An exploration of design systems for mass customization of factory-built timber frame homes

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ABSTRACT: Demographic trends are forcing the homebuilding industry to speed up the industrialization process through mass customization (MC). Our survey of companies in the sector of factory-built timber frame homes shows that data processing for the prefabrication of houses and their structural components comprises many iterations which generate a bottleneck at the technical design function. Companies must develop considerable agility in their design function to deal with repeated change in orders and to coordinate multidisciplinary information and often from multiple sources, while controlling costs, delays and quality. In order to develop MC of factory-built timber houses, a design system framework is proposed, taking advantage of a product platform based solution. The framework aims at integrating functional requirements and constraints in house prefabrication. Such conceptual work is an initial step towards emulating an advanced planning and scheduling system capable to provide efficient coordination through proper data exchange required for the processes of the homebuilding value creating network.

Keywords: Prefabrication, homebuilding, industrialization, information technology, design process

1 INTRODUCTION

The Science and Technology Council for the Province of Quebec (Conseil de la science et de la technologie, 2003) points out general conditions of the residential construction sector appearing favourable to greater development of prefabricated housing systems. These include a need for enhanced productivity, a growing demand for warranties of quality and sustainability, skilled manpower shortages in industrialized countries, and growing export markets. Schuler and Adair (2003) see the increase in the prefabrication of components for residential buildings in the U.S., mostly as a result of an aging population and a consequent labor shortage on building sites. A trend towards panelized components is developing mainly in high volume homebuilding networks meaning that large builders are taking steps to streamline building and lower job site costs. Larger builders, in a period of consolidation in the housing industry of the United States, Canada's biggest export market for softwood lumber, are seen as the leaders of an ongoing industrialization of homebuilding.

In their study of the U.S. homebuilding markets, Poliquin *et al.* (2001) estimate that factory built roof systems (i.e. with engineering of trusses and assembly) were used in 60 to 70% of the housing starts, and floor systems were used around 30 to 40%. Following the broad acceptance of manufactured roof and floor systems by stick builders (on-site framing), prefabricated walls appear to be now gaining market share. For the U.S. markets, Robichaud and Fell (2002) estimated that prefabricated wall panels were used in 18% of the housing starts. They are predominantly used by large builders and in the northern parts of the U.S. Non-volumetric panel systems are better for transport logistics than volumetric modular systems giving it more potential for distribution in high volumes.

The homebuilding sector offers highly customized products and services with an engineer-to-order (ETO) approach to markets. In this context, the Canadian manufacturers of prefabricated wood components for framing systems mostly operate in regional markets. None of these manufacturing systems in operation is considered as serving high volume mass markets.

The realignment of the homebuilding industry involving high-volume deliveries of prefabricated components is closely tied to the adoption of mass customization (MC).

> *The mass customised housing suppliers use `lean' and `agile' production systems, including the extensive use of prefabricated components, to deliver high levels of product choice at mass production costs.* (Barlow and Ozaki, 2005)

From the MC point of view, prefabrication brings forth the benefits of industrial manufacturing environments. With prefabrication, a majority of wood frame components are designed, manufactured and delivered to building sites for assembly. Principles of design for manufacturing and assembly increase efficiency and productivity on site, paving the way for use of prefabricated structural systems in high volumes. The adoption of prefabrication brings industrialization to the North American homebuilding industry and it poses challenges to meet high volume deliveries in a fragmented supply chain, involving a diversity of trades and professional expertise.

This paper first proposes an overview of the current operational practices and of the supporting technologies for manufacturing factory-built housing systems observed through a survey of such manufacturing companies. It then explores the parameters for the coordination of design activities and the applications of MC in homebuilding. Finally, it defines a strategic position for design function that this industry should take on in order to be able to reach high volume North American homebuilding markets with prefabricated wood structural components.

