i_Prefab Home

Customizing Prefabricated Houses by Internet-Aided Design

Joseph Chuen-huei Huang, Robert Krawczyk
Illinois Institute of Technology, College of Architecture, USA
http://www.iprefab.com, http://www.iit.edu/~krawczyk

The paper demonstrates a web-based system for use in the area of prefabricated housing to assist the customer and architect in selecting appropriate building components. 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.

Keywords: *Web-based design; clients input; mass customization; prefabrication.*

Introduction

Prefabrication technology combines 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, like automobile and aircraft 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 customizability 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 individually identified design (Kieran and Timberlake, 2004).

Background

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).

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 1, 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.

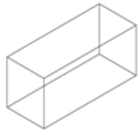
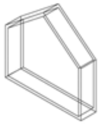
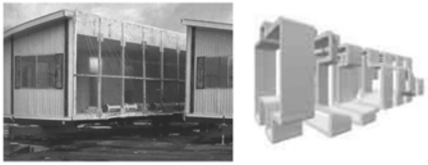
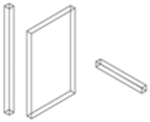
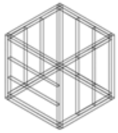
Basic Module	Features	Examples
 Fully Modular	• As 3D modules (like boxes) • Simple connections to the foundation • Size of the modular unit is restricted by highway or shipping constraints	
 Sectional	• Sectional modules for transport easily • It has some potentials for digital fabrication	
 Component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

Table 1
System types by basic modular element.

Methodology

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). Warszawski addressed five tasks for

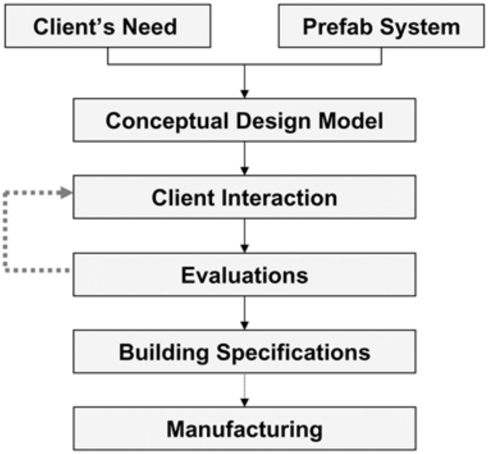


Figure 1
Conceptual framework of i_Prefab Home system.

computer-aided design and planning in prefabrication plant: (1) Input of architectural design, (2) Pre-estimating, (3) Outline of the elements, (4) Detailed design, and (5) Production planning (Warszawski, 1999). This research will be more focused on input methods of the end-users instead of architects for finding suitable design solutions of prefabricated housing.

Objectives

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

1. 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.
2. To explore the possible combinations of prefab modular housing according to client's preference.
3. To construct an intelligent database to host standardized components from existing market, possible prefab housing configurations, and fabrication methods by today's technology.

Significance of the research

The significance of this research is that no prior developments have been made that suggest utilizing dynamic questionnaires by web interface to customize modular housing design and select appropriate building components for manufacturing. It tries to identify the client's needs and housing requirements to match the existing prefabricated housing systems plus design modification. The web-based design tool allows clients to see the result of design feedbacks quickly and accessible everywhere.

Besides that, the research tries to explore the possibilities of a new prefabricated modular design system to address client-responsive issues. This ap-

