WEB BASED BIM FOR MODULAR HOUSE DEVELOPMENT

Query Approach in Consumer Participatory Design

CHUEN-HUEI (JOSEPH) HUANG AND ROBERT J. KRAWCZYK
Illinois Institute of Technology, College of Architecture, USA
huanchu1@iit.edu, krawczyk@iit.edu

Abstract. The paper describes the relationship of client's requirements and available design options of the proposed system by examples of its current prototype. By integrating the nature of modularity in prefabricated housing design, a proposed web-based design system will provide information filtering questionnaires to assist customers in selecting appropriate design components. A methodology has been developed that can generate design options based on the client's needs and available modular components from selected product suppliers making it possible to simulate the final design before processing orders for assembling and manufacturing. Overall, the research demonstrates the power of internet that acts as a feedback loop to receive the information from clients, streamline the communication in between design teams, and integrate all products and materials together.

1. Introduction

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, computer-aided manufacturing facilitates variations of the same product. The Internet has increased the opportunities to apply the concept of mass customization to customer interaction by tailoring the content to individual needs. 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, clothing, and automobile industries, but it has not been fully integrated in architecture, especially the housing industry which is more directly related to personal life style. The industry lacks a process that will lead to the customization of homes that respond to the unique values and needs of the occupants.

Although not a new trend, prefabricated building is becoming an increasingly viable housing option in the early years of twenty-first century. Typical delays from shipping to inclement weather are averted by providing the builder a more efficient means to create a precision house. One of the problems that prefabricated housing industries failed to address in the twentieth century was the lack of variability and an individual identified design (Kieran & Timberlake, 2004). In order to transform the prefabricated housing design from mass repetitive production level to mass customization level to meet flexibility and variability, the research methodology integrates a participatory home design concept with web technology to create an online interface that 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 with network connections (Larson, Tapia, & Duarte, 2001).

2. Background

2.1. CURRENT APPROACH OF CONSUMER PARTICIPATORY DESIGN

Sears mail-order kit houses, from 1908 to 1940, can be viewed as the first customer-tailored mass product in the housing industry (Thornton, 2004). Sears provided a house plan catalog with the added advantage of modifying houses and hardware according to buyer tastes, and shipped the appropriate precut and fitted materials to the customer's site. With today's technology, the internet is the perfect medium for the dissemination of domestic design. Many pattern book companies now have big websites offering thousands of house plans stored on databases searchable by type, style, square footage, average cost, number of bedrooms and so on (Davies, 2005). Some websites also provide the design tool for customizing exterior and interior finishes after the clients have selected the base model from a house plan catalog.

2.2. PROBLEM STATEMENT

Although the engagement of internet with pattern book concept can create a power of e-commerce for the housing industry, the end result of web surfing may or may not fit the client's spatial needs. Unlike the other industries (shoes or watch), a suitable house design is not only judged by its appearance or architectural style, but also involves a series of architectural programming phases. Figure 1 demonstrates that by reversing the sequence of choosing a product image to get spatial features and functional details, a knowledge-based questionnaire can be a new format to collect client's input (Huang, 2007). The main goal of this research is to investigate the possibilities of customizing mass housing by internet and prefabrication technology beyond the finish material selecting process.

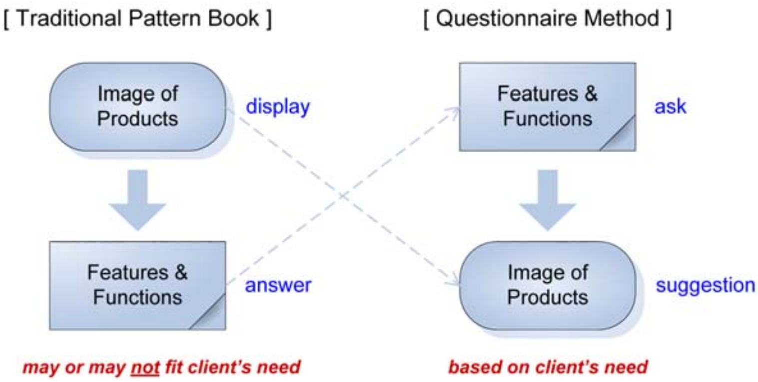

Figure 1. Difference methods of consumer-product interaction.

3. Methodology

3.1. CONCEPTUAL FRAMEWORK

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, i_Prefab, 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 2). This research will be more focused on input methods of the end-users instead of architects for finding suitable design solutions of prefabricated housing (Huang, 2006).