2 SURVEY OF TECHNOLOGIES IN THE FACTORY BUILT HOUSE INDUSTRY

A survey was conducted among the industry of prefabricated house and engineered timber framing systems, exploring the integration of design with other corporate functions and the state of the use of technologies. Semi-structured interviews were conducted in 13 companies of Central and Eastern Canada producing either modular or panelized wood structure systems for housing units. The companies selected covered a broad range of products, accounting for the various markets and business practices of the prefabricated housing industry. Three companies sold panelized house kits to builders including only the structural systems. Six companies sold complete house kits with various furnishings to consumers, three of those producing panelized structural systems and the three others making modular systems. One sold only panelized wall systems. Two sold metal connectors and engineered wood products (EWP) to structural systems manufacturers. All companies prefabricating structural building systems relied mainly on regional distribution capacity for their business development. One manufacturer of panelized house kits had nation-wide distribution as did the providers of metal connectors and EWP.

The interviews were conducted with managers and technicians involved in a way or another with the design functions (consultation, architecture, civil engineering, industrial engineering, manufacture configuration, logistics, etc.), the technological applications and the links with other management functions of their company and its value creating network (VCN).

As mentioned in Fenves *et al.* (2003), small manufacturing enterprises (SMEs) can gain efficiency by integrating advanced design and engineering tools into the product development process. The interoperability between the tools facilitates the creation of an advanced engineering environment (AEE). AEEs are defined as "*particular implementations computational and communications systems that can create virtual and/or distributed environments functioning to link researchers, technologists, designers, manufacturers, suppliers, and customers*" (National Research Council, 1999). Typically, they consist of design tools (e.g., computer-aided design [CAD], computer-aided engineering [CAE]), production tools (computer-aided manufacturing [CAM]), project management tools, data repositories (product data management [PDM], product lifecycle management [PLM]), and networks. AEEs can vary greatly in comprehensiveness, from a basic configuration utilizing limited CAE functions built into a CAD system, to a comprehensive configuration, maintaining a common database of design information accessible by all relevant design and analysis tools.

Taking the AEE scheme as a reference, the interviews paid careful attention to issues such as software integration with the design, planning and production processes, compatibility between multiple tools, use of appropriate design protocols, and data storage and exchange rules. Results of the interviews are grouped under three business functions: 1- sales, 2- design and production and 3- planning. The following sections describe how software programs are currently used in these three groups of functions and the level of implementation towards AEE. The aim of this explorative survey is to define the level of integration between the business functions involving design processes as well as the level of use of the technology. In the next section, we will draw from this picture a coordination framework of the main business functions.

2.1 Sales

To sell their products to consumers, manufacturers rely on paper or electronic catalogues, from which customers can design their houses by selecting features from the various options and components available. Two manufacturers of modular homes were using a basic architectural design software program to develop their clients' selections. Only one of them transferred this conceptual design into an electronic file for later use in technical design. Manufacturers of panelized housing selling to builders were reported to receive clients' orders in many different ways, from vague drawings on a piece of paper to complete architectural drawings.

Any salesperson needs to process clients' drawings into price estimates and delivery schedules. According to all manufacturers consulted, quick pricing is a major selling argument. Pricing data is updated on a weekly basis to reflect variations in material and service costs, as well as fluctuations in production capacity. Updates were provided by managers who were also responsible for generating production schedules, following up on them. They mostly entered all the data manually using a homemade template on an electronic spreadsheet (e.g. MS-Excel). Two house manufacturers indicated that their pricing software was accessible on the Internet, which made it easier to communicate updates.

Several design and engineering software for prefabricated housing components include cost calculation modules. Only one of the panelized housing manufacturers participating in the survey used the costing module provided by their engineering software for pricing orders.

The main reasons given for not using such costing modules included frequent wood price changes, frequent modifications to technical specifications and the excessive amount of work involved when performing too much engineering before costing. Access to databases from design and engineering software is limited, as these are proprietary solutions related to the brands of building materials supplied. Consequently, often times, only the supplier of software can update the data on materials in the software. In such context of limited control over updates, manufacturers are unable to ensure connections with other applications using materials data. In the factory-built housing sector, it is often a problem to interlink all functions using materials data.

