PREFABRICATION: A LEAN STRATEGY FOR VALUE GENERATION IN CONSTRUCTION

Anders Björnfot[1] and Ylva Sardén[2]

ABSTRACT

Despite a number of attempts to establish prefabrication as a Lean Construction method, there is still confusion of what prefabrication provides to the management of the construction process. It seems as if prefabrication can provide a means of dealing with value stream fluctuations in highly complex situations, such as a traditional construction project where it is difficult to define client value accurately. The prefabrication decision and the strategies for meeting customer demands have been studied for three Swedish producers of prefabricated timber components for multi-storey housing construction.

The case study results indicate that the Swedish construction industry is slowly changing from a traditional project based generation of customer value to offering specific products, adaptable by the customer to suit their own view on value. A prefabrication strategy where a well defined and tested product is offered to customers has the effect of redistributing resources from the design process to the value stream. Such redistribution enables companies with a well developed prefabrication strategy to better control the value stream and to implement new and better ways of meeting customer requirements while continuously improving their work and eliminating waste.

KEY WORDS

Lean Thinking, Multi-storey timber housing, Prefabrication, Product offer, Value generation.

[1] Tech. Lic., Div. of Structural Engineering - Timber Structures, Luleå University of Technology, 97187 Luleå, Sweden, Phone +46 920 492067, FAX +46 920 491091, anders.bjornfot@ltu.se

[2] Tech., Dr., Div. of Structural Engineering - Timber Structures, Luleå University of Technology, 97187 Luleå, Sweden, Phone +46 920 492866, FAX +46 920 491091, ylva.sarden@ltu.se

INTRODUCTION

Bertelsen and Emmitt (2005) promotes the view of construction as a complex system by arguing that the prevailing understanding of construction as an ordered process is completely wrong and that this misinterpretation may be the root-cause of the problems construction management meets over and over again in practice. Under complex circumstances, unforeseen events which completely invalidate the project's target, planning and approach may occur. These events forces the project team to frequently redefine the project's basic premises and to make decision based on incremental learning (De Meyer et al. 2002). The reason complexity has been introduced in construction seems to indicate that the nature of construction is beyond understanding and therefore beyond management; especially for on-site construction where the apparent inability of plans to represent reality seems to be a cause for complexity (Kenley 2005).

A possible strategy for controlling unpredictable site conditions is the introduction of an industrialised construction process utilizing prefabricated components (Björnfot and Stehn 2005). Prefabrication, the making of construction components at a place different from the point of final assembly, may lead to better control of the inherent complexity within the construction process (Höök and Stehn 2005). Positive experiences of prefabrication are plentiful, e.g., Luo et al. (2005) state that prefabrication can, if employed efficiently, enable process standardization, shorten lead times, improve quality control, and reduce material waste. Despite a number of attempts to establish prefabrication as a method of Lean Construction in academic circles, there still exists confusion of what prefabrication provides to the management of the construction process.

In this paper, the authors take the initial position that the inability of accurately understanding prefabrication as a strategy for Lean Construction implementation is due to not considering prefabrication in terms of value and value stream improvements (i.e., the first two basic principles of Lean Thinking). It seems as if prefabrication can provide a means (among other Lean methods) of dealing with value stream fluctuations in highly complex situations, such as a traditional construction project where client value is difficult to accurately define. This view is further explored in this paper through a literature review of value generation in construction supported by empirical evidence from three case studies of multi-storey timber housing projects in Sweden.

THE NATURE OF VALUE IN CONSTRUCTION

Client value generation

Construction is a process of delivering value to the client through a temporary production system, which consists of elements shared with other projects (Bertelsen and Emmitt 2005). The client has to make quite a few decisions in the initial stages of the project, e.g., which standards and regulations do I need to consider? Which quality in different parts of the facility do I need? How do I want the facility to look? The client also has to decide on the project budget, a location of the facility, the contractors and consultants who are to be engaged and how they should be organised. It is in these stages the client defines his value by the specific facility. Clearly, the clients' task of accurately defining value for the producer seems to be a complex process (Bertelsen and Emmitt 2005).

