EXPLORING THE OPPORTUNITIES AND BARRIERS OF USING PREFABRICATED HOUSE COMPONENTS

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ABSTRACT

To satisfy customers' desires with a maintained efficiency of the production process is a challenge for many house construction companies. Houses are one-off projects with a production process characterized by variability and complexity that often lead to unpredicted costs. Prefabricated component solutions could possibly solve these issues through modularization, mass customization and delayed product differentiation. The purpose of this paper is to explore the opportunities and barriers to use prefabricated house components. Interviews were conducted with two industrial house manufacturers to pinpoint these opportunities and barriers. The impact of this research may have value for house construction companies considering the use of prefabricated house components. The use of these components may lead to benefits such as shorter lead-time, higher quality, decreased complexity in coordination and reduced risks of production failures. Moreover, this research may be valuable to house component suppliers in the business development of their product offers to industrial house builders.

KEY WORDS

Prefabrication, mass customization, house components, process improvement

INTRODUCTION

Long and costly building times are common problems in house construction (Latham, 1994; Egan, 1998; London & Kenley, 2001; Briscoe *et al*., 2004). These problems are argued to depend on the uniqueness of every house construction project (Bertelsen, 2004), whose many interacting parts lead to complexity (Winch, 1998). Customers want unique products that respond to individual requirements, especially costly requirements. Therefore, houses cannot be mass-produced, even though it probably is the fastest and cheapest way. So how can houses be produced more efficiently and still be customized? Mass customization is a concept that aims to simultaneously realize the cost-efficiency of mass production and the customization of products for individual users (Davis, 1989; Boyton et al., 1993). In house construction, this means that house components can be factory produced, where their combination enables buyers to customize their homes according to individual demands (Noguchi and Friedman, 2002; Noguchi, 2003). The production method used by Swedish manufacturers of prefabricated timber multi-storey buildings allows for mass-customization through the integration of volume elements. However, the production process can still be refined and new house components can be created from primary

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products. The purpose of this paper is to explore the opportunities and barriers of using prefabricated house components.

LITERATURE REVIEW

IMPROVING CONSTRUCTION PRODUCTIVITY

In the age of efficient manufacturing, improving productivity is a great challenge facing the construction industry (Bertelsen, 2004). The peculiarities of production in the construction industry lead to variability, and thus waste and low performance levels with respect to productivity and customer value (Vrijhoef and Koskela, 2005). Gann (1996) proposes that the construction industry should learn from improvements to productivity in the manufacturing industry. By creating a mass production of cars, Henry Ford exploited productivity improvements from the manufacturing industry (Lamming, 1993). Through the inspiration of Ford, Taiichi Ohno later created what is known today as lean production (Womack et al., 1990).

From lean construction, the challenge to improve construction productivity should focus on improving flow and value generation (Bertelsen, 2004). Bertelsen (2004) also pointed out that by meeting the challenges of productivity, two different strategies emerge: reduce the level of variability and complexity of on-site construction or develop new methods for the management and control of the construction process. Turin (2003) presented three alternative approaches – the component approach, the model approach and the process approach, compared to the traditional one-off project approach. The component approach relates to the mass production concept and implies a repetitive logic on the component level (Vrijhoef and Koskela, 2005).

COMPLEXITY AND UNCERTAINTY IN CONSTRUCTION

When concentrating on the resources needed to complete a task and the environment where it is carried out, the primary constraints affecting the outcome are inherent complexity and uncertainty factors (Gidado, 1996). Many researchers have now defined a complex process in different ways. For instance, Perrow (1965) defines the complexity of a task as the degree of difficulty in the search process to perform the task, the amount of time required to solve problems and the amount of knowledge required to perform the task. Thompson (1981) states complexity as the measure of difficulty to coordinate a production process, including activities that lack uniformity. Malzio et al. (1988) suggest that a complex process is comprised of innovative operations performed in an uncertain situation. Moreover, a process containing operations that are not clearly defined or lack specifications should also be seen as a complex process (Malzio et al., 1988). According to Gidado (1996), the number of parts and interaction of parts, the difficulty to understand or carry out the task and the employed resources in the process all determine the complexity of the process. Hill (1991) suggests that the size and diversity of tasks involved in a production process make the process complex. Therefore, the reviewed literature suggests that the complexity of a process is determined by (1) the number of parts involved and their interaction of parts in the process, and (2) the degree of difficulty in understanding and carrying out the tasks, (3) the familiarity and uncertainty of the environment, and (4) the number and variety of tasks in the process.

