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3.2 Mass Custom Design for Sustainable Housing Development

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The societal pressure on sustainable housing development is on the rise. Homes need to be socially, economically and environmentally sustainable in response to the wants and needs of individual homebuyers/users as well as society. However, existing housing design approaches being applied by today's homebuilders barely lead to the accomplishment of the sustainability agenda. Mass customization was seen as one of the potential means to tackle issues arising in achieving the housing sustainability. Based on the notion, a systems approach to sustainable homes and the interactive design communication tool were introduced. This study led to a suggestion that along the line with the research on mass customization, the way to mass-personalize a house after occupancy, which may need to involve inclusive design approaches, should be examined for the delivery of truly sustainable homes that satisfy the dynamic and diverse market demands and requirements for housing over the lifetime.

Introduction

Since "Sustainable Development" was initially advocated by the World Commission on Environment and Development (WECD) in 1987, our society has urged the building industry to produce sustainable homes which contribute to reducing energy and material consumption. D'Amour (1991) claims that "housing is an environmental industry." Housing is constructed with, and operates on products from surrounding environment. In response to changing social values, demands are being made of the housing industry to fewer resources, both to build and to operate structures. Indeed, builders are beginning to employ resource saving strategies as marketing tools (Friedman et al. 1993). Housing manufacturers in Japan have been gaining a worldwide reputation for their unique design, production and marketing approaches to the delivery of sustainable mass-customized housing. The prefabricated housing sales in Japan dominate 12.4% of the market share today. Total 1,290,391 houses were newly built in 2007 and among them, 160,347 houses were prefabricated (JPA 2008). Moreover, in response to the societal pressure on sustainable development, the housing manufacturers started producing net zero-energy-cost homes through a net metering arrangement that enables the occupants to use their own power generation to offset their electricity consumption over a billing period (Richard and Noguchi 2006). Their industrialized housing is often equipped with a number of renewable energy technologies, such as a solar photovoltaic (PV) power generating system, an air-source heat pump and a combined heat and power system, and they tend to be installed as standard equipment rather than options today.

Contemporary consumers may no longer be satisfied with minimum quality housing which merely corresponds with the adequacy, suitability and affordability problems. Housing choices can be seen as major lifestyle and investment decisions. In other words, today's homebuyers are looking to purchase a customizable house at an affordable price that adapts to the societal demographic changes with regard to socio-economic profiles. In order to satisfy consumers' individual needs and demands for contemporary homes, builders are urged to consider the application of an innovative design approach to housing.

Traditionally, homebuilders are practicing three design approaches: production, semi-custom and custom design (Smith 1998; Noguchi and Hernàndez 2005). Production builders are organized for high volume construction and they usually produce ready-built model homes that are designed on a speculative basis. Builders, who apply the semi-custom design approach for their housing development, are often called semi-custom builders since they combine characteristics of ready-built and custom-built homes. In order for the semi-custom builder to consider clients' desires, requirements and expectations for housing, the design modification of a model house selected by the users is carried out based mainly on dialogue between the sales person/designer and the homebuyer. However, the dialogue that necessitates a number of meetings may still take a long time to reach the final design of a house in question. Custom builders start from a blank sheet of paper or computer screen to create a one-of-a-kind home. The user participation approach can be considered as the optimum way to customize a new home in response to the wishes and needs of individual homebuyers. However, the longer time required to design and build combined with lost economies of large-volume work leads to the higher prices typical for custom homes (Sadeghpour et al. 2006).

In short, homes need to be socially, economically and environmentally sustainable in response to the wants and needs of individuals as well as society. However, existing housing design approaches being applied by today's homebuilders (and architects alike) barely lead to the accomplishment of the housing sustainability agenda. In order to tackle issues arising in achieving the hosing sustainability, the emerging notion of mass customization was introduced to homebuilding operations. The following sections brief the notion and explore the potential means for the delivery of sustainable homes tomorrow.

