CUSTOMER VALUE IN LEAN PREFABRICATION OF HOUSING CONSIDERING BOTH CONSTRUCTION AND MANUFACTURING

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ABSTRACT

Prefabrication increases standardisation and repetitiveness both in processes and products and yields a progress of a construction process that is more comparable to manufacturing than on-site construction. Previous research shows that house prefabrication reduces waste and resolves some of the peculiarities of construction (e.g. one-of-a-kindness, on-site production and a temporary organisation). However, the need for value creation by considering construction peculiarities in prefabrication is also discussed within the IGLC community. Hence, the aim of this research is to contribute to the understanding of how to obtain a lean prefabrication strategy, i.e., a strategy that considers both waste reduction and value generation.

To find suggestions for development within value creation of a prefabrication strategy, a multiple case study of the total population of Swedish timber volume element (TVE) prefabrication, and a customer survey of 57 potential and previous real-estate trustees of the TVE building system was performed. The result shows that value generation is connected to meeting customer needs formulated within the deep-rooted culture of construction based on historical knowledge and attitudes. Traditional on-site production is still apparently perceived to allow a higher degree of control, trust and flexibility. To obtain a lean prefabrication strategy both waste reduction, through the use of manufacturing related project orientation, and consideration of the construction culture is therefore needed. Previous researches suggest flexibility, customisation and convincing design have to be met to obtain value generation and this is empirically confirmed by this research. However, the research also shows that a lean prefabrication strategy still has to meet the traditional needs of the process, as control and trust of the production process and the product, trust of the manufacturer together with information transfer, to obtain customer value. Control and trust can be supported by information transfer via strategic alliances and demonstration houses.

KEY WORDS

Lean prefabrication, Construction peculiarities, Customer value, Timber volume element housing

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INTRODUCTION

The needs for reduced costs and increased efficiency in construction are widely discussed in construction related areas. However, the efforts have shown to be slower and less successful (thus far) compared to manufacturing (Winch 1998). One solution mentioned in Swedish housing is development towards increased industrialisation to better control the process and the quality of the results. Herein industrialisation in construction is connected to prefabrication where production, as in manufacturing, is made in a controlled factory environment. Thus the development of industrialisation is a development that brings construction closer to manufacturing. The same train of thought is found in the lean construction area where ideas from lean production, also developed in manufacturing, are applied and adopted to construction. Hence industrialisation of construction through prefabrication, and the application of lean production/lean thinking to on-site construction are two separate, but parallel, ways towards the same goal.

Lean is about waste reduction and value creation and house prefabrication has in previous research shown to decrease some types of waste found in traditional on-site construction, (e.g. Höök and Stehn 2005) through reduction of the construction peculiarities. However, prefabrication of houses does not necessarily result in a lean production process and within the IGLC community an ongoing discussion points out the need for addressing value generation in prefabrication (e.g. Vrijhoef and Koskela 2005, Ballard 2005). Hence, the aim of this research is to contribute to the understanding of how to obtain a lean prefabrication strategy, i.e. a strategy that considers both waste reduction and value generation.

VALUE GENERATION AND THE CONSTRUCTION CULTURE

Value can only be defined by the customer and defining value is the first step in lean thinking (Womack and Jones 2003). However, Barshani et al (2003) argue that value not necessarily is customer driven and suggest that value, as conceived in the Lean construction community, is generated through the interplay between customer and supplier. Hence, the understanding of a customer's requirements and what is perceived to be value is basis to a supplier's value delivery. A perceived value of a construction product customer can be connected to needs formulated within the industry culture context, i.e., the norms the members of a given group follow and the material goods they create (Barthorpe et al. 2000). To understand what is perceived to be value in construction it is important to understand the technical and social context of construction, i.e., the construction culture. Here, learning from the knowledge of the intentions to change and accept innovations can help us understand what is perceived to be value.

