique parts had one intended position with a predetermined tolerance design built in at the digital design development model. The result is that a complex system of interlocking parts, cross-referencing and self-correcting each other. In the event that the tolerance dynamics vary across the system, a conflict will arise, resulting in unintended creep, specifically noticed vertically on the exterior panels.

The house took two people, three days to assemble. As this was the first prototype, opportunity exists to increase assembly efficiency. Firstly reduce the friction coefficient between parts and adjust the tolerance between subdivided planar geometry to suit the overall of the system criteria.

Where the opportunity for a serendipitous experience falls away (Willis, 2005) through a robust digital construction model, the CNC prefabrication process remains a craft-like experience, allowing for variation and "after-market" customization.

Acknowledgements

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References

Antonelli P.: 2005, Safe: Design Takes On Risk, *Museum of Modern Art*, New York

Chin Ryan C.C.: 2005, How Mass Customization Changes the Design Process: MIT Media Lab's Concept Car Project, *MCP2005*, Hong Kong.

Davies, C.: 2005, The Prefabricated Home, Reaktion Books, UK,

Duarte J. P.: 2005, A discursive grammar for customized mass housing: the case of Siza's houses at Malagueira, Automation in construction, volume14: pp 265-275.

Flemming, U.: 1987, More than the sum of parts: the grammar of Queen Anne houses, Environment and Planning B. Planning and Design, pp 14323-350.

Fuhrmann Oded, Gotsman Craig: On the algorithmic design of architectural configurations, *Environment and Planning B: Planning and Design,* 2006, volume 33, pages 131 - 140

Gershenfeld N., FAB: 2005, The Coming revolution on your desktop – From personal computers to personal fabrication, Basic Books.

Grant, Donald P.: How to construct a Morphological Box, *Design Methods and theories*, Volume 11, number 3, pages 129-158.

Kolarevic B.:2003, Architecture in the Digital Age – Design and Manufacturing, *Spon Press*, New York.

Koning H., Eizenberg J.: The language of the prairie: Frank Lloyd Wright's Prairie houses, *Environment and Planning B: Planning and Design*, Volume 8:pp. 295-323.

Pine B. Joseph (a):1993, Mass Customization: The New Frontier in Business Competition, *Harvard Business School Press*.

Pine B. Joseph (b), Victor Bart, and Boynton Andrew C.: Making Mass Customization Work, *Harvard Business Review*, September/October 1993, pp 108-116.

Sass L.:2005, Wood Frame Grammar: CAD scripting a wood frame house, *CAAD Futures*, Netherlands, pp 383-392.

Stiny, George:1980, Introduction to shape and shape grammars, *Environment and Planning B*, volume 7 pp 343-351.

Willis, D., Woodward, T. Diminishing Difficulty: Mass Customisation and the Digital Production of Architecture, *Harvard Design Review*, Fall 2005/Winter 2006: pp 70-83.