The construction process is comprised of numerous interacting tasks and parts. Therefore, the large number of tasks and parts involved in construction suggest that construction is generally complex in nature (Gidado, 1996). Bertelsen (2004) believes that complexity influences the productivity and quality of construction. Construction is the production of unique products of art (Bertelsen, 2004). Customer choices shape the different outputs that attribute the uniqueness of each project (Dubois and Gadde, 2000). The uniqueness of each project leads to the variability of construction projects, increasing the complexity and uncertainty of the construction process.

MODULARIZATION AND MASS CUSTOMIZATION

Modularization is a concept used to diminish the number of system parts by grouping them into components (Bertelsen, 2005). This decreases the complexity and variability as production control is gained (Lennartsson et al., 2009). By combining different components in various ways, a wider product range can be attained (Morris and Donnelly, 2006), known as mass customization (Davis, 1989; Boynton et al., 1993). Mass customization is claimed to be the key to successful business, a concept that is seen as a "marriage" between marketing and production (Pine et al., 1993). This "marriage" is claimed to combine the low production costs of mass production with customization to meet the needs of customers. However, Da Silveira et al. (2001) argue that certain factors need to be fulfilled for successful mass customization. These factors are:

(1) Customers must be willing to pay for a customized solution that is more expensive and lengthier to produce than a mass-produced product (Hart, 1996; Kotha, 1996).

(2) The market conditions must be appropriate, i.e. being the first with a system can be advantageous (Kotha, 1996).

(3) The value chain must be ready, i.e. suppliers must be willing to attend to demands from the manufacturing company (Lau, 1995; Feitzinger and Lee, 1997)

(4) Technology must be available in terms of process flexibility and IT-systems (Pine, 1993; Lau, 1995; Kotha, 1996; Hirsch et al., 1998)

(5) Products must be customizable (Pine et al., 1993). Merging independent components into a modular system must be possible (Feitzinger and Lee, 1997).

(6) Knowledge must be shared in dynamic networks (Pine et al., 1993) with manufacturing and engineering expertise (Kotha, 1996). Kotha (1995) argues that in-house development is preferred.

To relate to the third factor from Da Silveira et al. (2001) of having suppliers that are willing to attend to the manufacturing company, Vandermerwe (1994) discusses five requirements from a company to its suppliers: (1) more value that is connected to the usage and performance of a system, (2) solutions rather than product and services, (3) take advantage of the supplier's core competences, (4) a total solution that minimizes the number of suppliers, and (5) customized relationships. This also relates to the lean concept, where Lamming (1993) views close collaborations with suppliers as a prerequisite for lean manufacturing. Automobile manufacturers in Japan are a typical example of such constellations, which have been copied worldwide through the book "The machine that changed the world" by Womack et al. (1990). Automobile manufacturers pass on 50% of the engineer hours to their closest suppliers, which in turn collaborate with their suppliers. Through profit sharing and complete transparency, they are familiar with each other's processes. The lean supplier network actually seems to coincide with the three last factors of Da Silviera et al. (2001), with their modularized product, knowledge sharing and the development of new technology.

To facilitate the integration of house component solutions, there seems to be a need for collaboration beyond company borders. Construction materials can be turned into house components that are designed, manufactured and installed under a single contract (Bertelsen, 2005), termed by Van Weele (2008) as a "turn-key" contract. The advantage of this is that the sub-contractor has the responsibility to deliver the specified solution, i.e. the house component, at a fixed price. The purchasing of many smaller products and services is more complex compared to larger components and can be costly if managed poorly (Van Weele, 2008). The term "house component" in the context of industrial timber housing is somewhat ambiguous and can range from an entire structure of volume elements to a pre-sawn board of timber (Bildsten, 2011). Noguchi and Friedman (2002) have a similar definition and define "house components" as interior and exterior components and space arrangements that affect the total area of the home.