Mass Customization Concept

Mass Customization is an oxymoron. The term is composed of two opposite notions: mass production and customization. The notion was anticipated in 1970 by Alvin Toffler in his book entitled Future Shock. Toffler (1970) asserted that maximum "individual choice is regarded as the democratic ideal" and expressed anxiety at the emergence of more standardized mass culture and lifestyles in the future. In 1987, the term was eventually coined by Stanley M. Davis in his book entitled Future Perfect. Davis (1987) delineated the concept as follows: "The world of mass customizing is a world of paradox with very practical implications. Whether we are dealing with a product, a service, a market, or an organization, each is understood to be both part (customized) and whole (mass) simultaneously… For mass customizing of products, markets, and organizations to be possible, the technology must make it economically feasible in every case." Furthermore, in 1993, Joseph B. Pine II profoundly systematized the general methods of mass-customizing products and services. Pine II (1993) regards mass customization as "a synthesis of the two long-competing systems of managements: the mass production of individually customized goods and services."

In many industries, this innovative concept has already been introduced to product design in order to accommodate the unique demands of each consumer. Mass customization is based on user participation in the product design decision-making process. Thus, before discussing how the concept can be applied to the housing delivery process, the meaning of user participation, which is still vaguely understood today, should be reviewed.

Meaning and Criticism of User Participation

Generally, users, community or citizens participation is understood as a means to meet inhabitants' requirements in terms of housing design and planning, as well as improvement of landscape and public amenities. Its success depends on the extent to which full collaboration of professionals, local authorities and users in the participatory process is effectively carried out. Although the concept of participation is a few decades old, there is still great concern about its interpretation and use. Habraken (1985) indicates that participation has two meanings in opposite directions. Firstly, it is seen as a means to enable users to make decisions; thus, this transfers the decision-making power to the inhabitants. However, the process requires essential changes within the administrative structure. Secondly, it is perceived as a change of approach, however, within the same structures. The users' comments are taken into account and are guaranteed to be implemented (Habraken 1985).

Participation is also identified as a "face-to-face aggregation of individuals who share a number of values important to all, that is to say a purpose for them for being together" (Beheshti et al. 1985). However, participation has more chance for success in societies where citizens are free in deciding the future of their environment and their concerns are taken into consideration by local governments. It is also related to user control over decision-making which here again requires fundamental changes within the established political and administrative structures (Beheshti et al. 1985). Malpass (1979) claims that public participation has lost its role of a way to communicate users' interests and concerns to decisions-makers, arguing that participation should be "a way of discovering differences of opinion and conflicts of interest." Participation is also identified as "the means by which the victims of design decisions could influence the decision-making process" (Hellman 1973). Some professionals believe that participation in design is simpler than in planning; however, it is crucial that architects should learn how to deal and efficiently communicate with participants (Hellman 1973).

Although many professionals have attempted to implement user participation in order to produce, for instance, responsive environments or redevelop unpopular estates, views concerning the validity of participatory processes are still divided. Criticisms are related to the fact that they are time-consuming, complicated, costly and affecting progress of administrative work. Hamdi (1991) argues that despite some successes, participatory processes do not always lead to user satisfaction and more efficient maintenance of buildings and open spaces. That is to say that the validity of user participation is still creating cause for concern in many countries. In this sense, participation in design can be criticized for being unable to fulfill users' housing requirements. The goals of participation need to be clarified and the value should be explicit. The following section identifies a mass custom design system model for the delivery of quality affordable homes with due consideration of the meaning and criticism of user participation.

Mass Custom Design System Model

One of the successful mass customization approaches that can be applied to the homebuilding process is the modularization of housing components and the variations accomplished through the mass customization process can be quantified in the light of Set Theory, a branch of mathematics developed by Georg Cantor. The total number of possible ordered pairs (or combination) of given standard housing components can be simply calculated. To bring the concept of mass customization into effect, a total coordination (or systems) approach to considering products and services within the housing delivery process needs to be taken into account since to design, build and market a home requires consideration of these two aspects. In short, mass customization, when it is considered as a set of systems for designing, producing and marketing a product, is impossible if either customizable products or communication services are absent. To formulate the means to mass-customize homes, the system model was developed (Noguchi 2001; Noguchi and Friedman 2002a; Noguchi and Hernàndez 2005). To discuss the potential applicability to the delivery of quality affordable homes, this generic mass custom design system model was first introduced at an internal symposium on urbanism, which was entitled Prospectiva Urbana en Latinoamerica held in Aguascalientes, Mexico, on 31st August 2001. This televised symposium was organised by the local government and over 500 audience members from the academia, construction industry and government joined the discussion.