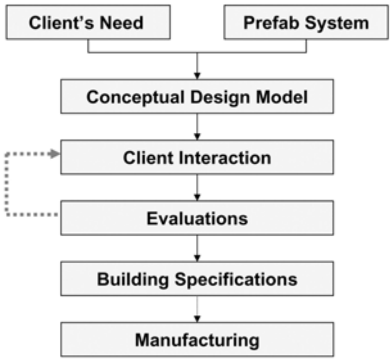

Figure 2. Conceptual framework of i_Prefab home system.

3.2. DIGITAL QUESTIONNAIRE

The proposed digital questionnaire model links a series of pre-established answers that define the architectural implementation from its database, and the users will receive real-time feedback to evaluate room layout and home design solutions from the digital interface. From general spatial need to detail preference, there are four different levels of questionnaire to be developed as the programming of this prototype system: (1) Generate a list of required spaces, (2) Determine each room size and relationship of plan by function, (3) Define the detail layout of individual spaces and the development of the plans and elevations, and (4) Customize material and color selections for exterior and interior components, Figure 3.

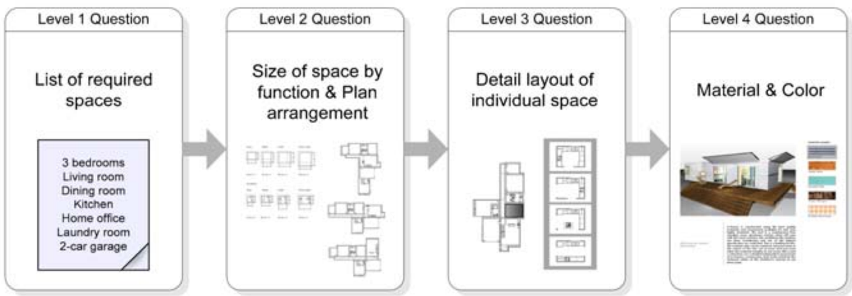

Figure 3. Four different levels of digital questionnaire.

4. Prototype and Usage Scenarios of Consumer Interface

In order to show how this proposed model works, a prototype simulation is developed to provide the modular housing design consulting and customization for the consumer as a simplified web-based application in the early phase of housing delivery process. The text information on the right window of the interface includes questionnaire, explanation and multiple choices for client to input. The graphic information on the left window is the visualization output from the advisory system. The information window on the upper-right corner indicates the status of design process.

4.1. DESIGN PROCESS I: LIST OF REQUIRED SPACES

There are three tasks in the information gathering step: A. Household Profile, B. Life style, and C. Activities at Home. The first question tries to define the household profile in the new home. The household profile here indicates the major occupants for the new house and does not relate with family profile. The content of the question will be based upon the answer of the preceding question. In some cases, this question tries to determine the future needs of the room requirements. For instance, a young couple planning to have children will affect the number of bedrooms in the list of required spaces.

Once the system gathers enough information from the user's household profile, a basic list of required spaces will be generated as a reference. The following questions will ask the life style of living members in order to create the additional list of extra needed space (Figure 5, left). By the end of this programming phase, the system provides a checklist for selecting any activities or functions which need to be included in the new home (Figure 5, right). This is the last question in the Level 1 Questionnaire with a form of checking list to avoid any missing required space that does not address in the previous questions. All of the activities or functions within the house can be translated as physical spaces.

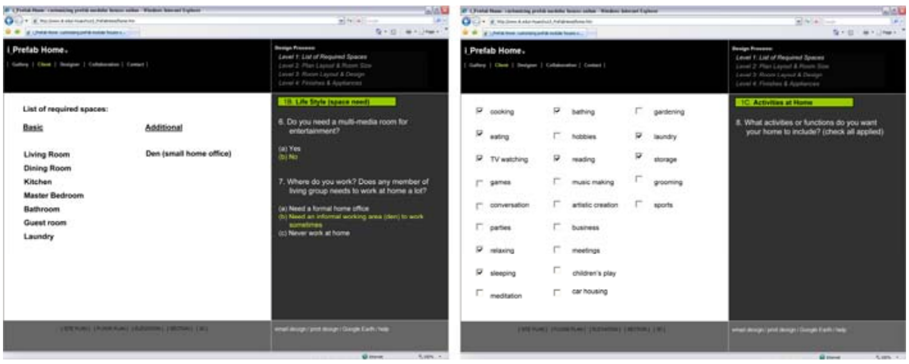

Figure 5. Defining required spaces by life style (left) and checklist of the activities (right).