CASE STUDIES: INDUSTRIALIZED HOUSE MANUFACTURERS

Interviews were conducted at two industrialized timber house manufacturers and observations were made at one of them to identify the opportunities and hindrances for the use of prefabricated house components. Table 1 shows the details of the case companies and the conducted interviews.

Table 1: Details of case companies and interviews

Case company	Turnover (million Eur)	Production method	Interviews	Observations
Company A	50	Timber volume elements	Two semi-structured with a purchasing manager and a carpenter	Observations were made of the production in the factory for four months
Company B	50	Timber volume elements	One semi-structured with the CEO	-

As Table 1 shows, the studied case companies are of the same size and use the same kind of production method. The choice of case companies is an information-oriented selection that can be seen as extreme cases (Flyvbjerg, 2001). The extreme lies in their particular production method that consists of prefabricated parts. The experiences of both companies are therefore considered valuable in a puzzle-solving analysis (Yin, 2007), concerning the opportunities and barriers of using prefabricated house components. The respondents were asked about their current prefabricated solution, which solution they have tried or wanted, and the opportunities and barriers that exist according to them. The interviews were conducted through personal meetings at the companies. Two case companies may appear to be little to underpin new theoretical knowledge, however Flyvbjerg (2001) argues that even a few number of cases can be important for an enhanced knowledge. With context-dependent examples, new levels of knowledge can be reached that cannot be gained through deduction and general principles (Flyvbjerg, 2001). Flyvbjerg (2001) argues moreover that in-depth learning of a particular context is a prerequisite for an advanced understanding and can provide a richer and more accurate picture of a certain phenomenon. This is because the researcher continuously is in pursuit of the perfect explanation during an extended period of time. The extensive observations of the production process of Company A makes the results of the interviews more reliable as the answers could be verified. For generalization however, such few cases have limitations but can serve as a starting point for further studies (Flyvbjerg, 2001; Yin, 2007).

OPPORTUNITIES OF PREFABRICATED HOUSE COMPONENTS

One of the main arguments when selling a house made from prefabricated components is the ability to deliver a solution at a fixed price. The CEO of company B states that this is a competitive advantage compared to traditional onsite house construction companies. This also applies for the house builder *per se* in creating the house. To be able to give a "fix-price", knowing the costs is important, house construction companies prefer to buy house components rather than coordinate different subcontractors. For example, Company B purchases prefabricated bathrooms, because it is a "turn-key" solution that does not require much coordination of different sub-contractors, such as plumber, masons, carpenters and electricians. These different sub-contractors may not give a fixed price for their services and the time for completion may be vague. Prefabricated bathrooms are ready to be plugged in with the electrical installations and plumbing already prepared. Because it is difficult to estimate the cost of subcontractors, buying house components at a fixed price is an alternative solution, providing greater security to the house construction company in allowing them to know the costs.

The lead-time is also much shorter and more exact when using volume elements compared to onsite house construction. This is because the production uses standardized work procedures and a fundamental customizable framing system. To further ensure the exactness of the lead-time, the procurement of materials for the house projects must imply *value-for-production*, see Bildsten (2011). For instance, Company A buys pre-sawn timber that can be directly disseminated into the production line. This eliminates the sawing station. To further shorten the lead-time, Company A is considering the use of prefabricated bathrooms and kitchens, as bathrooms and kitchens often become bottlenecks in production because of their many parts.

Factory production enables regular deliveries of materials on a long-term basis, thereby securing the availability of materials for production. Secure deliveries were seen by the interviewed companies as much more important than price in choosing supplier because not having the right component available at the right moment would lead to failure in production. To further reduce the risk of production failures, both companies strive after collaborations with suppliers to buy as much customized house components as possible. Both companies are also working on reducing the variety of components to decrease the complexity of both purchasing and production. According to Van Weele (2008), reducing the variety of components is a common improvement strategy among many manufacturing companies. Secure delivery, customization and reduced variety of components all imply close and long-term relationships with a limited number of suppliers, which was characteristic for both companies.