The mass customization (MC) was visualized simply by making use of a conceptual analogue model as follows:

$$MC = f\,(PS) \qquad (1)$$

In this model, the service sub-system (S) concerns communication techniques that lead users to participate in customizing their new home while the product sub-system (P) covers production techniques that aim to encourage housing suppliers to standardize housing components for mass production. In mass-customizing homes, user participation, as described above, is vital; therefore, housing suppliers need to offer design support communication services to their clients. Design-consulting staff and appropriate communication tools are required to facilitate user choice of standard components (Noguchi and Friedman 2002b). These fundamental design service factors can also be integrated into a comprehensive model:

$$S = f\,(l, p, t) \qquad (2)$$

In this model, the service sub-system (S) is supported by the existence of the location (l), personnel (p) and tool (t) factors. Even though these elements are necessarily interrelated, most homebuilders and housing manufacturers have already been applying these during the design stage. An important part of mass customization is that the user directly determines the configuration of their home from choices given as client input during the design stage. However, this cannot be achieved without the standardisation of housing components for the volumetric, exterior and interior design arrangements. These components should be organized in a visually attractive way in a component selection catalogue that enables clients to easily choose from many options given—as well, the value of each component choice may need to be explicit. Basically, housing components can be divided into three categories: volume, exterior and interior. These can be considered the main elements of the product sub-system (P) which can be explained by the following conceptual model:

$$P = f\,(v, e, i, o) \tag{3}$$

The volume (v) components are used to configure the space of housing that determines the number and size of each room while the interior (i) and exterior (e) components serve to co-ordinate decorative and functional elements that customize a home. In addition, "o" denotes other optional features such as air conditioning, home security system, emergency call buttons, handrails, dishwashers and other electrical appliances. Some optional features can be offered before or after occupancy with due consideration of inclusive design approaches to housing the elderly and disabled users. Both sub-systems can be considered the indispensable functions of mass-customizing homes. Generally, the unit production cost can be reduced through standardization and/or mass production of housing components. As well, the design cost associated with a number of meetings between the designer-builder and the buyer to reach the customization of a house can be reduced when the process accompanied with user participation in choosing housing component options is well standardized. It is also known that the higher the rate of in-factory completion of housing components, the more the product quality can be maintained under optimum conditions inside the factory where materials are not exposed to adverse outside climate (Hullibarger 2001). Moreover, the higher rate of in-factory completion helps control the elapsed time for the unit production and this in turn influences the labor cost.

The design process, where the aforementioned mass customization system is brought into full play, can be considered mass custom design. The existing elements (i.e. parts of a whole) can be standardized while the myriad combinations of these parts still provide great scope for creativity. Homebuyers can directly choose from the given options. The combinations of user choices from mass-producible standard housing components result in customizing houses—viz. these homes have been termed "mass custom homes" (Noguchi 2001). The mass custom design approach achieves the high level of standardization in housing components from which homebuyers participating in the design decision-making process can directly choose. The user choices of standard housing components paradoxically increase the level of design customizability (Table 1).

Table 1: The levels of standardization and customization by housing design approach (Source: Noguchi and Hernández, 2005).

Design Approach	Standardization Level	Customization Level
Production	High	Low
Semi-custom	Middle	Middle
Custom	Low	High
Mass Custom	High	High

The application of the mass custom design approach to reaching the customization of sequential housing units has the potential to reduce the design cost by 30-60% due to the economies of scope which can be achieved by the combinability of standard housing components (Noguchi 2004).