The actual product definition begins in the initial stages of the construction project. The client has to investigate the prerequisites for the project, specify requirements for the final facility, and estimate its economic consequences. These factors are often dependent on different political decisions executed by local authorities. During the following stages of the construction process, the means for the client to further specify value depends on the organisation of the project execution phase and the involved actors. In Sweden, approximately 35% of the apartments in multi-storey buildings are purchased as design/build projects while 50% are property development projects, managed and owned by a contractor (build-own). In design/build projects, where client value should have been defined in advance, the possibility for the client to further influence the value definition is, or should be, limited while the build-own project by definition permits a larger degree of involvement, i.e., client value is slowly emerging as the end product takes shape.

In construction, value may be divided into external and internal value (Emmitt at al. 2005). External value is the clients' value and the value which the project should end up with, while internal value is the value that is generated by and between the participants of the delivery team. The external value can be divided into process and product value, where the product value is the actual end product (the facility) and process value is achieved by providing the customer with the best experience possible during the design and construction phases. How the stakeholders in a construction project perceive value is presented as examples of external and internal value parameters in Table 1.

Table 1: Examples of value parameters for stakeholders in construction projects (inspired by Bertelsen and Emmitt 2005, and Cuperus and Napolitano 2005)

	Stakeholder	Perceived value
External value	**Owner**	• Durability • Low costs (maintenance and investment) • Flexibility
	User	• Perceived environment (external and internal) • Safety • Involvement in design • Flexibility
	Society	• Aesthetics • Environmental aspects • Durability
Internal value	**Contractor**	• Profitability • Independence • High degree of liability
	Sub-contractor **Designer**	• Profitability • Independence

The client is often an organization representing three distinct client groups: owners, users and the society (Bertelsen & Emmit 2005). These groups of clients' value different things at different times during the life of the building, e.g., durability, usefulness, beauty, capital value, flexibility, and environmental aspects. The other construction team members also have values to fulfill, but their main concern should be on delivering the best value to their client whom otherwise would look elsewhere (Emmitt et al. 2005).

In Lean Thinking terms (Womack and Jones 2003), the construction process should be aimed at satisfying customer value (external value), while value for the involved project participants (internal value) should come from continuous improvements and waste reduction endeavours within the value streams. In order for construction to be able to satisfy external value for the customer (e.g., the client), value must first be accurately defined. However, client value can, and in reality does, change over time (Bertelsen and Emmitt 2005) making value management in construction a difficult process indeed.

Defining value – a construction peculiarity?

Design changes initiated by the client and other stakeholders in a construction project often leads to variability and wasted effort before the changes are implemented and control is restored (Cuperus and Napolitano 2005). For the producers of construction products (contractor, manufacturers, and suppliers) it should therefore be imperative to accurately define customer value before the design process begins. However, based on the multitude of possible client wishes and requirements, and the lack of methods and tools for this purpose available today, it may not even be possible to accurately define value. Construction management involving methods and tools originating from the manufacturing industry has in most cases failed and lead to disappointment. For example, information technology, an everyday tool in manufacturing design and production, has not brought any major benefits to construction; the failure of construction computing is said to be attributed to a deficient understanding of construction (Koskela 2000).

The understanding of production in construction is constrained by the fact that its products and forms of production are different from most other industries. Compared to the production of for example a car, production in construction is considered peculiar in the sense that each product is unique, i.e., construction produces one-of-a-kind products. The main cause for this peculiarity is the fact that the client, i.e., the customer (not necessarily the end customer) who for a majority of construction projects is new and inexperienced with different values that must be fulfilled (Bertelsen and Emmitt 2005). To produce value for the client, the construction process is set up as a temporary production system involving a temporary project organization including all involved participants. The main causes for the temporary organisation is that each time a new building is constructed, the production is set to a new location with new site characteristics and working environments, often involving different contractors based on the client needs and the availability of subcontractors at the location. Not surprisingly, it seems like the client and the way value is considered in construction is a peculiarity in itself, or rather a cause for the perceptions of construction peculiarities. However, again it is worth stressing that the uniqueness of construction is not extreme from the point of view of production and operations management (Koskela 2003).