For complex orders, the need for validation by the engineering department during the sales process leads to repeated iterations between engineering and the client. All companies make use of electronics for internal data transfers in this situation, but many of their communications are still on paper, particularly regarding technical drawings. Standardization of drawing symbols is minimal, and they vary with internal methods and practices. For this reason and due to the fact that most CAD systems offer little interoperability, companies prefer re-entering drawings from outside sources to ensure that all details are properly covered for production planning purposes. Housing manufacturers with a large distribution network increasingly use electronic communication, relying on a complete control over the possible changes to design and submissions.

2.2 Design and Production

The production of factory-built houses requires manufacturing flexibility, since it involves customizing products to clients' preferences. It does not allow for mass production unless companies achieve a high level of system standardization and integration with CAD/CAM systems. Implementation of such systems requires significant sales to recover costs and to surpass human productivity. Among manufacturers surveyed, only those producing an estimated 500 or more residential units a year were found to operate integrated and automated systems (including CAD/CAM) mainly for the production of roof and floor trusses. Only one of them used an automated system for walls. For all other surveyed manufacturers, the housing component production system was handled manually in most aspects.

For floor systems, a broad range of design approaches was observed, with some companies providing complete floor systems, while others provided only components along with engineering, leaving the assembly of the parts to the builder. Companies selling complete floor systems manufactured their own floor trusses with wooden or steel webs that integrate proprietary CAD/CAM systems according to the brand of metal plates and webs used. Those selling only components used mainly floor I-joists with panel webbing that are mass produced by EWP companies, or sub-contracted the floor truss manufacturing.

Engineering software designed for roof and floor trusses have reached a high level of CAD/CAM integration, from drawings to manufacturing, including assembly. They start from architectural profiles, from which the structure is automatically generated, taking into account manufacturing parameters and structural design standards. A technical validation is then computed and includes consideration of the codes and standards applicable in the jurisdiction where the building is to be erected. Following this validation, a cutting bill is generated; part production schedules are optimized and transferred to automated saws for cutting to precise dimensions. The parts are organized into kits and moved to assembly tables, where a laser system projects the various profiles, numbers and part positions, ready for assembly. Similar trend in automation can be observed in the wall manufacturing sector, but to a lesser degree.

To design their floors and roofs, all manufacturers use proprietary software from their I-joist and metal plate suppliers. Data generated from the design of structural systems provide a link between the geometrical shapes to be built, structural analysis and the specification of the materials and assemblies required to manufacture the product.

We observed the same proprietary software environment as seen by Bouchard *et al.* (2002) for wall panels:

> *"A study of software used in the manufacture of wall panels shows that integration with architectural drawings is very limited, even though the programs allow for various levels of integration with management and production. In addition, many software programs do*

not provide engineering calculations or validation against building codes. As a result, these have to be based on data included in databanks containing design values for the components."

The development of software able to handle such links is complex and costly. Whether owned by suppliers of metal plate connector, automated equipment suppliers and other software developers, these programs are a strategic element for prefabricated housing, being the source of all the information systems controlling the manufacturing environment. Most manufacturers use them in isolated design units not allowing data to be used by other software systems and forcing repetitive data entries. Only manufacturers using a CAD/CAM software programs combining a specific family of equipment, are able to implement data sharing and interoperability. Such integration applies only to a particular subsystem (roof, floor or walls). None of the manufacturers is using a software solution capable to integrate all of the manufacturing units for structural components.

Following the settings of these independent automation centers, various software environments have to be coordinated to allow for re-utilization of data throughout the business systems. The manufacturers we have met manage these repertories and CAD-generated documents mostly in accordance with informal procedures. Only three of the thirteen manufacturers surveyed had developed a formal management system for documentation and archiving. All of the visited companies mentioned the design activities as the core of their business, and over 90% of the respondents identified the design function as the bottleneck of their production flow.

2.3 Planning and Control

Among the manufacturers participating in the survey, production management methods focused on material supply planning tools (Material Requirements Planning - MRP) and Just-in-Time delivery. The planning of production processes generally uses in-house systems based on office software, but one modular housing company was in the process of Enterprise Resource Planning (ERP) software. One of the issues still requiring attention, relates to the integration of production planning tools, sales tools and product design tools.