Mass custom homes in Japan

Japanese housing manufacturers have been successful in mass-customizing their industrialized homes. SANYO Homes Co. Ltd. produces their mass custom homes, winning the Good Design Award 2004 (Figure 1). Sekisui Heim (or Sekisui Chemical Co., Ltd.) brings their wood- and steel-frame modular housing system into full play, marketing over 55,000 net zero-utility-cost mass custom homes to date where a PV system is often installed as a standard feature rather than an option (Figure 2). PanaHome Corp. is successful in the solar communities consisting of mass custom homes equipped with renewable energy technologies, such as a PV system, an air-source heat pump and a combined heat and power system. In their mass housing development, every house is designed and built after the sales so that the functions of each dwelling unit built on the lot of the client’s choice are tailored to the wants and needs of the individual buyers (Figure 3). Misawa Homes Co., Ltd. is known as the first zero-energy mass custom home manufacturer in Japan and their initial research on an eco-energy housing system using solar energy is dated back to 1974. In 1998, the company succeeded in commercializing the world's first 100% self-sufficient zero-energy home. Sekisui House, Ltd. maintains the top sales of steel-frame mass custom homes in Japan, gaining the net sales of $13,112,487,000 (US $) and the net income $514,770,000 in 2007. The company is recognized as the first company in the Japanese housing industry as to the creation of a recycling system in 2005 that achieves zero emissions of waste material at the construction sites of their newly built homes.

Figure 1: Logia-Type E. (Source: SANYO Homes Co. Ltd., 2008a).

Figure 2: Sekisui Heim unit assembly line.

Before actually making a contract with the client, Japanese housing manufacturers are willing to give a variety of catalogues to the client, visualize the client's image of the house in question, and estimate the total price (Noguchi and Friedman 2002b). At the marketing and design stages, the manufacturers usually provide their clients with four types of catalogues: general catalogue, commodity style catalogue, technology catalogue and design component selection catalogue.

Figure 3: PanaHome-City Seishinminami solar community. (Source: PanaHome Corp., (c2007)).

The general catalogue contains information on the company's profiles and commodities. The commodity style catalogue provides detail information on specific housing types. The technology catalogue visualizes the value of innovations. The design component selection catalogue encourages the user choices of standard housing elements, which are inevitable in mass-customizing homes. The first three catalogues are usually provided during the marketing stage while the design component selection catalogue is used during the design consulting stage. The component selection catalogue corresponds with the housing styles selected and helps clients choose standard components for the exterior and interior arrangements of the home. The catalogue describes the material, size, color, texture and functions of each component; however, it tends not to include any prices. Additionally, Japanese manufacturers use a computer-aided design system for the creation, modification, analysis and optimization of a design. The virtual image of the house is erected based upon the housing components selected by the client. Then, the manufacturer also provides a cost estimate. Once the client is satisfied with the plans, the manufacturer will finalize the design and, at last, enter into a contract with the client.

An important part of the mass custom design approach is that the user directly determines the configurations from choices given as client input during the design stage. This could hardly be achieved without the standardization of housing components for the space, exterior and interior design arrangements. The concept of component standardization can be illustrated with LEGO® building blocks. A number of simple modularized blocks can be connected in a variety of ways because of their interlocking tabs and holes. Likewise, Japanese housing manufacturers offer a variety of standard housing components, which can be mass produced, to their clients and then encourage them to participate in combining the components to customize their new home. The design feedback suggested by the manufacturer extends to the considerations of future changes of family structures as well as potential renovation patterns of the house over the lifetime. The services may aim to support social and economic sustainability in housing. These design options are visually presented in the component selection catalogue so that clients can easily make their buying decisions.

Mass customization is an effective means to provide optional features that help users to customize their end product to be purchased; however, there are some hidden standard features that aim to maintain or elevate the minimum level of product quality that the company expects to achieve. Environmental design features that buyers tend to opt out due to the high prices are the typical examples in today's homes since the value of the user choices is still unclear. However, in response to societal needs for sustainable homes, green aspects should also be incorporated into the housing delivery process.

The following sections introduce design and marketing strategies that help to initiate and maintain the sales of environmentally-friendly sustainable mass custom homes being built in Japan and Canada.