The difficulty of defining customer value in construction is apparent but there are ways of facilitating value generation, for example, computer aided design using 3D and 4D CAD are becoming more common (Woksepp et al. 2005), partnering (or concurrent engineering) is once again being brought up as a viable method of defining customer value (Cheng and Li 2004), and target costing is being developed for construction based on its success in the manufacturing industry (Granja et al. 2005). To better plan for and control the delivery of value in construction, improved planning tools such as Line-of-Balance (Kenley 2005) and the Last Planner System of production control (Ballard 2000) has become increasingly popular. However, these methods and tools seem not to, at least by themselves, be able to accurately define value for the client. Rather they seem to be designed with the acceptance that the value stream in construction will fluctuate and the purpose is to eliminate this variability or to dampen its effect. If we accept the fact that the value stream will fluctuate due to the strong influence of the client and the lack of methods to accurately define customer value, then prefabrication can be considered as a strategic method for value stream management.

Prefabrication of construction components is for contemporary Swedish multi-storey housing more a way of how things are done than a question of if prefabrication should be used at all. More and more producers (clients, contractors, manufacturers etc.) of such structures have increased their awareness of the construction process and subsequently increased the level of prefabrication of their production systems. Production of multi-storey timber structures in Sweden has in recent years been performed using a variety of prefabricated components, all from elements up to complete volumes sometimes containing whole completed apartments. The case study results presented in this paper provides a broad view of the use of different prefabrication strategies used on the Swedish construction market and how these strategies facilitate the management of value for the client and other involved stakeholders.

CASE STUDY RESULTS

The first two case studies are part of ongoing extensive research projects with results and analysis presented in other academic publications, e.g., for Case study 1: Björnfot and Stehn (2005), Sardén (2005); Case study 2: Höök and Stehn (2005), Olofsson et al. (2004). Only for Case study three are the results presented not discussed elsewhere. Data collection for all three cases has been performed through interviews, site observations, design and production meetings, and design and production documentation. We refer to the above cited publications for more information on the case study methods utilized. The case study results describe; the company, their product offer, client perceived value, and the prefabrication decision and its effect on stakeholder value.

Case study 1 – Element prefabrication

This case study concerns a supplier of prefabricated floor and wall elements based on massive timber slabs for the Swedish construction market, Figure 1. The supplier owns his own sawmill and in addition to producing elements for use in multi-storey housing projects, glulam timber beams are produced for use in other types of construction projects. The supplier strives towards complete prefabrication of the elements, generally including surface finishing, façade and installations. All this work is performed at the supplier's factory where automated machinery is utilized in combination with traditional construction work. When the elements are completed they are delivered to the construction site and assembled to a complete structural system. The goal of the supplier is to provide a complete system of prefabricated elements, i.e., design, manufacturing, delivery, and guidance for on-site assembly.

The prefabricated element system was recently tested in practice on a multi-storey timber housing project consisting of five houses of six floors each. Due to the material and the element system being relatively fresh on the Swedish construction market, the client decided to procure the contractor under a design-build contract with fixed price to minimize his economic risk. The structural system was procured in the same manner by the contractor, who was promised full responsibility for the design and assembly by the element supplier even though this was the first time this particular system was used in practice. As a result, the system was continuously developed during the project resulting in waste due to rework and delays. This situation was not acceptable to the contractor who, rightfully, was expecting a fully developed system which eventually led to claims on the supplier during production and after completion of the project.