Improvements and innovations such as industrialised housing are requested by construction actors but the construction industry lacks a systematic and strategic approach to change because its culture remains essentially adversarial, e.g. with continuing reliance on price competition and firm contractual arrangements (Saad et al. 2002). The "problem-solving" culture of construction does not allow any evaluation of current problems because on-site problems and problem solving are a natural part of the construction culture (Winch 1998). The construction industry thus has difficulties to emphasize essential needs, as many problems are either not seen or ignored, and are rated among "normal features of the business" (Vrijhoef and Koskela 2000). Bröchner et al. (2002) have investigated the Swedish construction sector with an emphasis on the implications of the local culture and have found that even though interest in

developing more innovative organisational relations and production methods has increased in recent years, the actors nevertheless seem reluctant to change the traditional allocation of responsibilities and the traditional way of working. Construction professionals will also not adopt new technologies and innovations until they are seen to be beneficial (Crowley 1998). The same arguments are found in innovation diffusion theory where the level of innovation adoption is argued to be based on the possibility of an adopter to see advantages of the innovation (Rogers 2003), i.e., value. As discussed above, the apprehension of an innovation and what is perceived to be value is connected to a potential adopter's norms and environmental culture. Previous knowledge, practical experience (Roehm and Sternthal 2001, Pereira 2002), social environment (Rogers 2003) and level of information distribution (new knowledge) of an innovation influence the apprehension as the customer not necessarily is sophisticated enough to grasp the merits of a product (Womack and Jones 2003).

The social and technical environment of construction can be characterized by the construction peculiarities that influence the characteristics of constructed products, ways of production, and the industry itself (Vrijhoef and Koskela 2005). Peculiarities found in on-site construction are the:

- *One-of-a-kind production* that is argued to be caused by different customer needs and priorities, differing sites and surroundings, and different views of designers on the best design solution (Koskela 2003).

- *Site production* that conveys temporary production facilities and the project is, e.g. exposed to the uncertainty and unpredictability in clerk of the weather.

- *Temporary organisation* (Koskela 2003, Riley and Clare-Brown, 2001) that is designed and assembled for the purpose of the particular project and is composed of different companies and design practices that have not necessarily worked together before (Dubois and Gadde 2002).

- *Governmental control* via plan and building regulations. Each project is one-of-a-kind due to governmental plan and building regulations and each project has to pass through construction permissions issued by local authorities (sometimes with local interpretations).

Hence, the peculiarities of construction convey a social and technical knowledge based context that is difficult to modify. The construction actors are used to this "surrounding" where the construction process is divided into separate phases and several different actors cooperate in projects.

JOINT CONSIDERATION OF MANUFACTURING AND CONSTRUCTION

A large part of the lean construction movement has claimed that construction improvements and innovations have to be managed within construction itself, i.e. within the context of the existing production situation. This "internal" view is claimed to be important to cope with the dynamics of construction, through e.g. planning systems of on-site activities, as the last-planner system (Ballard 2000). Others implicate that prefabrication, industrialisation and a shift of focus from construction towards manufacturing is another possible solution (e.g. Pasquire et

al 2004). Traditional construction has been shown to convey difficulties for innovation adoption when improvements are made within on-site construction (e.g. Green 1999, Low and Mok 1999). Considering this, a shift from construction to manufacturing might experience a similar difficulty.

Eliminating construction peculiarities does not necessarily solve problems by itself, instead a wider approach is needed (Koskela 2003). The basic argument is that construction peculiarities causing production problems and waste, i.e. any activity not contributing to the creation of value, are needed to be solved or reduced. But peculiarities do not necessarily have to result in production problems leading to waste, and peculiarities are thus not equal to problems or waste. Sometimes achieving value (economic, environmental, social, cultural and historic) is more important than reducing waste (Vrijhoef and Koskela, 2005). Therefore, the relation between waste and value generation has to be noticed in the context where improvements in construction are considered. Peculiarities that lead to waste and not value need to be better managed, though in some cases the peculiarities of construction must be accepted if the value is greater than the loss caused by waste, e.g. from an economic view. Large and complex building projects may contribute to waste in terms of production, but still produce value for the social and cultural environment (Vrijhoef and Koskela 2005). Thus, there is not always a need or a solution to reduce or resolve the peculiarities and the culture of construction to achieve improvements.