The framing system of timber volume elements allows houses to be mass customized. No housing project is identical to the other and houses can even be triangular! The modular system make product differentiation possible late in the project as production is much faster than regular onsite construction, however once production has started, changes must be avoided. The Company A has developed a bathroom floor together with a supplier that can have customized patterns created by a professional designer. The bathroom floor product also improves quality by securing the risk of water leaks as it comes in "one piece". The company A is looking into developing more interior house component solutions as the handling of customers' choices is time-consuming and risk disruptions in production if poorly managed. The use of standardized house components makes it easier to control quality in production as continuous improvement of repetitive processes can be made e.g. according to the lean concept. The better quality of factory produced house components compared to regular onsite construction, has also been studied by Johnsson and Meiling (2009). Moreover, the factory environment protects from the exposure of bad weather and theft. From a sustainable perspective, prefabricated house components are adaptive to changes and houses can be moved to a different location through reassembly. Table 2 summarizes the opportunities found when analyzing the interviews and observations.

Table 2: Opportunities in using house components

Opportunities	Explanation
Knowledge of costs	Buying products instead of services makes it easier to make a budget.
Lead-time reduction	Through the use of prefabricated components in tasks with long execution times, the lead-time can be reduced.
Securing availability of materials	The purchasing of materials and services is simplified through standardized work procedures and limited variety of components with long-term supplier contracts. This reduces the risk of standing without materials.
Reduced risk of production failures	The decreased complexity of coordinating people and materials through repetitive systems of house components reduces the risks of production failures.
Mass customization	Exterior and interior design is handled systematically through professional designers.
Delayed product differentiation	Modularization could possibly enable a delay of customization to the end of the production process.
Improved quality	The delegated responsibility makes people concentrate on a particular activity, which they do well through repetitive experience. Also, the factory environment prevents exposure to bad weather that otherwise may destroy materials.
Moveable houses	Through modularization, exterior and interior house components make it possible to simply move the house to a new location.

BARRIERS OF PREFABRICATED COMPONENTS

Tolerances are often regarded as a hindrance for prefabricated house components and both companies are working on improving the exactness of the volume elements. A as straight angle is enough to integrate prefabricated bathroom pods into timber volume elements. However, prefabricated kitchens that can cover an entire wall of a volume element can be harder to fit as the sizes of the volume elements can vary with a couple of centimeters. The size is inaccurate because of inadequate assembly of the wall layers, according to the interviewed carpenter of Company A. This leads into another issue that occur when integrating the volume elements, the living area is reduced because of the multiple layers of walls. The same problem occurs for every type of house component with a wall structure. Another barrier to the implementation of new house components is the cost of developing the components and trying new things disrupts current production. When adopting the manufacturing system to the purchasing of house components from external suppliers, the system may be vulnerable if the suppliers disappear. This is because with advanced house components, the whole production relies on a few particular suppliers of solutions that are hard to replace. Moreover it is difficult to calculate the value of the "solution" that the house component comprises in production, making purchasers reluctant to buy prefabricated houses or house components. The reluctance is also depending on the fear of committing to something unknown. Finally, finding suppliers willing to deliver the desired solution is the last barrier. According to the interviews, it can be difficult to convince the suppliers of making customized solutions, especially since most suppliers of construction materials are large and dominant players. Table 3 summarizes the barriers found through the interviews and observations.

