INTEGRATING MASS CUSTOMIZATION WITH PREFABRICATED HOUSING

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Abstract. The paper will give an overview of mass customization concepts and how they can be applied to prefabricated modular housing. 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 prefab housing based on computer-aided design and a web-based product configuration system will be presented.

1. Introduction

The design of industrialized housing has been a pre-occupation in architecture since the start of the industrial revolution in the nineteenth century. In the first half of the twentieth century, architects attempted to solve the housing shortage by introducing a production process based on the assembly line. The assembly line was initially developed for the automobile industry by Henry Ford, but soon became a paradigm for the housing industry (Duarte, 2001). For example, the Dymaxion House designed by Buckminster Fuller was trying to achieve the mass production goal by retooling the aircraft factory.

Prefabrication technology groups building components into larger-scale modular units, such as a prefab 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.

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.

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 computer 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. Presently, only five percent of the population in the U.S. can actually hire an architect and pay them to design and build a home in which is tailored to their preference (2003 AIA Firm Survey). Although home builders who also provide a certain degrees of choice, most of them are focused on interior layout and finishes within standard and popular residential styles.

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). How prefab housing design can be evolved from mass repetitive production level to mass customization level to meet flexibility and variability is the primary issue to be explored in this research.

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 1. Definition of Terminologies in Prefabricated Housing.

TERM	DEFINITION	EXAMPLE
Prefabrication	Any manufacturing process that takes place in a controlled environment, usually a factory.	General term
Mobile Home	Housing made in a factory and transported to a building site that either a permanent or temporary location and hooked up to existing utilities.	Double Wides; Trailer Home
Manufactured Housing	The factory-made home must be permanently affixed to a foundation with the characteristics of site-built housing and meet all HUD code.	Many examples
Modular Housing	The factory-made home must be permanently affixed to a foundation and meet local zoning and building codes.	Habitat '67 by Moshe Safdie, 1967
Panelized House	Panelized factory-built walls are inserted into a modified post-and-beam structure by a builder on-site. It could be sold as do-it-yourself house kits.	Packaged House by Walter Gropius, 1941
Precut House	House made by precut timber with interlocking wedge-shaped joint.	Log House
Emergency House	Immediate relief in emergencies triggered by natural disaster or war.	Paper Log House by Shigeru Ban, 1995
Container Home	Modified shipping container as a modular/ transportable living spaces.	MUD by Lot-ek, 2003

2.2. HISTORICAL OVERVIEW OF PREFABRICATED HOUSING

The history of prefab housing began nearly four hundred years ago, when a panelized wood house was shipped from England to Cape Ann, Massachusetts in 1624 to provide housing for a fishing fleet (Arieff, 2002). Swedes introduced a notched building-corner technique for the construction of log cabins just a little over a decade later. By the nineteenth century, portable structures had grown in number as new settlements and colonies were formed to support a demand for immediate housing solutions. The kit houses shipped by rail during California Gold Rush in 1849 are one example (Arieff, 2002). During the early part of the twentieth century, many architects and inventors were experimenting with these systems for housing. 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. Many aircraft companies turned to producing industrialized housing and component parts. 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).

2.3. TYPES OF PREFABRICATED HOUSING SYSTEM

Representing scale of individual components, there are six different types of prefabricated housing systems: fully modular, sectional, panelized, precut, components/ kit of parts, and chassis and infill.

2.3.1. Fully Modular

All the components of a single housing unit are entirely made, assembled and finished at the plant; as three-dimensional modules (like boxes) requiring only simple connections to the foundations and main service conduits once at the site. The size of the modular unit is restricted by highway law or shipping constraints. There are some examples, Habitat '67 in Montreal, Canada by Moshe Safdie and Nakagin Capsule Tower in Tokyo, Japan by Kisho Kurokawa in Figure 1 (Arieff, 2002).

Figure 1. Nakagin Capsule Tower, Tokyo, Japan, 1972.

2.3.2. Sectional

Small and easy to transport sectional modules but incomplete, as they need a complementary component or process once they reach the site. There are not many examples can be found from historical review, but it has some potentials for digital fabrication and mass customization. ESG Pavilion

(Figure 2) by graduate students in ETH is an example of creating sectional modules.

Figure 2. ESG Pavilion, Zurich, Switzerland, 2005.

2.3.3. Panelized

A panelized home is a site-built house where some of the components are assembled or prefabricated in a controlled factory environment thereby saving on-site framing labor. In most cases, the panelized components, such as the Tilt-Up Slab House (Figure 3), are load-bearing walls to replace post and beam framing system.

Figure 3. Tilt-Up Slab House, Venice, CA, 2001.