4.2. DESIGN PROCESS II: PLAN LAYOUT AND ROOM SIZE

Compare to Level 1 design process, Level 2 Questionnaire is more focus on the building geometry and space adjacency. There are three sub-categories under Level 2 design process: 2A-General Site Context, 2B-Life Style, and 2C-Room Size. As mentioned previously, collecting data of site context is important because it can avoid the problem that a suggested design option does not fit the site boundary. The first question in this phase is to gather the general site context information by simplified three options: urban site (narrow lot), suburban site (wide lot), and undecided location (show both conditions).

The questions followed by the general site context are related with the issue of space adjacency. By asking what is the first space to see when the client enters inside of the house can determine the first room module's location. Once the system has the first module located as a reference point, the rest of the modules can be easier to locate based on the room adjacency preference. After answering all space adjacency preference questions, the system will provide design suggestions from its database in the visualization window (Figure 6).

4.3. DESIGN PROCESS III: ROOM LAYOUT AND DESIGN

The building geometry and floor plan boundary have been decided before moving to this phase of design process. The task of this phase is to provide the alternative content of individual spaces. The options of different room layout have been treated as replaceable and compatible "space tiles". The four different kitchen layouts in Figure 7 left is an example for showing the graphical layout in the visualization window and feature explanations in the client's input window. The different kitchen layout may reflect the different cooking and living style from the clients. Besides that, the system also provides a choice option of future expansion. It is important to concern about this issue since the configuration of household profile may be changed after a couple years. Figure 7 right demonstrates two expansion options: vertical and horizontal with the precise modular components as a reference.