Waste reduction is often connected to an increased amount of repetitiveness in products or in processes, a view related to manufacturing. As a result, design has been related to making and one-of-a-kindness, while value generation has been related to waste reduction. The degree of customisation of a product is therefore often considered only in terms of repetitiveness, without considering the process of design and its relation to value generation (Ballard 2005). The challenge is to understand design and customisation as a process of value generation and to learn how to integrate design and repetitiveness without sacrificing the essential nature of either (Ballard 2005). The need for contemporaneous value generation is also confirmed by the low adoption of early attempts of industrialisation of construction, where main goals were decreased costs and lead times, while flexibility in the product could not correspond to customer demands (Gann 1996).

Prefabrication and lean production in a factory environment enable waste reduction through process orientation that entails one process owner, controlled production and a standardised process. However, from the above discussion, a lean prefabrication strategy does not imply waste reduction through process orientation and lean production, value generation that considers the construction culture is also needed in the same context. The construction peculiarities entail a project orientated construction culture where the actors are used to a flexible, customised product with a practically unrestricted design. These factors have to be considered to obtain value in construction. The prefabrication context in construction, Figure 1, is thus edified by project orientation that enable value generation in a construction environment, and process orientation that enable waste reduction in a manufacturing environment. According to the above literature examination, a lean prefabrication strategy has to consider the interface between construction and manufacturing to be accepted by construction actors, and not only focus waste reduction in manufacturing related areas.

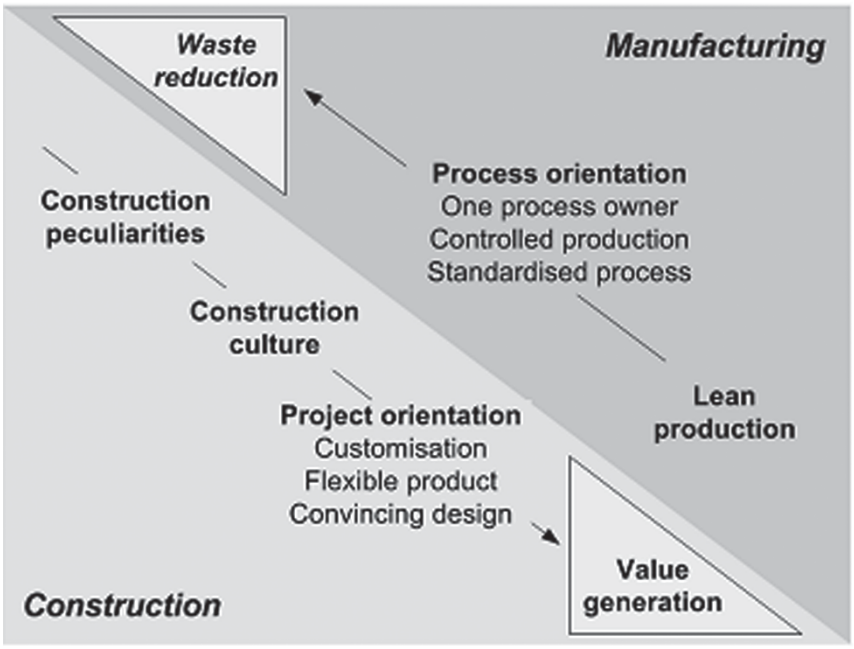

Figure 1: The prefabrication context in construction incorporates both manufacturing and construction

Swedish timber volume element (TVE) prefabrication is a building system that makes use of factory production where approximately 90 % of a building is produced in-door. The building system is industrialised and manufactured through prefabrication and factory production. TVE prefabrication is thus an example of an innovative building system where the actor roles and the production process are changed compared to traditional on-site construction (c.f. Höök 2005). Despite the shown possibilities for increased efficiency and quality and decreased costs of TVE housing through the use of industrialisation and prefabrication, the building system has not yet gained confidence from the Swedish market. The building system reduces construction peculiarities found in on-site construction and part-wise element prefabrication and thus reduce waste (Höök and Stehn 2005). However, the hypothesis employed herein is that the loss of acceptance and innovation diffusion for the TVE system are due to an incomplete prefabrication strategy that needs a value creation formulated in a traditional construction context.