Process performance indicators vary from one company to another. Process improvements are adjusted based on in-house staff expertise, and we heard no mention of any optimization programs being applied to support process engineering in regards to improving production efficiency. However, manufacturers using CAD/CAM integration have access to integrated monitoring tools for the various production functions, which they can use to track orders and work-in-progress in real time in addition to tracking some production indicators. We observed no bar code being used. Only one manufacturer used electronic equipment to monitor labor activities or time spent on specific projects. Quality control was typically entrusted to skilled employees and senior technicians who relied on specification sheets and the standards and building codes applicable to the area where the building was to be erected.

2.4 Technological challenges

The survey of companies in the prefabricated wood-frame house sector showed some duplication in the exchange and processing of data for prefabricated houses and structural components. There have been many advances, but the technologies used cannot effectively deal with the heavy burden placed on design processes, considered by most of the respondents as the bottleneck of their businesses. It relates to the obstacles that Rivard *et al.* (1998) identify for the integration of the building design process in the AEC industry (Architecture Engineering and Construction) : *"industry fragmentation, archaic data exchange, islands of automation, information growth and multiple views."*

From sketches to architectural, engineering and production plans, companies have to demonstrate a great deal of agility in design in order to handle the demand for changes and at the same time control costs, timelines and quality. Sub-contracting of structural components often adds to the complexity of the design processes. This highly distributed environment, where design information is exchanged across business functions and networks, using different data formats and linking interdisciplinary activities, poses a coordination challenge.

3 COORDINATION ACTIVITIES FOR DESIGNING PREFABRICATED STRUCTURAL SYSTEMS

Design of structural systems involves input from various stakeholders in the VCN at various steps of the process. Initially, the architect of the housing unit documents the building concept by identifying the profile of structural components, the structure permanent connections, details of the live and dead loads, and the integration of mechanical, electrical and sanitary systems. He has to design a structure that ensures that the components are not adversely affected by humidity or temperature and that the various component systems are compatible.

Once this design is set, a number of actors are brought together to make the design a reality, and the activities they perform and their relationships result in various coordination needs. Here is where a manufacturer of prefabricated structural systems needs integration. The diagrams on the top row of figure 1 traces a generic process for performing these activities. As we have seen, this process primarily uses paper plans as a means of coordination, mostly dependent on intensive design activities intervening in the first five processes, until manufacturing of the components is launched.