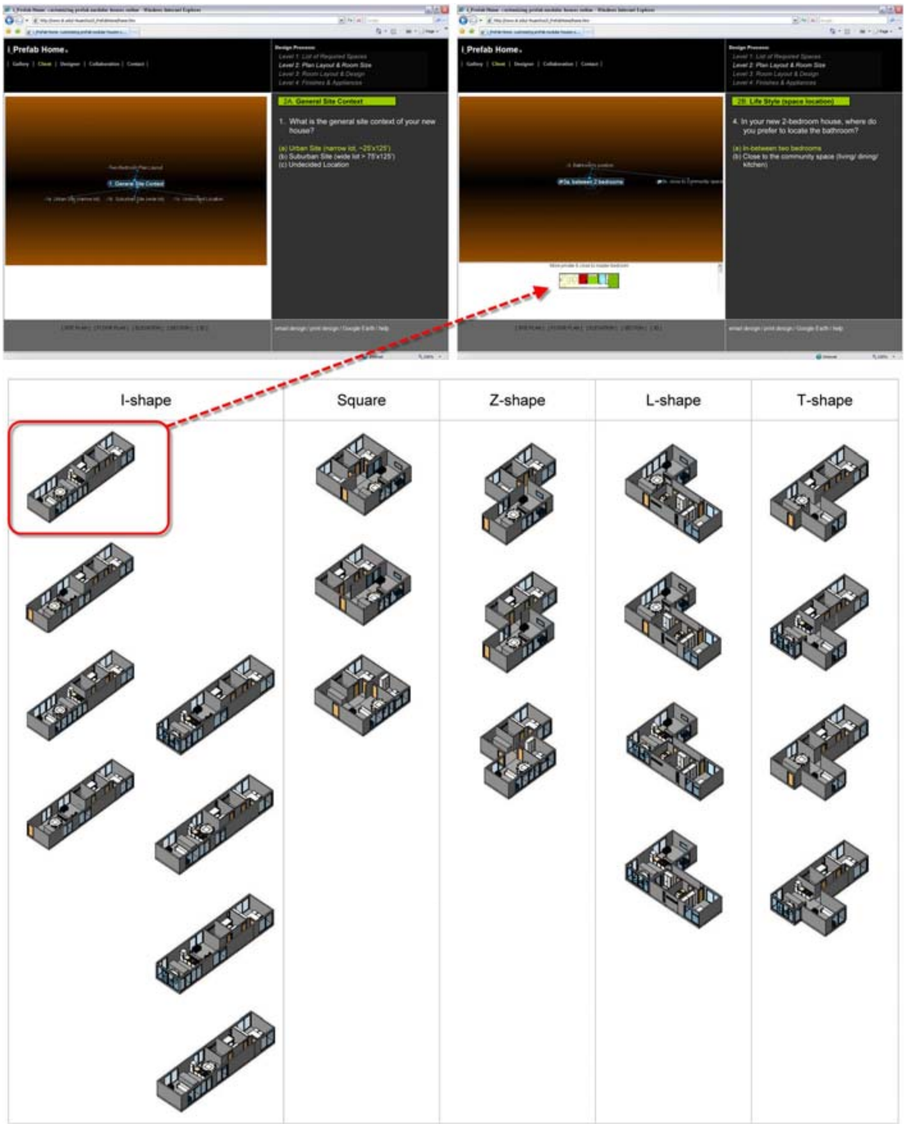

Figure 6. Defining building geometry by site context and the variable design suggestions.

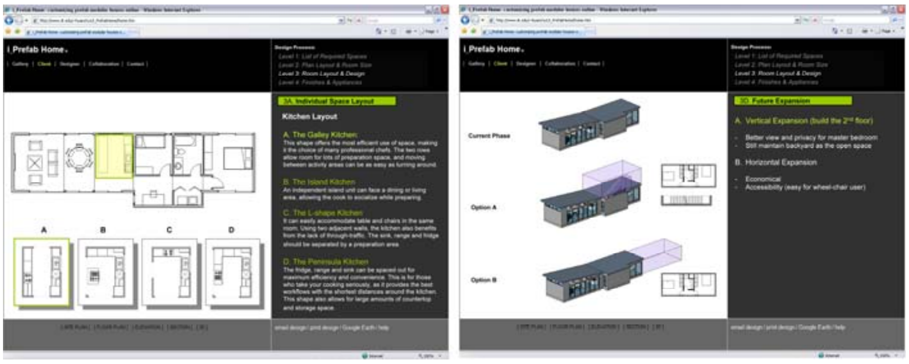

Figure 7. Selecting individual space layout (left) and options of future expansion (right).

4.4. DESIGN PROCESS IV: FINISHES AND APPLIANCES

Once the building geometry, wall openings, and roof forms have been decide, the rest of the customization options are about the finishes and appliances. The concept of customizing building elevation materials or interior finishes have been proposed and even implemented in the existing modular housing vendors. The reason to include this method is to proof that the i_Prefab advisory system can achieve this level and even better. Figure 8 left simulates the proposed modular house design model with a human scale perspective for the client to preview their future house. Exterior siding materials and colors can be customized by a simple mouse click. Moving from the exterior to the interior, each room has a simple perspective with ID numbers to identify its space element, like floors, walls, ceiling, doors, trim, curtain track, etc (Figure 8, right). After the client selected the desired finishes, the interior perspective will show as a real-time rendering to represent the finishes.

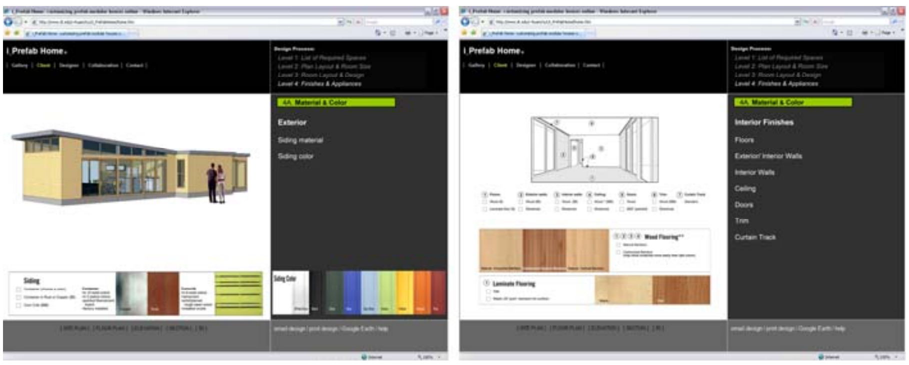

Figure 8. Selecting exterior material and color (left) and interior finishes (right).