Figure 1: Prefabricated timber floor and wall elements used for multi-storey housing

The main reason it was decided to prefabricate the structural system and integrate as much as possible already in manufacturing was a wish to increase the productivity of site assembly and to guarantee a high quality in on-site work. Site production was already in the conceptual design stage viewed as a possible problem during site production. Since timber is generally susceptive to weather, a "dry construction" process was aimed at through the use of a covering tent (Figure 1). Additionally, use of the tent enabled improved productivity of site production through an assembly type of production process. To facilitate delivery of elements to the construction site, the contractor and supplier decided to limit the height of the timber elements. However, not surprisingly, this decision resulted in an inability to apply surface finishing and major installations at the factory, later identified as one of the main reasons for the problems in structural and internal finishing work observed in site production.

For this particular project, there was really only one supplier able to deliver elements on such a large scale which lead to the supplier taking on the role of a contractor rather than a supplier of construction components as would have been expected; i.e., the prefabricated element system was as good as designed from scratch for the particular project instead of being offered as a ready system. Clearly, all project stakeholders would have been better off if the prefabricated element system had been fully developed before the project start. This is especially true for the design of installation systems not included in the prefabrication decision, which was difficult to do in advance since initially the elements were continuously being redesigned. Despite all these problems, the prefabricated system was agreed on as advantageous in assembly which progressed according to schedule. However, to become a competitive alternative to other building systems and to increase its market share, further system development is necessary.

Case study 2 – Volume prefabrication

This case study concerns a specific Swedish company producing timber frame multi-storey houses for the Swedish construction market. The company projects are run with everything in-house, i.e., they procure land, they design the building according to customer demands, they produce prefabricated volumes in their factories, and they assemble and finish them on the construction site, Figure 2. The company is very much focused on providing customers with what they want while keeping the design and production process as simple as possible. One reason this is possible is that the company own the majority of the value stream by themselves, e.g., they bring subcontractors for installations in-house and uphold long-term relationships with important suppliers.

Figure 2: Prefabrication and site assembly of volumes including finishing

The company product offer of prefabricated volumes governs the company work in marketing, manufacturing, client negotiations, and on-site production. The volumes are produced through a standardized manufacturing process where wall and floor elements are first produced and then assembled to three-dimensional volumes in the factory. Before the volumes are ready for delivery to the construction site they are finished with installations, façade, interior surfaces as well as other interior finishing such as wardrobes, cabinets, sinks, and toilets using the companies own workforce or hired sub-contractors with long-term relations to the company. Through this work, only minimal finishing work is required on site, i.e., an assembly type of site production is achieved.

The standardized design of the product offer leads to a standardized delivery of the volumes to the construction site, using trucks and trailers. In this manner, the company is able to produce and deliver volumes for projects all over Sweden (a large country in distance if not in size). Before the volumes are delivered, the foundation has already been constructed. While the foundation work is underway, work on the roof is started (which commonly is made out of prefabricated rafters from local producers) leaving only assembly of the volumes, a task performed straight from the trailers using one crane and a local workforce with long relations to the company. Therefore the process of assembling a normal sized house is quick, usually about one days work. When the volumes are assembled, the process of finishing installations and remaining interior commences. Due to the standardized design of the volumes, the finishing process is straightforward and often performed with a minimum amount of wasted effort.

Through the standardized product offer, the company is able to utilize a “simplified” tendering process only including adaptation of the house layouts to the project in question, negotiation of price and date of delivery, and setting up a list of options for the clients’ tenants. Only minor changes of the principle design are allowed to keep a high production-cost efficiency. The client initiates the sales and customization process of the houses when the contract has been signed. When 30 % of the apartments are sold, the start order is given and the detailed design and engineering work commence. From the detailed design phase, design drawings are delivered to the manufacturing process. When production starts, information of selected customer options from the customization process is passed to the construction company in order to individually customize the tenant-owned purchased apartments.

Even though it seems like the company is strict in keeping to its volume production system, they are in reality keen on meeting customer demands. However, client involvement is to a high degree limited to interior and façade design, and add-ons such as balconies. This may seem like a severe limitation in meeting customer demands; however, the customers generally know what to expect from the company product offer and how much involvement they are allowed in design. The volume system has been perceived as limited in flexibility and customization and therefore mostly been used for repetitive standardized housing projects such as student dwellings even though the volume system should be able to cover a larger share of the market. Despite historical setbacks, the company has a firm belief in their prefabrication strategy, striving towards new marketing strategies and better ways of meeting customer demands.