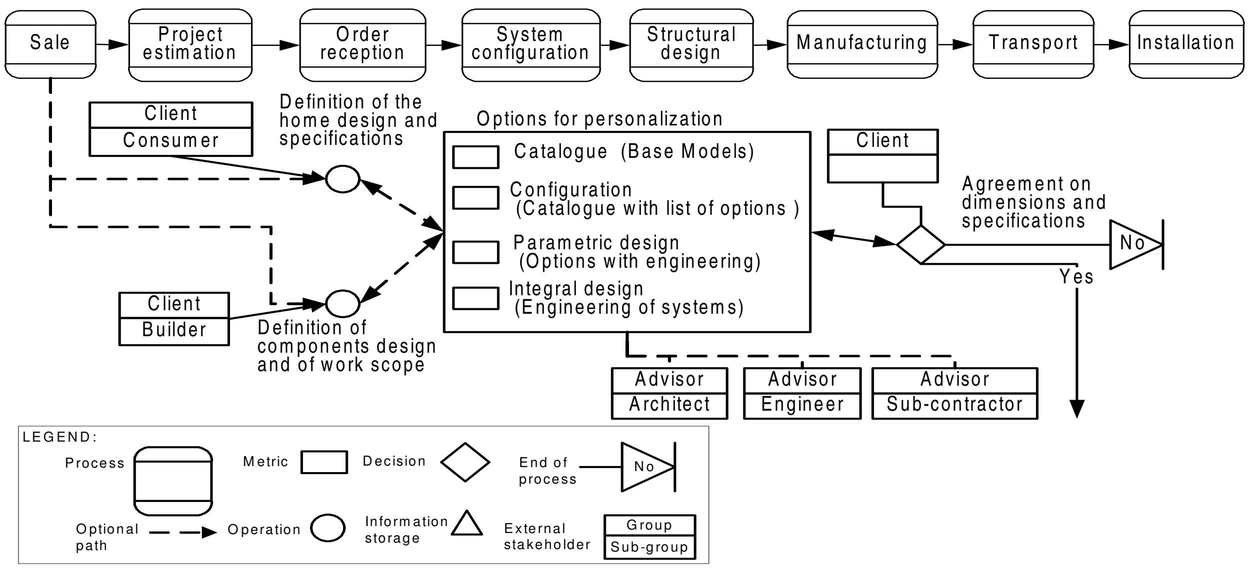

Figure 1. Description of the sale process

As detailed in the lower part of figure 1, the sales process is organized according to the type of clients. Selling directly to the consumer is done by companies producing entire house kits, such as modular homes. It is mainly marketed through catalogues with options. The model variations offered enable changes based on client needs and choices and make it possible to accelerate certain technical validations and subsequent approvals. They also make it possible to refine the specifications submitted to manufacturers. More frequently, sales are made through builders who then obtain the house in the form of components. In this instance, they define their design as thoroughly as possible, often using architectural plans, in order to permit integral engineering of systems.

At the time of the sale, information exchange becomes intensive. The buyer and the manufacturer go over the plans and review the available options. The objective is to inform the customer about quality, product availability, design options and opportunities for customization. The options and changes decided by the customer are recorded on the model plans.

The plans are reviewed in the project estimation phase by the sales representative who checks a general production schedule and sends the plans, terms and conditions of sale to the design/engineering division and accounting so that they can do a technical review and costing, respectively for the selected items. The project estimations are sent to the customer so that he can go over the drawings and construction costs related to the desired changes, and if everything is satisfactory, the customer signs an agreement in principle. If more changes are requested, the construction documents are sent back to the engineering division for more revisions and then returned to the customer for approval until a firm order is placed and the clients credentials are validated (order reception phase).

Some component configuration takes place to meet specific technical requirements in addition to standard code requirements. These systems include a series of predefined options that are pre-approved and often meet formal certification schemes. A manufacturer's use of these systems consists only of configuring the assembly options for the house to be produced. As presented in figure 2, these systems are available for both building structure and for the building envelope.