METHOD

To understand the connection between the acceptance and the innovation diffusion (i.e. the spread of a new idea or practice throughout a social system) and the need for value generation to create a lean prefabrication strategy, qualitative interviews with potential Swedish customers of the TVE building system was performed. The interviews both examined customers' needs of a general building system (based on their traditional construction culture and construction peculiarities view points) and specific TVE prefabrication product offer attitudes and needs. Initially, 25 Swedish municipalities with a high growth were selected and 54 respondents

contacted from municipality's owned and private real-estate companies. The achieved response rate was 87%. Completing this, ten real-estate companies with specific experience of TVE prefabrication also participated in the study and the number of participants in the survey thus totaled 57. The purpose of these interviews was to compare the main survey with attitudes of customers with previous experience and knowledge of the building system to understand if the low acceptance level also is due to a loss of information distribution of the suppliers. The results from the customer survey were compared to the product- and process strategies found in the multiple case study with the total population of Swedish TVE manufacturers of commercial, multi-storey and multi-family houses (Höök and Stehn 2005).

RESULTS

The Tve Product Offer

TVE prefabrication processes span from owned or purchased architectural and structural design to the manufacturing and delivery of highly customised turnkey houses or complete projects. Timber volume elements are manufactured with a repetitive production process in a controlled factory environment. A timber volume element is a closed three-dimensional structure built up by timber based structural elements, complete with technical installations and finishing. After the volumes have been finished in the factory they are transported to the construction site, assembled (mainly by the manufacturers own staff) into a complete house. Finally, depending on the material, the façade is finished in the factory (timber panels) or on-site (plastered), Figure 2.

Figure 2: Manufacturing and assembly of volume elements to a finished house in TVE prefabrication

TVE manufacturers are able to, and prefer to, take care of the whole construction process from design to a complete building. The most profitable (for them and for their customers) concerning the total cost and lead time is if they have the opportunity and are allowed to take care of and control the whole process. In the design phase, the companies often have their own architects or contracted architects on a long-term basis. When the architectural design is ready,

the companies also have their own structural engineers working out the frame and the building elements design. The main advantages of the building system, from the manufacturers' point of view, are:

- High quality due to controlled factory production and experience feedback.
- Risks such as moisture damage are decreased compared to traditional on-site construction as production is made in-doors and assembly and finishing of a house on-site only takes a couple of days.
- Reduced lead times because of the factory production and cost control due to long-time supplier relations that bring value to a customer.
- Reduced house prices, if the project contains repetition effects (e.g. student dwellings projects).

However, when projects are highly customized, the price is not always advantageous, but still equivalent to traditional on-site construction. TVE manufacturing is competitive when the whole building system - the whole product concept - is considered by customers. TVE manufacturers do not compete with highly technical solutions in their products, but with knowledge of component integration and the construction, and a total economical offer.

The collected apprehension from the TVE manufacturers regarding potential customers is that they in general still are doubtful of TVE prefabrication because their knowledge of the system advantages and disadvantages is low. If the project has been designed by architects and consults without any knowledge of volume element prefabrication (as is usually the case), the TVE concept has difficulty in corresponding to the flexibility demands offered by traditional on-site construction. Moreover, today's clients do not seem to understand the construction process of the building system, where they in the early stages have to decide the complete design of the house, because late changes cause problems and additional costs in the factory production.

Customers General Building System Needs And View Of The Tve Product

The results of the survey of potential TVE customers is presented as needs and requirements on a general building system together with apprehensions of the prefabricated TVE building system in Table 1. The percentages in the table show the response rate of potential customers (previous customers not included) within each area. Concerning a general building system, the research shows that the majority of the potential customers express a need to have own control of quality, costs and structural and architectural design. The mentioned need refers to the respondents' wish to be able to control and influence the design of technical solutions as well as the contractors' performance that, according to the respondents, eventually influences quality and costs. By their experience, if this control is maintained it will with a higher possibility lead to the fulfilment of functional demands and to a high quality and long-term durability. The expressed needs, in column 1 of Table 1, all refers to the clients need for low, long-range dwelling administration costs. The respondents often mention the ignorance of contractors to address, or show solutions, aimed at producing long-term quality. A majority of the interviewed potential customers claim that they (personally or through consultants) have to control technical

details and solutions, and that they reluctantly leave structural and architectural design to contractors. Except control, the results from the survey show that flexible design and convincing exterior and interior design are clear general building system needs. Flexible design refers to the call for a non-limited plan-layout, and convincing design refers to the requirement for an exterior and interior design that could more clearly add value and variation to the customers' end users, display high quality, or serve as a trademark for the real-estate companies.