2.3.4. Precut

Precut wood framing systems have been developed in Japan over 14 years ago. MF Technologies, Minnesota based company, applied this system with precut, engineered lumber and connectors (Figure 4), which allow a group of four to eight untrained workers to assemble a precise frame in several days time. The components of the house are actually numbered, and are constructed as you would a piece of kit furniture. Materials cost 10-20% more than those for conventional framing, but the cost is offset by reduced labor expense.

Figure 4. MasterFit Precut Wood Framing System.

2.3.5. Components/ Kit of Parts

A kit-of-parts is a collection of discrete building components that are pre-engineered and designed to be assembled in a variety of ways. Components are sized for convenient handing or according to shipping constraints. LV Home (Figure 5) is a good example of affordable modernist house by kit-of-parts system.

Figure 5. LV Home Kit, Perryville, MO, 2003.

2.3.6. Chassis and Infill

This is a hybrid system that includes prefabricated posts and beams to form a framing system as the fundamental structure, and using the automobile industry's term – chassis. This is made possible by dividing the house into two notional elements: the chassis, the standardized, mass produced part of the system, provides the structure and services for the building, and the infill, which consists of interchangeable wall and floor components, provides for customization and adaptability. This system was proposed by MIT *House_n* Research Team (Figure 6).

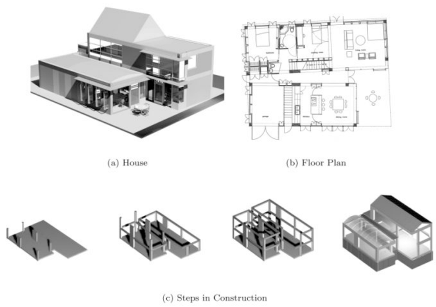

Figure 6. Chassis + Infill System House, 2003.

3. New Trend toward Mass Customization

3.1. CONCEPT OF MASS CUSTOMIZATION

At the beginning of the twentieth century, industrialized economies were focused on mass production, mass distribution, mass marketing and mass media. Presently, a combination of advances in information and digital technology is making it increasingly possible to rapidly respond to consumers with customized products at mass-production prices. 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).

The term “mass customization” was coined by Stan Davis in his book *Future Perfect* but the term was popularized by Joseph Pine in his book *Mass Customization: The New Frontier in Business Competition* in 1993 (Schodek, 2004). Mass customization has different implications for different products and in different sectors. There are also different methods and strategies to achieve it (Crayton, 2001). Some products can be tailored or customized directly by the consumer; other products may only have limited degree of customization at the retail outlet or dealer.

One of the most important distinctions running through all the different senses of mass customization is somehow the consumer may involved the design through production process. The choice is configured to what extent the process is “transparent” or “collaborative” and forms part of a dialogue between the producer and the customer.

The key to cost effective customization is modularization and configuration (Crayton, 2001). One of the key ideas and strategies to achieve mass customization is modularization. Products are “decomposed” into modular components or subsystems that can be recombined to more nearly satisfy customer's needs. The modularization approach is very close to the spirit of prefabricated housing, and this model can be viewed as a revitalization of mass production housing. The configuration systems present the choices to consumers and determine what goes with what. Using web technology, the configuration systems can be represented as a design interface to convert customer's input to final product's configuration, and the on-demand production can combine standard modules together by the assembly line (Figure 7).

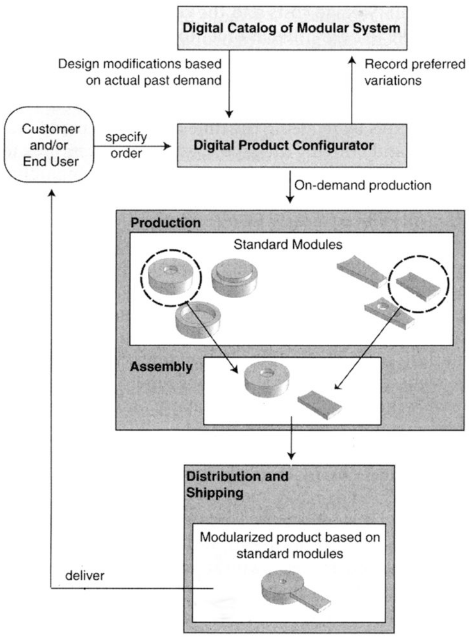

Figure 7. Schematic process diagram of mass customization.

3.2. CURRENT APPLICATIONS

Compared to approaches of mass customization in product or furniture design, like Nike-iD series products, there are more challenges to apply this model to architecture. From design to construction, a new building is a complex process involving a number of independent parties. There is usually no one party that is expert in all areas, and the industry-specific fragmentation is a major obstacle to mass customization. Before reaching mass customization in architecture, it is might be easier to apply this model to architectural products. Currently, there are only a few companies that have successfully adopted mass customization concept. E-skylight.com supported by Architectural Skylight Company (ASC) (Figure 8) is a good example as a case study.