Case study 3 – Industrialised construction

Case study three concerns an innovative effort on the Swedish construction market where the supplier in case study one and the company in case study two has joined forces together with an architect and construction component suppliers. The aim of this initiative is to increase the involved companies marked shares on the multi-storey housing market, i.e., to produce cheaper houses to a larger market segment than the companies can do by themselves. Even though the case has not been seen in practice yet, a discussion of its prefabrication strategy and customer value generation is of relevance to this paper.

The product offer of the "group" is based on the perceived internal value of the product offer already under production at the involved companies; timber element prefabrication (Figure 1) and volume prefabrication (Figure 2). Hence, the main idea of the initiative is to use the timber volumes and timber elements where they are best suited. In conceptual design of the product offer it was identified that a large and difficult part of site-production is concerned with finishing off "wet areas" such as bathrooms and kitchens. Therefore it was decided to attempt to prefabricate such areas as volumes in order to better control the difficult finishing work on site. It was also decided to include as much as possible of the installations in the volumes since experience from volume prefabrication has shown that site production of installations is a common source of waste and higher quality can be maintained in factories.

The layout of the houses is based on volumes, but to achieve a higher degree of flexibility than can be accomplished with volumes alone, prefabricated timber elements are used to complement the volumes. Using elements, almost any kind of building can be produced. However, heavy efforts of standardizing the elements to simplify the manufacturing and site assembly processes has been made. This design effort has significantly reduced the number of different elements used. Effort has also been made from the involved companies to pinpoint and simplify the supply chain by reducing the number of suppliers for construction components, i.e., it has been decided on the suppliers able to deliver the required parts when needed and at the right price and quality.

Since this project has only undergone the conceptual design stage, it is not possible to report on perceived value for eventual clients or stakeholders. However what are interesting to note is why this endeavour has taken place and why the involved companies has such a high belief in the endeavour. The volume producer achieves a higher flexibility in his product offer, able to better meet new forms of client requirements while still offering a standardized product which is familiar and therefore possible to be produced efficiently. The element supplier, whose prefabricated element system is lacking in development and has only really been tested properly on one project, gains an increased share of the housing market and the possibility of developing its product offer in real applications. Even though it seems like this company endeavour has all possibilities of success on a fragmented construction market, it will be interesting to see if all ideas are transferable to practice. Based on experiences from a similar initiative, Bertelsen (2001) concludes that cost saving can be obtained if a long sequence of projects is established.

MANAGING THE VALUE STREAM THROUGH PREFABRICATION

Product offers and prefabrication strategies

From the case studies, and the experience of the authors, a general material related value stream for a multi-storey timber housing project can be depicted as in Figure 3. This value stream can be used to relate the product offers presented in the three case studies. The prefabrication strategy in each case can be illustrated as a decoupling point (DP) between factory and on-site production, e.g., a decoupling point further to the right (downstream) would exemplify a prefabrication strategy utilizing more and more factory produced construction components (Björnfot and Stehn 2005).

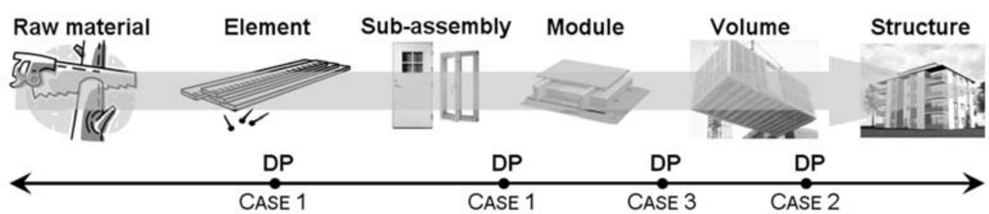

Figure 3: The case study product offers related as a decoupling point between factory and site production.