Table 3: Barriers in using house components

Barriers	Explanation
Tolerances	To make all house components fit together, the house components require accurate sizes.
Reduced living area through multiple layers	The assembly of volume elements and interior components creates multiple layers of walls that reduce the living area.
Cost of development	Before the house components are ready to be disseminated into the production, there is the initial cost of developing them.
Dependency on suppliers	Suppliers that offer customized products and services may become difficult to replace if for some reason they disappear.
Acceptance of system by house buyers	Acceptance of innovative construction systems, e.g. timber volume elements, is sometimes difficult, since customers often have a tendency to prefer traditional on-site constructions.
Price	The price is generally higher, because a house component system is an "all inclusive price" for both services and materials. Therefore, prefabricated solutions are often rejected, since other offers seem cheaper.
Supplier dominance	Construction material suppliers are generally a few large players that provide standard components and are reluctant to customize their products.

FINDINGS AND CONCLUSIONS

House components have the potential to decrease complexity in production by reducing the number of parts. By turning raw materials into house components, the production process of housing has the potential to become more efficient. The most complex areas of the house, consisting of many parts, would probably be the most favorable to organize as sub-systems of house components. Bathroom pods, which are already on the market, are a typical example.

To reduce variability and complexity in construction projects, construction companies have an increasing demand for innovative component solutions. The parameters of supplier's products and the common construction system affect the efficiency of production. Therefore, innovation at the component level must be regarded as a promising area of investigation and investment for many construction material manufacturers. For suppliers of house components, there is a business opportunity in not only improving the production process of industrial house manufacturers, but also the entire business process, including design and sales. House components not only contribute to reducing lead-time, production cost, and operation complexity, they also have the potential to create a new product range of customized houses.

The new type of industrial construction has placed challenges on construction management in several ways, particularly the supply chains and purchasing functions in construction companies. The right product from the right supplier used as input to a system integrator with a flexible construction system would be ideal. To obtain this, a strong centralized organization must be created through one process owner, i.e. the system integrator with total responsibility for design, production and erection of the house. The head manager of the house building company must have the technical knowledge, power and resources to incorporate the sub-system into the whole house framing system. The purchasing team acts as a gatekeeper to collaborate with suppliers. This team must have competence of the technical system and production to interact with suppliers in the development of the construction process. Therefore, purchasing must be a strategic function at a top management level if the construction process needs to be changed. A bridge must be built between the supplier and house manufacturer to render the supply chain more efficient and cross-functional teams more transparent of each other's processes. Such long-term collaboration could make the production of houses more efficient in terms of productivity, and effective to satisfy users needs of variety.

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REFERENCES

Bertelsen, S. (2005). "Modularization – A Third Approach to Making Construction Lean?" *Proceedings of the 13th Annual Conference of the International Group for Lean Construction, Sydney.*

Bertelsen, S. (2004). "Lean construction: Where are we and how to proceed?" *Lean Construction Journal.* October.

Bildsten, L. (2011). *Towards Partnerships in Industrialized Housing.* Licentiate thesis. Linköping University.

Boyton, A., Victor, B. and Pine, J. (1993). ”New competitive strategies: Challenges to organizations and information technology.” *IBM Systems Journal,* 32 (1) 40-64.

Briscoe, G. and Dainty, A. (2005). “Construction supply chain integration: an elusive goal?”, *Supply Chain Management: An International Journal*, 10 (4), 319-326.

Egan, J. (1998). *Rethinking construction.* DETR, London.

Da Silveira, G., Borenstein, D. and Fogliatto, F. (2001). “Mass customization: Literature review and research directions.” *International Journal of Production Economics*, 72, 1-13.

Davis, S. (1989). “From future perfect: Mass customization.” *Planning Review*, 17 (2), 16-21.

Dubois, A. and Gadde, L-E. (2000). “Supply Strategy and Network Effects Purchasing Behaviour in the Construction Industry.” *European Journal of Purchasing & Supply Chain Management*, 6, 207-215.

Feitzinger, E. and Lee, H. (1997). “Mass customization at Hewlett- Packard: The Power of postphonement.” *Harvard Business Review*, 75 (1) 116-121.

Flyvbjerg, B. (2001). *Making social science matter: why social inquiry fails and how it can succeed again.* Cambridge University Press. Cambridge.

Gann, D. (1996). ”Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan.” *Construction Management and Economics*, 14 (5), 437-450.