Greening mass custom homes

Japanese housing manufacturers has been implementing a marketing strategy that is aimed at supporting the commercialization of their green mass custom homes. In fact, the housing manufacturers started installing expensive renewable energy technologies and attempting to materialize the environmental sustainability by their new tectonic integration (Figure 4). The manufacturers tend to invest heavily in advertising and educate their clients to appreciate the distinguishing features of their high-cost and high-performance (i.e. high cost-performance) housing where a variety of amenities (including renewable technologies today) that drastically improve housing quality is installed as standard features rather than options. Their quality-oriented production approach is rooted in the high cost-performance marketing strategy (Noguchi 2003).

Figure 4: Wa no Nagomi type-R (Source: SANYO Homes Co. Ltd., 2008b).

Japanese housing manufacturers emphasize that they have been producing better-quality homes for about the same price as conventional ones. In fact, the selling price of their high-quality industrialized houses is about 8% more expensive than that of conventionally-built moderate-quality houses (Noguchi 2003). The cost-performance marketing strategy can also be seen in other industries—e.g. the automobile industry. Although today's automobiles can be produced with lower production costs than those in the past, their selling price does not seem to be affected dramatically by higher productivity and new cars are still generally regarded as expensive. However, the list of items now offered as standard features in new cars, such as air conditioning, a stereo set, airbags, remote-control keys, power steering, power windows, and adjustable mirrors, were offered only as expensive options in older models. Clearly, the quality of newer models is much higher than that of older models. The same is true for the housing industry in Japan. Quality-oriented production contributes towards the delivery of high cost-performance housing in which high-tech modern conveniences that are installed as options in conventional homes are now available as standard equipment.

There is a debate about whether or not a PV system, for instance, should be installed in housing as a standard feature rather than an option. Barbose et al. (2006) indicate that the optional approach to PV sales in new homes has several distinct disadvantages from a PV deployment perspective. The most fundamental problem is a complex buying decision that homebuyers need to make for adoption of a PV system. This becomes contingent on each individual homebuyer who makes separate decision about PV amidst all of the other decisions involved in buying a new home, most of which are much better understood. Additionally, sales staff must receive a much higher level of training so that they can explain the PV system and its benefits to potential homebuyers. The installation scheduling can also become more complex and prone to delays. Offering PV as an option ultimately may not be a profitable business model for large production home-builders since the lower number of PV systems likely to be installed may increase the transaction costs (Father et al. 2004).

PV systems equipped with housing reduce carbon dioxide emissions when the house comes into operation. Renewable energy technologies that alleviate negative impacts on environment can be installed as standard features while other housing design features (e.g. volume, interior and exterior components) that affect the functionality or usage of a house should remain options. Low-cost passive energy techniques that optimize the use of clean free sunlight for heating and lighting space, for instance, can be incorporated into volumetric sunspace and exterior window options. The quality-oriented design and production approaches reflect Japanese housing manufacturers' success in initiating and maintaining the mass sales of net zero-energy-cost mass custom homes today.

Interactive Mass Custom Design Communication Tool

In 2005, the Canadian team composed mainly of Concordia University's engineering students participated in the Solar Decathlon housing competition, aiming to showcase their low-energy solar-powered house, called Northern Light. This PV solar house was the only Canadian entry to have competed in the Solar Decathlon, a week-long event that took place in Washington, D.C. in October, 2005. The house was featured by a 7kW PV system that covered the rooftop area of approximately 74 m^2. The solar modules were rated at the conversion efficiency of 13.9%. In addition to the generation of electricity, the PV system was also designed to capture heat in order to supplement the indoor space heating (Pasini 2005). The house consisted of a small-sized bed room, a living room and a kitchen/dining space and was initially designed on a speculative basis. Thus, the design customization was totally neglected before the concept of mass customization was introduced. To reduce the on-site construction time, the house was built by making use of a prefabricated modular housing system that helped lessen exposure to site nuisances such as bad weather, theft and vandalism.