Table 1: Building system needs, perceived advantages and disadvantages of TVE prefabrication and required information for customer acceptance

Customers general building system needs	Disadvantages of TVE prefabrication	Advantages of TVE prefabrication	Required information for acceptance
Control of design/quality/costs (93%)	Uncertainity in functional demands (fire/sound/ moisture) (37%)	High quality (46%)	Demonstration objects (83%)
Fulfill functional demands (56%)	Low quality/short-time durability (37%)	Time efficiency (46%)	Technical descriptions (44%)
High quality and long-term durability (49%)	Limited flexibility (29%)	Moisture protection (27%)	Study visits and process descriptions (22%)
Flexible and convincing design (52%)	Visible volume joists/low-quality design (22%)	Cost efficiency (20%)	
Increased efficiency and decreased costs (49%)			
Involve contractor dialogue (17%)			

Also shown in Table 1 (columns 2 and 3) are the results concerning the potential customers' attitudes of TVE prefabrication. The general attitude is an uncertainty for timber and specifically that the system will fulfil functional demands (sound levels, moisture and fire protection). The building system is by a historical prejudice connected to a low quality, short-time durability, limited flexibility and an overall "low-quality-design" e.g. with visible volume joints. Several respondents express a similar opinion as: "I am positive to TVE prefabrication, but only for small or detached houses". When multi-storey housing is considered, the respondents articulate a more negative attitude, i.e. "timber is not fire resistant" or "the material is sensitive to moisture and cannot manage required sound levels". The reported characteristics of TVE prefabrication are independent of the customers' practical TVE prefabrication knowledge and thus show practical experiences as well as guesses and practical beliefs. However, 95% of customers with own practical experience positively perceive that it is possible to also manage functional demands for TVE multi-storey houses. Customers with previous knowledge of the building system equalize TVE prefabrication to traditional on-site construction regarding fulfilment of functional demands, and also raise advantages as increased quality, time and cost efficiency and moisture protection for the building system.

ANALYSIS AND DISCUSSION

Improvements to increase efficiency and reduce costs in construction are requested by actors in the construction industry, but to obtain changes and innovations towards these goals, also other market needs have to be met to obtain value generation. Prefabrication and industrialised housing can meet the efficiency and cost reduction requirements trough the use of manufacturing like production, but this research claims that value generation is missing to obtain a lean prefabrication strategy. Swedish TVE prefabrication utilise factory production and thus reduce

waste, and the survey shows that this is confirmed by previous customers. The study also confirms the needs for customisation, flexibility and convincing design found in literature (Vrijhoef and Koskela 2005, Ballard 2005). However, these parameters are not enough to achieve the value generation that may lead to innovation diffusion and acceptance of a lean prefabrication strategy. Control, trust, information transfer and cost and time efficiency are parameters that also have to be met to obtain value generation according to this study.

Control Of Design Quality And Costs

The need of control is connected to high quality, long-term durability and fulfilment of functional demands. The control is by potential customers argued to be needed to obtain long-term durability and fulfil functional demands as customers do not have trust in contractors. Traditional on-site construction entails perceived customer control of the process due to customers' previous knowledge of on-site construction, and a process where the customer have a perceived control through well known contractual agreements and rules of the game with different actors in the construction process. However, the shown need of customer control contradicts the acceptance of a prefabricated system delivery as TVE housing because the whole construction process is handled by one single building system supplier. Thus potential customers may experience lost control of the construction process when actor roles and the production process are changed by the prefabricated building system. Potential customers' desire to personally contribute to the design to obtain trust to the product is not compatible with the TVE manufacturers desire to work out the product (the house) to fit into the production and the building system to obtain efficiency. Hence, a challenge for a lean prefabrication strategy is to make customers experience control of the product design and the production process to obtain value generation.