Gidado, K.I. (1996). “Project Complexity: the Focal Point of Construction Production Planning.” *Construction Management and Economics*, 14, 213-225.

Hart, C. (1996). “Made to order”. *Marketing Management*, 5 (2) 10-23.

Hill, T. (1991). Production/Operation Management- Text and Cases, 2nd edition, Prentice Hall.

Hirsch, B., Thoben, K-D and Hoheisel, J. (1998). ”Requirements upon human competencies in globally distributed manufacturing.” *Computers in Industry*, 36 (1-2) 49-54.

Johnsson, H. and Meiling, J.H. (2009). “Defects in off-site construction: timber module prefabrication.” *Construction Management and Economics*, 27 (7), 667-681.

Koskela, L. J. and Vrijhoef, R. (2000). ”The prevalent theory of construction is a hindrance for innovation.” *Proceedings of the 8th Annual Conference of the International Group for Lean Construction, Brighton, UK.*

Kotha, S. (1995). “Mass-customization: Implementing the emerging paradigm for competitive advantage.” *Strategic Management Journal*, 16, 21-42.

Kotha, S. (1996). “From mass production to mass-customization: The Case of the National Industry Bicycle Company of Japan.” *European Management Journal*, 14 (5) 442-450.

Lamming, R. (1993). *Beyond Partnership, Strategies for Innovation and Lean Supply.* Prentice Hall, New York

Latham, M. (1994). *Constructing the Team*. HMSO, London.

Lau, R. (1995). “Mass-customization: The next industrial revolution.” *Industrial Management*, 37 (5) 18-19.

Lennartsson, M. (2009). “Production control through modularization.” *Proceedings of the 17th Annual Conference of the International Group for Lean Construction Proceedings, Taipei, Taiwan.*

London, K. and Kenley, R. (2001). “An industrial organization supply chain approach for the construction industry: a review”. *Construction Management and Economics*, 19 (8) 777-788.
Malzio, P., Moselhi, O., Theberg, P. and Revay, S. (1988). “Design Impact of Construction Fast-Track.” *Construction Management and Economics*, 5, 195-208.
Noguchi, M. (2003). “The effect of the quality-oriented production approach on the delivery of prefabricated homes in Japan.” *Journal of Housing and the Built Environment*, 18, 353-364.
Noguchi, M. & Friedman, A. (2002). ”Mass custom design system model for the delivery of quality homes— learning from Japan’s prefabricated housing industry”, *Proceedings from the CIB W060-096 Syllabus Joint Conference, Measurement and Management of Architectural Value in Performance-Based building*, pp. 229–243.
Perrow, C. (1965). *Hospitals, Technology, Structure and Goals.* Handbook of Organizations, Rand McNally, Chicago.
Pine, J., Victor, B. and Boyton, A. (1993). “Making mass customization work.” Harvard Business Review, 71 (5), 108-111.
Thompson, P. (1981). *Organisation and Economics of Construction*. McGraw-Hill, UK.
Turin, D.A. (2003). “Building as a process”. *Building Research & Information*, 31(2), 180– 187.
Vandermerwe, S. (1994). “Service Network Structures for Customer Oriented Strategies”, in Kosteki, M. (ed.) Marketing strategies for services: Globalisation, Client- orientation, De-regulation, Pergamon Press, Oxford, 41-63.
Van Weele, A.J. (2008). *Purchasing and supply chain management: analysis, strategy, planning and practice.* London: Thomson Learning.
Vrijhoef, R and Koskela, L. (2005). ”Revisiting the three peculiarities of production in construction.” *Proceedings of the 13th Annual Conference of the International Group for Lean Construction, Sydney, Australia.*
Winch, G. (1998). “Zephyrs of Creative Destruction: Understanding the Management of Innovation in Construction.” *Building Research and Information*, 26 (5), 268-279.
Womack, J. P., Jones D. T. and Roos, D. (1990). *The Machine that changed the World.* Free Press.
Yin, R.K. (2007). *Case study Research: Design and Methods.* London: Sage Publications.