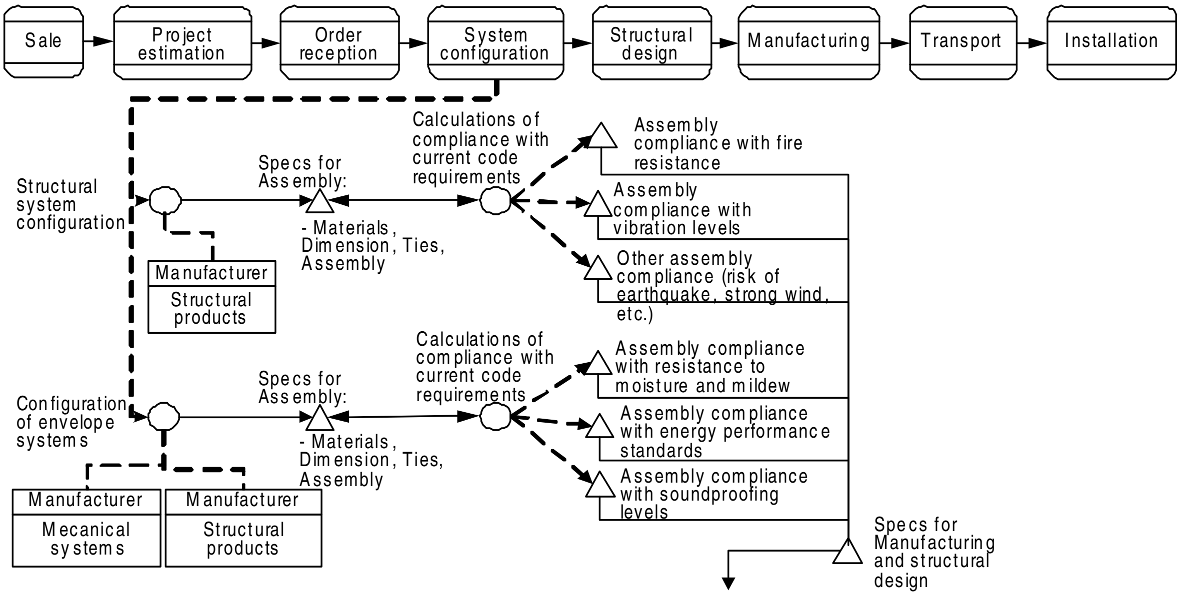

Figure 2. Description of system configuration process

For structural design of systems, most work is done by computer with proprietary software under engineer guidance and supervision. From the systems configuration and assemblies' definition, he will design structural elements as well as connectors. Cross-section properties will be analyzed and adaptations will be made to ensure the integrity of the structural system. For complex designs, this process requires multiple iterations with the customer and sub-contractors as well. Finally, at delivery, the manufacturer's shop drawings and assembly plans are provided in compliance with the details supplied by the builder.

4 MASS CUSTOMIZATION AND VALUE CREATING NETWORKS

While prefabricated component manufacturers are dealing with a bottleneck in design activities and with a lagging technological system, high volume homebuilders are looking for suppliers capable of automation in prefabrication.

The realignment of the homebuilding industry involving high-volume deliveries of prefabricated components is closely tied to the adoption of mass customization (MC). Da Silveria *et al.* (2001) have identified three basic trends for the adoption of MC. The first factor relates to the level of flexibility allowed by novel manufacturing and information technologies, which makes it possible to supply, with greater agility, an increased product variety at a lower production cost. The second factor is a growing demand for product variety and customization, where producers aim for narrow market niches rather than to rely on mass market segments. As a third factor, the need for customer-focused production strategies that account for shorter product life cycles and increasing competition in a global market environment. Internet sites of large homebuilders present a good overview of the results from focusing on customized services and market niches with product variety using web technologies (e.g. www.centex.com; www.pulte.com).

With the buying power of large builders and the application of MC, business strategies along the homebuilding network require additional services, including engineering, prefabrication and installation of components.

> *"On the other hand, large pro dealers are more likely to offer prefabrication and installation services to large builders than to small builders, either due to customer demand or due to the dealer feeling that there is more potential margin (and less competition) in offering services than in merely distributing products."*(Abernathy *et al.*, 2004)

With ongoing consolidation in the sector, the power of large builders as clients will increase (Schuler and Adair, 2003). The movement toward high volume delivery of housing units in the framework of homebuilding VCN (figure 3) may contribute to changing the rules of competitiveness in the sense of "network against network" competition. It has yet to be determined whether consolidated groups including large builders will effectively develop cooperative business practices such as some recent alliances suggest. Indeed, major changes in client-supplier relations occurring in high volume homebuilding are pointing in that direction (Lefaix-Durand *et al.*, 2006).