5. Professional Consulting and Evaluation

5.1. INTEGRATE BIM FOR COLLABORATION

In order to transform the client selection design information and the evaluation process by professionals (architects and engineers) with the fabrication process by the manufacturer, the virtual design geometry should be represented as an information-contained object, not just a graphic entity. Figure 8 demonstrates the pre-design diagnostic website (left image) which is available anywhere with internet connections. All design suggestions are represented as a virtual building online and the digital design model with customized client-input data is then transformed into a Building Information Modeling (BIM) application using Autodesk Revit or a similar program (Figure 9, middle). After professional review, the BIM digital design model includes all of the construction information and is ready for the coordination with manufacturing and the assembly of the building components in the factory. The digital design model also can be exported from the Revit application to Google Earth (Figure 9, right) to position directly with the exact site information and provide the client with a review of the house as a four-dimensional experience. Overall, the diagram shows the expectation of housing delivery process from web-based programming to digital design collaboration and virtual environment simulation.

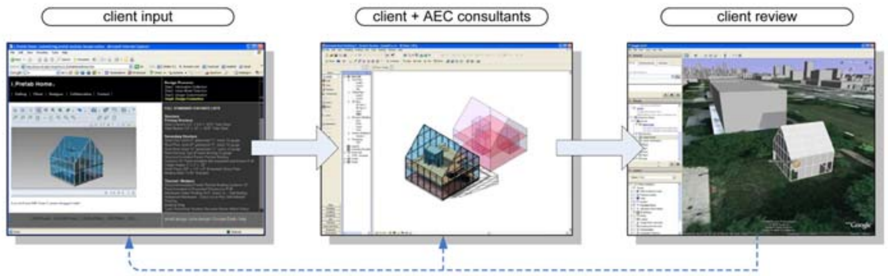

Figure 9. Expectation of proposed housing delivery process.

5.2. DIGITAL INFORMATION MODELS FROM SUPPLIERS

Unlike other large industries of aerospace or the automobile industry, the building industry is highly fragmented with most projects undertaken by one time only project-based organizations consisting of the many different individual roles of client, architect, engineer, contractor, and suppliers. There is a high risk of human errors generated during the communication and exchanging of data among these individual groups. Ironically, the architects may use computer-aided design to produce the drawings required for bidding and construction, but these digital work products are not necessarily useful for the tasks performed by the contractor: costing and scheduling (Cohen, 2005).

If most of the individual prefabricated modular housing components could be standardized for interchanging and manufacturers or suppliers could provide the information of modular building elements as an interchangeable digital format on their website to represent their products as accurately as possible for the final construction assembly, modular housing systems could then be developed by assembling these components to create many different compositions. Here are two examples to restate this proposed concept. First, Autodesk Revit Content Distribution Center provides many families for users to download. These families can be viewed as parametric information objects as well as three-dimensional geometrical representations. However, the usage of these intelligent “blocks” is still being treated as traditional blocks in most architecture firms. Since Autodesk provides the information as generic references from its library, architects still need to customize any selected Revit family to become a real constructible object based on the supplier’s shop drawing.

The second example is Herman Miller, Inc., a global provider and manufacturer of office furniture and equipment which provides 3D digital models from the product showroom of their website. Moreover, the website utilizes i-drop technology to provide the drag-and-drop capability for the users to apply their products easily to the digital design platform, like Autodesk 3D Studio Max, AutoCAD, or Revit (Figure 10). This promises to vastly accelerate the process of manufacturers used to conduct business with those that are responsible for evaluating and specifying their products (Autodesk, 2003). To avoid many human errors and time consuming during the design development process, the product suppliers or vendors should provide 3D information imbedded digital models from their website, as a supplemental to the shop drawings.

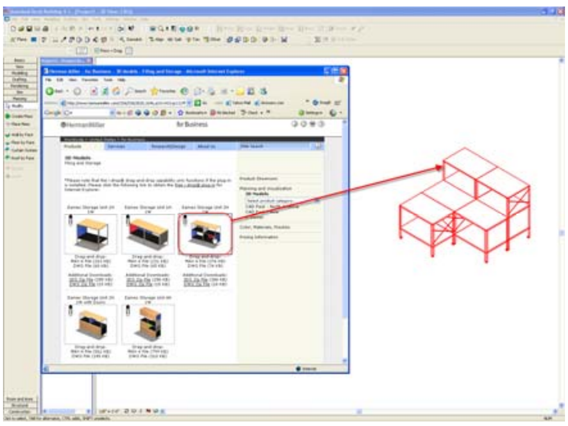

Figure 10. The Capability of "drag-and-drop" from Web page to Revit.