ASC uses object-oriented design approach to the design and manufacturing custom skylights. This system supplements AutoCAD with several plug-ins, including third-party software and programs developed by ASC. The website interface provides step by step customizing process to generate a final design model, and the virtual model is used directly for computer numerical control (CNC) manufacturing of frame members and for the CNC cutting of custom glass sheets.

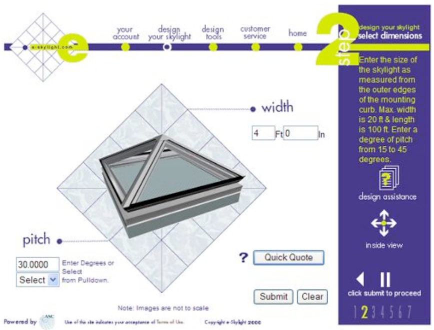

Figure 8. Design Interface of e-skylight.com.

4. 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 9).

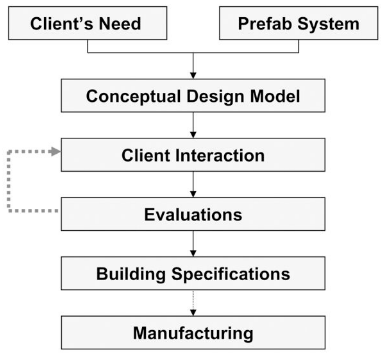

Figure 9. Conceptual Framework of i_Prefab.

4.1. 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.

4.2. 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.

4.3. EXISTING MODELS AND PROPOSED MODEL

Only five percent of people in the United States can actually hire an architect and pay them to design and build a home in which is tailored to their preference. Besides the architect's fee, clients also need to wait a tremendous time for design and construction. Factory-made prefabricated housing system tried to solve this problem previously. However, most industries failed to address the issues of variability and individual needs. Plants closed due to they produced more than the market needed, and traditional prefabricated housing provided less value to compete with stick-built housing market (Figure 10).

The advanced digital technology makes it possible to communicate design ideas and concepts to others more effectively. Demand-to-order is not a dream for prefabricated housing industry anymore. As long as we have some interchangeable standardized components in the market, mass customized prefab housing does not depend on serial repetitions to be cost effective.

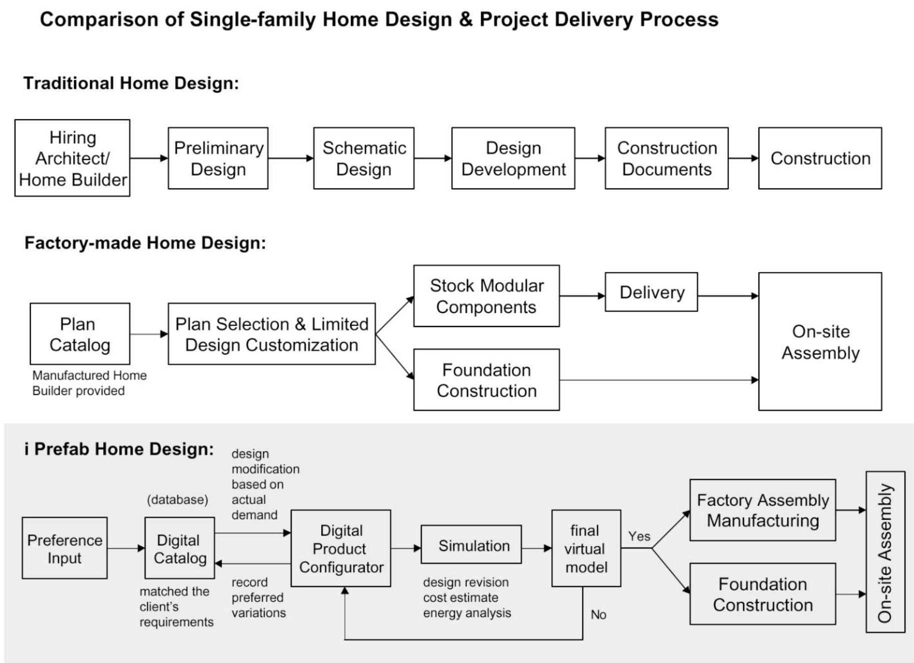

Figure 10. Existing Models and Proposed Model.

4.4. RESEARCH ISSUES

The proposed model will generate other related research issues:

1. How will choices be explained to non-architecture trained clients?
2. How will mass customization affect the housing design process?
3. How will other people (consultants or inspectors) be involved in this design process?
4. What kind of format should be developed as the result of this design process?
5. What will be the architect's role in this new system?

4.5. 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 solutions for a design problem. For the technical challenge in standardizing the various building systems, it will be easier to implement in the government controlled countries, like China, or setup a new standard system for universal and interchangeable parts in developing countries.

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