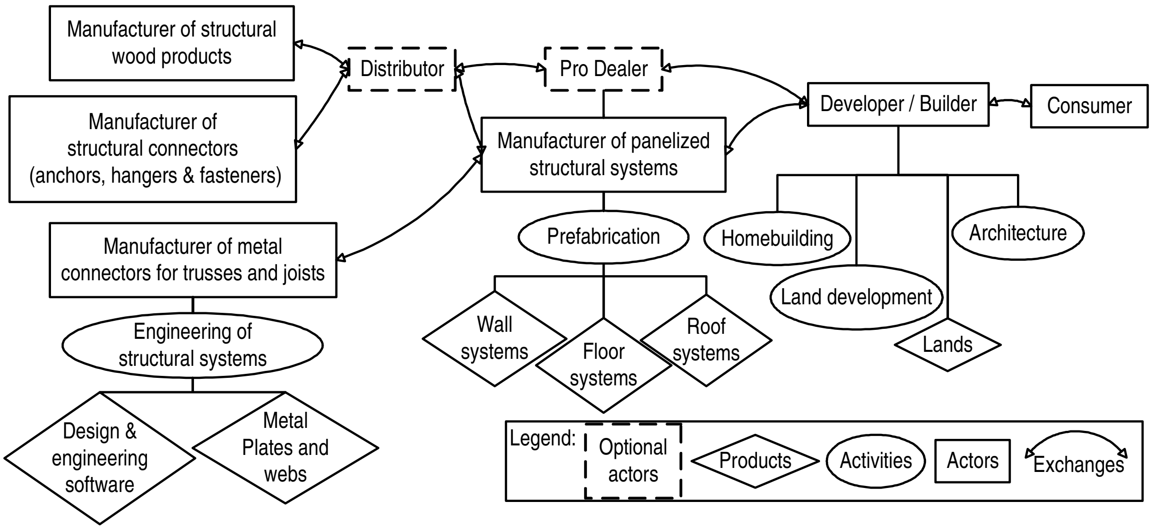

Figure 3 Prefabricated structural systems in the high volume homebuilding value creating network

> *"Business relations between companies are traditionally characterized by strong competition rooted in transactional issues (costs, product specifications, quality, deadline, performance, etc.). Such practices foster within value creating networks (business networks) inefficiencies in the form of accumulated stock, redundant activities, non-compliance with specifications, delays, etc."*
>
> *"…Those companies have therefore started to work differently with those partners by sharing certain information, training them, making them responsible for certain processes and trusting them."* (Translated from Frayret, D'Amours and D'Amours, 2003).

Competitive advantages can be expected through increased standardization of components, processes and information technology, as it may provide more efficient control tools and improved process coordination. A similar combination of standardization and prefabrication have led in other industrial sectors (e.g. cars, electronics) to the adoption of new manufacturing techniques to develop and introduce new types of equipment leading to enhanced productivity and quality (Barlow *et al.*, 2003).

According to these authors, Japanese house prefabricators have adopted build-to-order techniques which involve standardization, prefabrication and management of the supply chain such that houses can be provided with a high level of customization. With their approach, these prefabricators are able to meet the needs of individual buyers and specific market segments without incurring the costs of traditional customization.

5 ENGINEERING DESIGN FOR MASS CUSTOMIZATION IN HOMEBUILDING

The partners in a homebuilding VCN face significant challenges in order to be able to manage information and coordinate actions under a MC strategy. Environments where a network of several companies has to integrate the downstream activities of planning, production and delivery with the upstream activities of response to market demand and product design pose a complex problem.

The use of product platforms presents a way to manage the complexity by collecting the various assets shared by a set of products such as components, processes, knowledge, people and relationships (Robertson and Ulrich, 1998). A well-designed platform is essential to connect different parts of an enterprise including soliciting customer needs from order fulfillment to after-sale service. It is also critical to achieve the economy of scale by identifying repetitive applications involving to share tooling, knowledge and other resources. By evolving around a product platform, as used today in many discrete manufacturing environment (e.g. cars, computers, furniture, etc.), the design processes are expected to have an accelerated diffusion of the information required by production teams and homebuilding networks.

The integration of MC strategies requires the design process to take into account four basic platform strategies that will be discussed: commonality; modularity; scalability; and postponement (Huang, Simpson and Pine, 2005). As can be observed in catalogues of large builders on the Internet, some house designs incorporate such options.

> *Sekisui House (of Japan), for example, offers around twenty-two house models, each with about fifty different floor plans. These can be built in either steel or timber frame, finished externally in various prefabricated cladding systems, and their interiors can be adapted to three basic design concepts (Japanese, Western or hybrid). Finally, customers can choose between different specifications of interior fixtures and fittings.* (Barlow and Ozaki, 2005)

5.1 Platform strategies in homebuilding

Maximum repetition is essential in attaining mass production efficiency and effectiveness in sales, marketing, production and logistics. This is achieved through maximizing common design features so that modules, knowledge, processes, tools, equipment, etc, can be reused.

This approach is reflected by repetition in structural elements and dimensions seen in the catalogues of large builders or by the various system configurations offered for the structural elements and envelopes mentioned in section 3.

The most visible effect of product platforms in homebuilding is the ability to configure variations of models quickly and inexpensively by rearranging the components within a modular design. Modular design creates a clearly defined and relatively stable technical infrastructure. The creation of new products can thus draw on a growing choice among modular components by configuring product variations. As MC strongly relies on the ability of the product developer to identify and capture market niches, modular design should subsequently be conducive of a build-to-order configuration to meet the evolving needs of its different customers.