In order to enhance the innovativeness of architectural designs, the first author was assigned to mass-customize the house and he developed an interactive mass custom design (MCD) communication tool in collaboration with the local illustration firm. The design tool was proposed to support the initial design decision-making and the future modification. It is a digitalized interactive design component selection catalogue developed with the aim of value visualization of each standard housing component option given to the design decision makers. On a computer screen, the design image can be created instantly in response to the users' direct choices of housing components. Indeed, the interactive design communication facilitates design decisions. Due to the project's time and budgetary limitations, the standard design options were confined to the volumetric and exterior components. With consideration for the disabled wheelchair access, the volumetric design components encompassed two basic options for the entrance design: a ramp access and a porch entrance (Figure 5). Additionally, a horizontally extended skylight that affects both the interior volume and the level of natural day-lighting was introduced featured as a solar option.

As for the exterior components, standard design options were given to the walls, fascias and window and door frames. Each component extends the visual variations achieved by the combinations of different materials, colors and textures (Figure 6). In this project, PV modules were installed as standard features; however, color options were given to the panels that could be integrated seamlessly into the rooftop.

After the competition, the PV solar housing prototype was re-built on the university's Loyola campus in Montreal where the engineering students can continuously examine the energy performance in the local contexts. Consumers are aware that advertisements are far from trustworthy and they continually check what they see and hear in advertising against their own experience and the experiences of others (Schiffman 1999). Experience is more reliable than other sources of information so that consumers may wish to confirm the advertisement's claims by examining the product themselves before they buy it. The Northern Light house is now open to the general public and exhibited permanently so as to sharpen the consumers' awareness of low-energy mass custom homes (Figure 7).

Building a house consumes a large amount of energy during construction and after occupancy. A considerable amount of waste materials is generated in the process of housing development. Hullibarger (2001) suggests that more waste materials are generated by on-site construction than by in-factory production which reduces or eliminates site interruption such as bad weather, site disturbance, theft and vandalism. The proposed interactive mass custom design communication tool encourages housing producers to further standardize their home-building components. The product and process standardization may create opportunities for increasing the level of in-factory production as well as reducing, reusing and recycling resources towards sustainable housing development.

Figure 5: Interactive mass custom design communication tool. Volumetric options: porch entrance (top) and ramp and solar access (bottom).