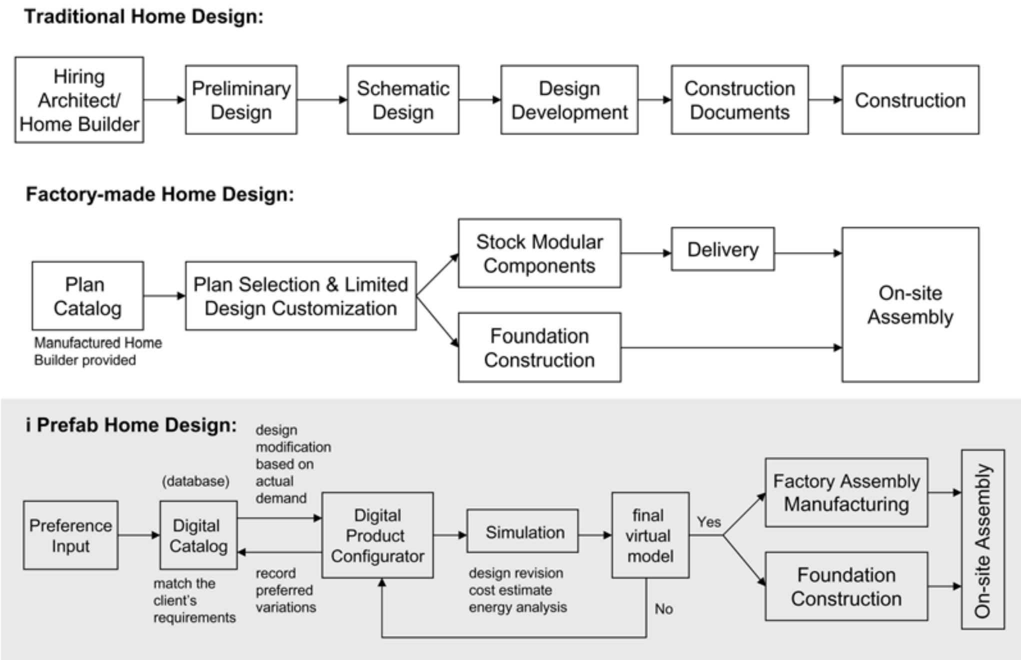


Figure 2
Existing models and proposed model.

Modular Types	Product & Vendor's Name	Image	Location	Basic Modules	Existing Models
Fully Modular	**weeHouse** (Alchemy Architects)		St. Paul, MN, USA	14' module	10
Sectional	**kitHAUS** (Sandonato & Wehmann)		Los Angeles, CA, USA	16' module	2
Component	**FlatPak** (Lazor Office)		Minneapolis, MN, USA	8' module	4

Table 2
Selected prefabricated housing design products from existing market.

proach will suggest a new way to integrate the involvement of end-users into housing delivery process with today's technology.

Existing models and proposed model

Presently, only five percent of people in the United States typically hire an architect and pay them to design and build a home which is tailored to their preference[1]. Besides the architect's fee, clients also need to wait an interminable 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 because they produced more than the market needed, and traditional prefabricated housing provided less value to compete with stick-built housing market.

The advanced digital technology makes it possible to communicate design ideas and concepts to others more effectively. The project delivery process leads itself to customization, embodying principles of lean production (Pine, 1993), flexible computer-integrated design interaction with clients, and reduced cycle times; all effecting rapid response between consumers and producers (Figure 2). Demand-to-order is not a dream for prefabricated housing industry anymore. As long as people have open minds to accept this new concept, prefabricated housing will swift from the stereotype of "factory-like" repetitive industrialized products to flexible and customizable humanized products.

1 http://www.aia.org/press_facts: April 2006

Case Studies

In order to create a reasonable consumer-driven design interface for prefabricated housing, a full understanding of the modular systems is the first step. In the background review, four different types of prefabricated housing systems have been introduced as fully modular, sectional, component, and hybrid. Since the hybrid system is a combination of the other three basic modular systems, it has been eliminated in this case study.

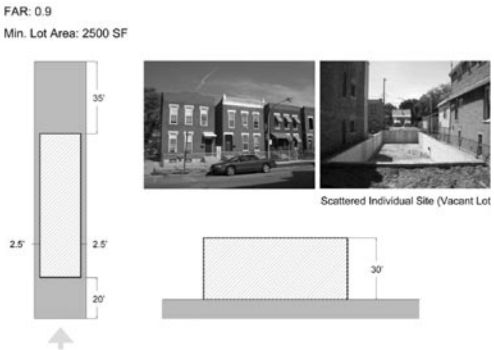


Figure 3
Design criteria of Chicago Standard Lot in Residential Standard 3 (RS-3) zoning district.

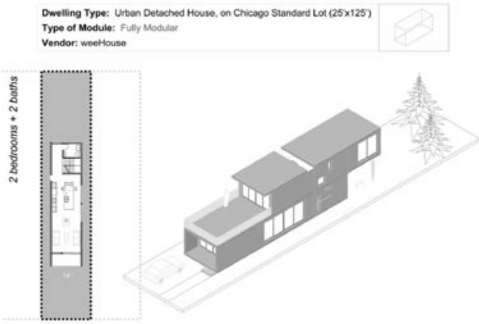


Figure 4
Fully modular system for Chicago Standard Lot, after modification of the original model.