Standardizing earlier portions of the production process and postponing differentiation help improve the flexibility of the supply network (Feitzinger and Lee, 1997). Postponement of differentiation is a similar practice to the parade of trades on the construction site where the specificity of the final product (house) is realized closer to its delivery (on site). With postponement, the companies in the network have the benefit of focusing on a narrow aspect of operations where they have the greatest competitive advantage. The implementation of postponement in high volume VCN depends on coordinated and reliable information exchange between partners. It seems from our observation of product catalogues as a regular practice for the large builders where they define common house frames but offer various accessories of domestic use and of esthetic impact such as HVAC and cladding, respectively, delivering customization closest to final delivery.

Scale-based product families are developed by scaling one or more variables to ‘stretch’ or ‘shrink’ some of the platform elements and create products whose performance varies accordingly to satisfy a variety of market niches (Huang, Simpson and Pine, 2005). Platform scaling is a common strategy employed in many industries such as cabinetry, airplanes and cars where serialisation of product parameters can be performed. Scaling in homebuilding can be found in the work of Friedman (2002), who developed the adaptable house concept responding to such needs as affordability, adaptability, and sustainability linked to various market niches. He uses scaling for wall panel specifications permitting various interior lay-outs and variations on the house elevations.

This product platform approach should help systemize planning and control of the manufacturing system because the new products would be only a variation on known components; technical and operational evaluation and design would not have to be repeated in order to get a product to the market. Such systemization is determinant to the application of advanced technological application such Internet sales portals and advanced planning systems that can underpin the development of the VCN.

6 DISCUSSION

In the context of homebuilding, as in engineer-to-order manufacturing industries, it is difficult to optimize design processes because most of the expertise is distributed throughout the company and its network. Moreover, the design technologies in use are not capable to provide effectively planning and control systems over such network.

The development and use of interoperable technology for AEC building design activities, such as the CIS/2 neutral file format, and IFC based interoperable building information model for design and construction software are seen, respectively by Coleman & Jun (2004) and Bazjanac (2005), as the opportunity to reclaim the inefficiency costs for poor interoperability.

Advanced technological solutions to building design problems can bring valuable applications as proposed by Ugwu *et al.*(2000) to:

- filter information and retrieve design and project management data;
- customize information in order to be in proper line with users in distributed decision-making environments;
- automate routine design and project management tasks, including negotiation leading to the best design optimization.

These technological applications are part of a larger scheme known as Enterprise Integration (Vernadat, 2002) that concerns: efficient business process integration and coordination; concurrent design and engineering activities; increased flexibility throughout the company; total quality deployment; and interoperability of IT solutions, systems and people to face environment variability in a cost-effective way.

Reaching markets in time by linking execution schedules through the VCN depends on such integration from product inception to delivery and servicing. The integration concept, which aims at providing quickly the right information at the right place at the right time under the right format throughout the enterprise is therefore of utmost importance in order to implement mass customization strategies for high volume homebuilding. From a functional standpoint, this means expanding the reach of the planning and control processes over the VCN.

The companies which control well the integration of the decisions from strategy through tactics, down to the operational level are in a position to develop a competitive advantage. For such control over an entire network, the high volume housing suppliers will have to rely on information and decision technologies. They are a fundamental part in the integration and the coordination of the relations within the VCN. Technologies such as advanced planning and scheduling (APS) systems will make it possible for the companies to carry out current transactions, to make planning and control decisions and to collaborate to solve problems (Frayret *et al.*, 2005). They will be used to compress the reaction times and to reduce the inventories, to make agile the companies of the VCN.

In order to mass customize prefabricated wood frame components, it is suggested by our survey evidence that this manufacturing sector has not yet been provided with the proper integration scheme. As suggested by Vernadat (2002), more enterprise modeling work is needed to provide:

- a better understanding of the enterprise structure and operations (i.e. to visualize enterprise knowledge);

– support for engineering of existing or new parts of the enterprise both in terms of analysis, simulation, and decision-making (e.g. in the design of product platforms); and

– a model used to plan, control and monitor enterprise operations.

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