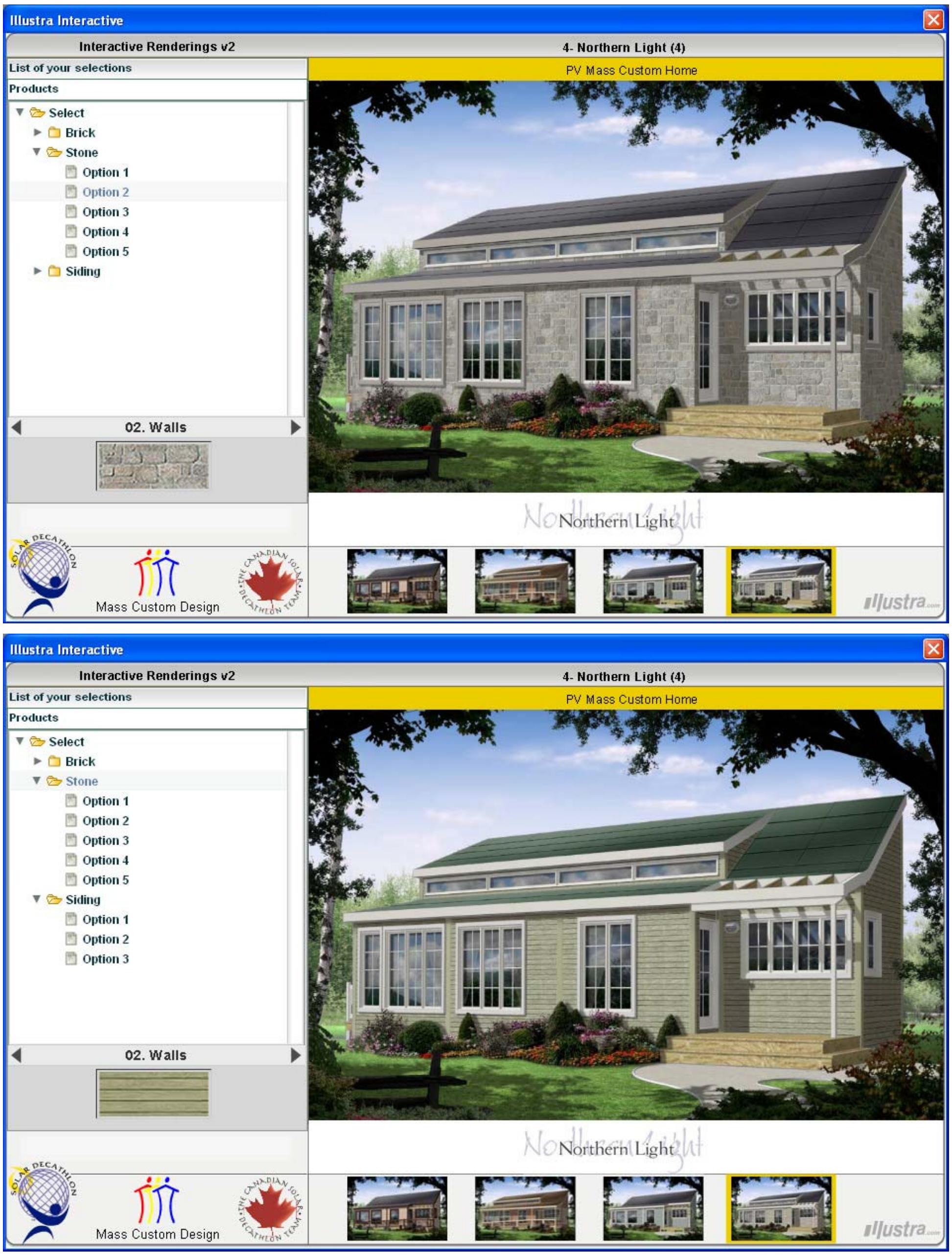

Figure 6: Interactive mass custom design communication tool. Exterior component options: stone veneer (top) and wood siding (bottom).

Figure 7: Canadian PV mass custom home, North Light, built by Concordia University.

Conclusions

The notion of sustainable development tends to link the collective aspirations of the world's people for improved living conditions and a healthy environment with the need to reconcile conflicting perspectives on the economy at present and in the future. The homebuilding industry is no exception and builders today are requested to deliver homes that correspond with the social, economic and environmental sustainability targets. Mass customization was considered the effective means to create options from which the users can choose. User choices are critical in how a house is designed, constructed and operated. Without the user participation, homes may never achieve the sustainability agenda. On the other hand, too many options given to users may paralyze their choices and the vagueness of the value concerning component selections may make them troubled over the buying decisions. The interactive mass custom design communication tool introduced in this study facilitates user choices and helps visualize the value. The given options can also encompass the design principles rooted in inclusive design approaches, affordable housing strategies, passive solar techniques and active renewable energy technologies—those that help achieve sustainability goals specified.

Mass customization aims to customize a house at the time of sale so that it may barely affect the way to personalize space after occupancy. Accordingly, the effect of mass personalization on housing evolution after occupancy may need to be explored further. The growing patterns of space in response to the usage should be incorporated into the development of housing design options given to the users before and after occupancy. Homes need to be customized and personalized so as to meet the timely needs and dynamic demands of buyers/users over the lifetime of housing.

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net zero-energy healthy housing that won the federal government's sustainable housing completion. His Mass Custom Home research extends to the integration of inclusive affordable housing design techniques, passive energy and environmental systems and renewable energy technologies. He is the initiator and co-ordinator of the Zero-energy Mass Custom Home Mission to Japan where in total 17 industry executives, 6 government officers and 14 academics from the UK, France, Canada, China and Japan joined to date and visited the state-of-the-art production facilities of leading housing manufacturers in Japan. Moreover, he was the co-host for 39 series of Japanese community TV program entitled ARIGATO on CH Montreal, assigned to introduce the essence of Japanese business culture.
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