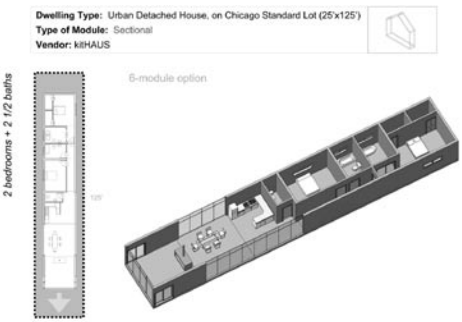


Figure 5
Sectional system for Chicago Standard Lot, after modification of the original model.

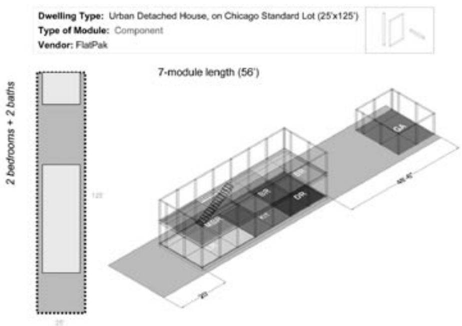


Figure 6
Component system for Chicago Standard Lot, after modification of the original model.

Select prefab systems from existing vendors

The reason to select prefabricated housing systems from the existing vendors (Table 2) is to understand the available systems in the market. Since there are many decent design products already proposed by architects/ fabricators, we can save time for inventing a new building system and focus on the issues of consumer-driven interface and customizing process. Furthermore, these selected prefabricated design products have been pre-engineered in the factory and followed the building codes as realistic elements. The selected products can also be used as examples in the interface prototyping of this research.

Urban vacant lots in Chicago

In order to establish some design criteria, this case study adopted a valid site for implementing the three different prefabricated modular systems. By following the restriction of the local zoning code, the case study not only analyzed the systems to be directly applied the design models, but also modified the design models to meet the local context. Figure 3 shows the floor-area ratio, minimum lot area, setbacks, and maximum height requirements based on Chicago Standard Lot (25'x125') in Residential Standard 3 (RS-3) zoning district.

System application and variations

There are three methods for testing these three selected prefabricated modular systems from the existing vendors: (1) Directly apply from the vendor; (2) Different configurations; (3) After modification. Most of design models provided from the existing vendors can not be fitted in the urban lot condition. The reason is they are over-sized and the orientation

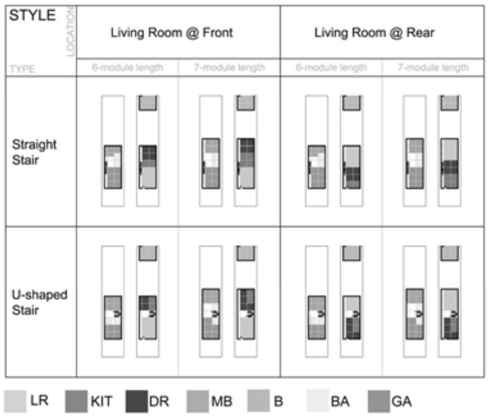


Figure 7
Matrix analysis of spatial layouts based on FlatPak House.

Figure 8
i_Prefab Home design interface.

of the design models is designed for a wide lot in suburban area. Here are some examples (Figure 4, 5, 6) of modified design models for fitting in Chicago Standard Lot.