5.3. DIGITAL-BASED HOUSING DELIVERY SYSTEM

Although the majority of the current architectural design process already has been shifted from the traditional paper-based method to an advanced digital-based method, the problem of delay and error output in the project delivery process can still exist. The building process would be much better served if the entire chain of information from design to construction to operations could remain in one seamless digital format (Cohen, 2005). Using the expanded i_Prefab theoretical model as an example, a client inputs spatial requirements, an advisory tool organizes the client's need and generates available design suggestions, an architect reviews and revises, an engineer calculates, and a construction/ fabrication manager schedules, all using information from a common project database that is accessible over a network (Figure 11).

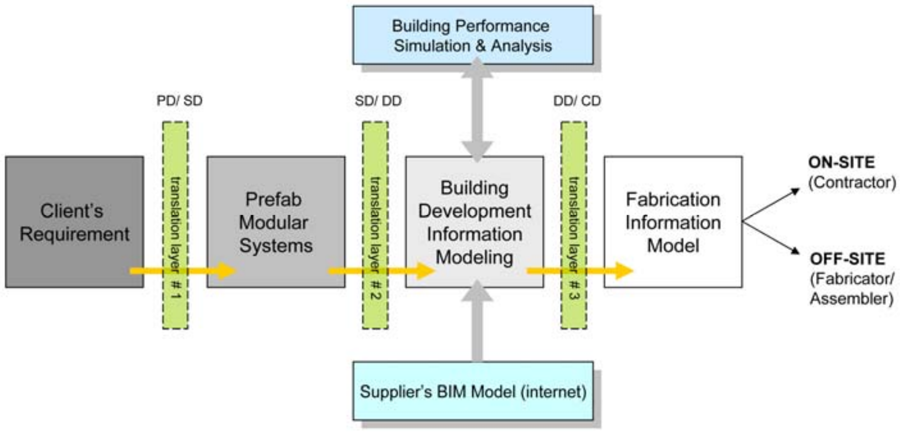

Figure 11. Value-Enhanced BIM in Modular Housing Delivery Process.

6. Conclusion and Outlook

The results of this current phase of research establish an open-ended framework of a decision support system by dynamic questionnaire to find design solutions for future reference. The interpretation of translating the client's need to match different spatial configurations of the design models from the selected prefabricated modular housing vendors is an online recommendation to replace the limited face-to-face first meeting time between architects and clients. Revising the modular unit to be more flexible and client responsive is the feedback to the modular housing architects and vendors. The future direction will be focused on the output format for manufacturing and the bi-directional linkage between the advisory system and Building Information Modeling applications to make a seamless design collaboration in the housing delivery process.

Acknowledgements

Special thanks for my thesis committee, especially Prof. Robert Babbin and Prof. George Schipporeit from the College of Architecture, Illinois Institute of Technology.

References

AUTODESK, 2003. The i-drop® Web Publishing Framework: Publishing Intelligent Design Content on the Internet. Autodesk White Paper.

COHEN, J., 2005. Integrated Practice and the New Architect: Keeper of Knowledge and Rules. AIArchitect, Available from World Wide Web: http://www.aia.org/aiarchitect/thisweek05/tw1028/tw1028bp_change_cohen.cfm [Accessed 23 March, 2007].

DAVIES, C., 2005, *The Prefabricated Home*. London: Reaktion Books.

HUANG, C., 2007. A Choice Model of Mass Customized Modular Housing by Internet Aided Design. *Joint Conference Proceedings of International Mass Customization Meeting 2007 (IMCM'07) and International Conference on Economic, Technical and Organizational Aspects of Product Configuration Systems (PETO'07)*, Hamburg, Germany, 61-75.

HUANG, C. AND KRAWCZYK, R., 2006. i_Prefab Home: Customizing Prefabricated Houses by Internet-Aided Design. *Proceedings of the 24th International Conference on Education in Computer Aided Architectural Design in Europe (eCAADe)*, Volos, Greece, 690-698.

KIERAN, S. AND TIMBERLAKE, J., 2004. *Refabricating Architecture: How Manufacturing Methodologies are Poised to Transform Building Construction*. New York: McGraw-Hill Companies, Inc.

LARSON, K., TAPIA M., AND DUARTE J., 2001. A New Epoch: Automated Design Tools for the Mass Customization of Housing. *A+U*, 366, 116-121.

THORNTON, R., 2004. *The Houses That Sears Built*. Alton, IL: Gentle Beam Publications.