MASS CUSTOMIZING PREFABRICATED MODULAR HOUSING
BY INTERNET-AIDED DESIGN

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Abstract. By collecting and evaluating client’s requirements with web technology, a methodology can be developed that can generate design options based on the client’s needs and available modular components in the market, and simulate the final design before beginning manufacturing. In this proposed model, a process of providing mass-customized prefabricated housing based on computer-aided design and a web-based product configuration system will be presented. How prefabricated housing design can be evolved from a mass repetitive production level to a mass customization level to meet variability and personality is the primary issue to be explored in this research.

1. Introduction

Prefabrication technology groups building components into larger-scale modular units, such as a prefabricated wall panel with window and door openings. Each module is made in the factory using assembly line techniques, and then transported to the building site to be installed on a permanent foundation. This is advantageous because it shifts portions of the construction process from the site to the factory where worker productivity is increased, quality is higher, costs are lower, and the overall need for labor is reduced. The construction of a new site-built home in the U.S. typically consists of 80% field labor and 20% material costs (Larson et al., 2004) – an extraordinarily high labor component compared to other industries. With prefabrication technology, the improvements of quality and efficiency are
accomplished because factories can offer better working conditions, automation of some tasks, fewer scheduling and weather-related problems, and simplified inspection processes.

The Sears Roebuck catalogue made prefabricated homes available to subscribers as early as 1908 (Thornton, 2004), and prefabrication was later explored by such eminent twentieth-century architects as Le Corbusier, Walter Gropius, Frank Lloyd Wright, Jean Prouvé, and Paul Rudolph, who saw the technology as a new solution to the problem of housing in modern society. After World War II, this approach was extensively used in the reconstruction of Europe and for the postwar housing needs of the United States. Once the housing shortage was satisfied, the implied degree of repetition became unacceptable by a society increasingly focused on individual freedom and choice (Duarte, 2001).

If mass production and prefabrication methods of the assembly line were the ideal of architecture in the early twentieth century, then mass customization and the development of digital technology are the recently emerged paradigms of the twenty-first century. The development of the digital revolution has already prompted the shift towards mass customization. In this new industrial model, the computer-aided manufacturing facilitates variations of the same product. Mass production was all about the economy of making things in quantity, but mass customization does not depend on serial repetitions to be cost effective. It is about cultural production as opposed to the industrial output of mass production (Kieran and Timberlake, 2004). Within limited design parameters, customers can determine what options they wish by participating in the flow of the design process from the beginning. This concept has already been implemented in the computer (Dell), clothing (Lands’ End), and shoe (Nike) industries, but it has not been fully adopted in housing industry. The fundamental premise of mass customization is to no longer manufacture products "blindly" according to a predicted demand, but instead allow production to be directly driven by actual orders (Schodek, 2004).

Today's information technology has become even more interactive and powerful than the last century. Integrating a participatory home design concept with web technology to create an online interface can become the design platform by which the clients can make more choices and establish a better communication with architects and/or manufacturers. Face-to-face meeting time between architect and client is always limited and time consuming, while a computational web-based design approach is infinitely patient and always available (Larson, 2001). One of the problems that prefab housing industries failed to address in the twentieth century was the lack of variability and an individual identified design (Kieran and Timberlake, 2004).
2. Prefabricated Housing

2.1. WHAT IS PREFABRICATED HOUSING?

Prefabricated housing is a general term that indicates modular building components are pre-made in the factory, and then transported to the building site to be assembled and installed on a permanent foundation. It may include manufactured housing (following HUD code), modular housing (following local zoning and building codes) and production housing (site-built housing produced in a systematic manner). Each name change reveals a different categorization system created by the authorities. Table 1 includes the definition and example of each term.