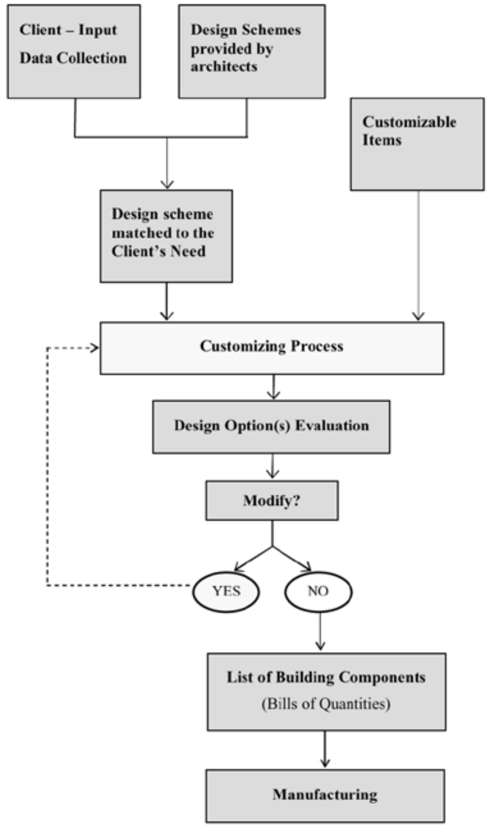


Figure 9
Conceptual model of i_Prefab Home design system.

Findings

There are some findings from this case study for providing a better understanding of prefabricated housing design. From the testing of different configurations, the results tell us the bigger the basic module, the less flexibility of design options can be created. If the space units totally follow the module as a layout guideline, some odd situations will be presented like an inappropriate size or a bizarre shape for each individual space. Matrix analysis of spatial layouts presents a series of design options that can be generated from each system (Figure 7). These findings help architects to design a more flexible prefabricated system. Different categories of the matrix analysis also provide the information for the interface data structure in the next chapter.

Prototyping

Design interface of proposed model

The proposed design interface for customizing prefabricated housing shows in Figure 8.

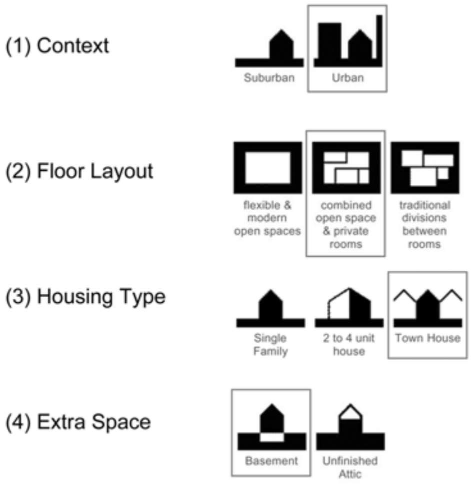
The design interface will consist of 6 elements:

1. Information Bar: includes help, about, 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.
4. Design Process: indicates the sequence and status of current step.
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.

Figure 10
Questionnaire of multiple choices with text description.



How the system functions

As shown in Figure 9, the process begins by preparing the methods of collecting client's requirement. The *i-Prefab Home* design system should be to accomplish the following tasks:

1. Preset a questionnaire for clients to input their requirements.
2. Select prefab modular systems from existing vendors in the specific area.
3. Convert client's data to match the prefab modular systems, and show the step-by-step results simultaneously.
4. Analyze the selected prefab modular systems for creating the potential customizable items.
5. Generate design options for reviewing after finished the customizing process.
6. Evaluate the feasibility of selected design options.
7. Record preferred variations and client's input data into database as templates for modification.
8. Generate building specifications for costing and manufacturing.

Client's input by digital questionnaire

This digital format dynamic questionnaire will replace the traditional paper questionnaire in the design interface. Clients can input their requirements and desires by answering some questions with the form of (1) Multiple choices with text description (Figure 9), (2) Graphic icon selection (Figure 10), and (3) Visual favorable impression (Figure 11). The visualization window will output the results simultaneously and step by step for simulating the design for evaluation purpose. At the end, the required building elements and budget will be prepared for revising or sending to prefabrication plant and ready for manufacturing (Figure 12).

Conclusion

Today, we are immersed in the digital age that has created opportunities never before available to connect information, people, products, and tools in a

1	How does your family dine most often?	[A] Formally, in the dining room [B] Informally, in the kitchen, breakfast room or family room
2	Where do you entertain?	[A] In the living room and dining room [B] In the kitchen and/or family room [C] In the backyard
3	Where do you work?	[A] Always at the office [B] Sometimes at home [C] Always at home

Figure 11
Questionnaire of graphic icon selection.

Figure 12
Questionnaire of visual favorable impression.

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 today's generation. How the prefabricated system can be more flexible and client responsive to meet the varied requirements from different users is another issue generated from this research. Moreover, this approach encourages architects to develop a series of solutions rather than single solutions for a design problem.

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