Trust And Information Transfer

This research shows that potential customers do not trust the TVE product offer to meet expectations e.g. regarding functional demands, despite the fact that the building system today has already shown this. However, timber in Swedish housing has a long history and is influenced by governmental strategies that historical and up until 1994 has restricted the use of timber in multi-storey housing. The attitude of potential customers are coloured by these historical prejudices and lack of knowledge. Hence, except fulfilment of customer demands and needs, a prefabrication strategy also has to make customers perceive fulfilment of the demands. A prefabrication strategy thus also has to focus information transfer to obtain trust and the sense of control the customers ask for. This is confirmed by Saaksjarvi (2003) who suggest that new knowledge of specific innovations and products are needed in construction as the assumption of risk taking by potential adopters' decreases with increased knowledge (Frambach, 1993; Meyers et al., 1999).

According to the customer survey, demonstration houses and study visits, together with technical and process descriptions are information sources that could enable acceptance of TVE prefabrication and "involve contractor dialogue" is also mentioned by respondents as an important building system need. The interpretation is that knowledge and trust seem to have to be created by the experience of individuals, without other intervening information channels. The importance of strategic alliances for innovation push in construction has been shown

(Andersen et al, 2004) and some of the TVE manufacturers also cooperate closely with large contractors as an alternative way to render trust and information transfer between different projects. Hence, the TVE manufacturers may need an organisational or competence change to obtain a more lean prefabrication strategy. A possible example inspired by Lean thinking (Womack and Jones 2003) is for the manufacturers to provide a common working site for the manufacturer and the customer where customers and the manufacturer can cooperate.

Increased Time And Cost Efficiency

Increased time and cost efficiency are requested in construction in general, but a contemporaneous control and demands for "unlimited" flexibility are the normal way of working. This investigation shows that these demands are contra productive for the TVE prefabrication and will lead to higher costs and longer lead times. The TVE prefabrication strategy is based on facilitating decreased costs and lead times. Customer control, i.e., customer involvement in product design, and flexibility are, however, the main internal problems for TVE prefabrication to obtain lower costs and shorter lead times. Lack of flexibility and convincing design are also seen as disadvantages of TVE prefabrication by potential customers. Results from this research also shows that TVE prefabrication is successful for student dwellings where the value for the real-estate companies are pronounced to be decreased costs and short lead times, and where the demand for flexibility and special design do not have the same importance. Hence, if the TVE manufacturers are to obtain a more lean prefabrication strategy that considers customer demands, they have to develop their production process to become more flexible.

CONCLUSIONS

Lean is about waste reduction and value generation. Prefabrication of houses reduces some of the peculiarities found in traditional on-site construction and thus reduces waste, but to obtain a lean prefabrication strategy also value generation formulated within the construction context has to be considered. Value for a customer is connected to the customers needs (conscious and perceived needs), in its turn connected to the social context, i.e., the culture of construction. Thus, to obtain value these needs have to be met, and by that, the traditional on-site type construction culture has to be considered to obtain lean prefabrication. Literature, empirically confirmed in this research, shows that increased time and cost efficiency, flexibility, customisation and convincing design are customer needs that have to be met to obtain value generation, but to obtain a lean prefabrication strategy also control, trust of contractor and product and information transfer have to be obtained to gain acceptance from the construction market according to this study. Trust and control of the product can e.g. be mediated by visible information to enable personal experienced knowledge via demonstration objects. Trust and control of the TVE manufacturer and information transfer can e.g. be increased through the use of strategic alliances and cooperation between manufacturer and customer.

This research confirms the hypothesis that the low acceptance of the TVE system is due to the incomplete prefabrication strategy that needs a value creation formulated in a traditional construction context, and emphasizes the importance of a joint construction and manufacturing consideration to obtain lean prefabrication. The challenge for and a necessity of lean prefabrication is thus to manage the construction - manufacturing interface to obtain both

waste reduction and value generation. The results obtained in this study concerning perceived lack of fulfilment of functional demands that are connected to timber in multi-storey housing might also yield learning to more general construction areas. New building systems that utilise a prefabrication strategy that is deep rooted in historical knowledge and prejudices have probably to meet the similar customer needs as in this study to obtain perceived fulfilment of needs and to achieve lean prefabrication.

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