<table>
<thead>
<tr>
<th>TERM</th>
<th>DEFINITION</th>
<th>EXAMPLE</th>
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<tbody>
<tr>
<td>Prefabrication</td>
<td>Any manufacturing process that takes place in a controlled environment, usually a factory.</td>
<td>General term</td>
</tr>
<tr>
<td>Mobile Home</td>
<td>Housing made in a factory and transported to a building site that either a permanent or temporary location and hooked up to existing utilities.</td>
<td>Double Wides, Trailer Home</td>
</tr>
<tr>
<td>Manufactured Housing</td>
<td>The factory-made home must be permanently affixed to a foundation with the characteristics of site-built housing and meet all HUD codes.</td>
<td>Many examples</td>
</tr>
<tr>
<td>Modular Housing</td>
<td>The factory-made home must be permanently affixed to a foundation and meet local zoning and building codes.</td>
<td>Habitat ’87 by Moshe Safdie, 1987</td>
</tr>
<tr>
<td>Panelized House</td>
<td>Panelized factory-built walls are inserted into a modified post and beam structure by a builder on-site. It could be sold as a do-it-yourself house kit.</td>
<td>Prefabricated House by Water Getz, 1941</td>
</tr>
<tr>
<td>Precut House</td>
<td>House made by precut timber with interlocking wedge-shaped joint.</td>
<td>Log House</td>
</tr>
<tr>
<td>Emergency House</td>
<td>Immediate relief in emergencies triggered by natural disaster or war.</td>
<td>Paper Log House by Skaja, 1990</td>
</tr>
<tr>
<td>Container Home</td>
<td>Modified shipping container as a modular transportable living spaces.</td>
<td>MUD by Latek, 2003</td>
</tr>
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</table>

2.2. TYPES OF PREFABRICATED HOUSING SYSTEM

Representing scale of the basic modular element, there are four different types of prefabricated housing systems: fully modular, sectional, component, and hybrid. In Table 2, it describes the basic modular type, feature, and example for each system. This analysis will help us to understand the strength and potential of each system, and provide opportunities for customization and spatial adaptability.
TABLE 2. System Types by Basic Modular Element

<table>
<thead>
<tr>
<th>Basic Module</th>
<th>Features</th>
<th>Examples</th>
</tr>
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<tbody>
<tr>
<td>Fully Modular</td>
<td>• As 3D modules (like boxes)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Simple connections to the foundation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Size of the modular unit is restricted by highway or shipping constraints</td>
<td></td>
</tr>
<tr>
<td>Sectional</td>
<td>• Sectional modules for transport easily</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• It has some potential for digital fabrication</td>
<td></td>
</tr>
<tr>
<td>Component</td>
<td>• Factory-made components to save on-site labor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Allows flexible building shapes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Includes Panelized, Precut, Kit-of-parts system</td>
<td></td>
</tr>
<tr>
<td>Hybrid</td>
<td>• prefabricated posts and beams to form a framing system (like chassis)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Interchangeable infill wall panels and floor components</td>
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</table>

3. Conceptual Framework of Internet-Aided Prefab (i_Prefab) System

In order to achieve the goal of mass customizing prefabricated modular housing, the conceptual design model must combine the results of two important parts: data collection of client’s requirement and prefab system design combinations. The web-based prototype can simulate the interaction between clients and the adoptable systems. The evaluation part can include a series of case studies to demonstrate and revise the data-input method within the design interface. Finally, the resultant design can generate building specifications prepared for manufacturing (Figure 1).
3.1. OBJECTIVES

The main goal of this research is to investigate the possibilities of customizing mass housing by web and prefabrication technology. This framework aims to:

A. To research how to collect and interpret client’s need to become design options to address the issues of individual needs from the end-users.
B. To explore possible combinations of prefab modular housing according to client’s preference.
C. To construct an intelligent database to host standardized components from existing market, possible prefab housing configurations, and fabrication methods by today’s technology.

3.2. DESIGN INTERFACE OF PROPOSED MODEL

The design interface will consist of 6 elements:

1. Information Bar: includes about, help, contact, and login functions.
2. Visualization Window: shows 2D/3D images in every important step.
3. View Options: provides different view angles to understand the design.
5. Client’s Input: questionnaire by text description and image selection.
6. Output Service: shows the options to deliver the end result.

It can be used by:

1. The client alone with instant assist from online help center
2. An architect with the client
3. A salesperson with the client

3.3. SIGNIFICANT OF THE RESEARCH

1. Identified issues of client determination via digital configurator may improve the project delivery process in housing industry.
2. Identify the issues that prefab system should address to be more client-responsive.

3.4. CONCLUSION

Today, we are immersed in the digital age that created opportunities never before available to connect information, people, products, and tools in a comprehensive manner. Many industries adopted mass customization concept as their business goal and utilized the web as a communication interface to satisfy their individual client’s need. Although architecture has not reached this point due to its complexity and industry-specific fragmentation, this is a new concept for architects to consider. Especially in the case of housing, how to create a unique space that reflects end-user’s lifestyle out of many ready-made components will be the issue of our generation. Moreover, this approach encourages architects to develop a series of solutions rather than single solution for a design problem.

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References