The product offer of the first case company is aimed at producing construction components in the form of prefabricated elements. However, lack of time, or deficient knowledge of the construction process, lead to an undeveloped system for practical use which resulted in a two phase on-site construction process; assembly and structural finishing work (depicted as two decoupling points in Figure 3). The second case company's aims at offering a complete volume system with limited adaptability to its customers (depicted as the decoupling point furthest downstream in Figure 3). Development of the volume system has lead to an increased control of factory and on-site variability through better control of the customer value generation process. The product offer in case study three concerns the integration of the element and volume prefabrication strategies aimed at an increased adaptability of the elements and an increased flexibility of the volumes so that new and before unattainable housing market segments can be reached. From the case study results it seems like the case companies utilize different prefabrication strategies to reach diverse segments of the housing market.

Value generation for clients and stakeholder

Each of the case companies have well defined product offers suited for market segments where customers have different perceptions of value and varying requirements on design involvement; Table 2 presents the main customers and product strategies of the three case companies. The element producer primarily offers its product to contractors who integrate the elements into their production systems. Since the element producer generally has no direct contact with the end customer, they primarily consider contractor requirements, e.g., high quality, low lead times and constructability. However, the integration of more and more construction components (installations and finishing) within the elements seem to be an emerging demand from Swedish contractors, forcing the element company to move further downstream on the material value stream (Figure 3).

Table 2 The main customers and company product strategies for the case companies.

Case company	Main customer	Company product strategy
Case study 1 **Element**	Contractor	Strives towards being able to produce a complete element system targeted at contractors.
Case study 2 **Volume**	Landlord	Strives towards keeping its volume system as straight-forward as possible but also to increase the flexibility of the system and reach a larger market segment.
Case study 3 **Industrialized**	Contractor Landlord	Strives towards an increased flexibility in its product offer, aiming at an even larger customer base by an adaptable product offer to landlords and contractors.

The customer base of case company two is fundamentally different from the element producer since they offer their product straight to the customer (often a landlord who represents tenants). The volume system therefore attracts a special type of customer who is provided with a well developed and tested product (they know what they get!) which is adaptable according to predetermined guidelines from the producer. The producer thus assure they can provide a system that can be produced efficiently and to a high quality (internal value), while the customer know they will be provided with the right product to the price and quality agreed upon (external value); unfortunately not a matter of fact situation in construction today emphasized by the development of value-adding decision making methods (see e.g., Thomson et al. 2004). The prefabrication strategy in case study three offers additional adaptability over the volume on the system level. Therefore, this system is not only suited to be offered straight to a landlord but also suited for a general contractor who wants to implement a well defined product into their production systems.

Clearly, most customers want to be offered a product and then have the possibility of adapting the product to suit their own needs. This way of thinking is quite the opposite of today's project oriented construction process where, commonly, a product is designed from scratch to suit the customers demands, instead of being offered to the customer as a well developed and tested product. In the studied case companies (especially case company two and three), the strategy of offering a product has lead to the companies being able to redirect resources from the customer requirements capture process to the continuous improvement of the value stream of their product offer. It seems difficult to implement such improvements for a project oriented construction process where customer value is defined and created, basically, from scratch, and where customers are often allowed to influence design decisions well into the production stage.

From the perspective of case company two and three, construction is not much different from the manufacturing industry, e.g., the automobile brand Volvo is marketed as the car of choice for families, while the BMW brand approaches a completely different market segment, still defined but nonetheless customers with different perspectives of value. Manufacturing companies commonly offer a product that focus on a specific market segment which allows for better control of customer requirements, but maybe most importantly; limiting the customers involvement in late design stages. Such a strategy frees additional resources to more tightly control the value stream and the associated supply chain (see e.g., Womack and Jones 2003). Why should value generation in construction be viewed differently?

DISCUSSION AND CONCLUSION

In this paper the product offer and the strategies for meeting customer demands has been studied for tree Swedish producers of prefabricated timber components for multi-storey housing construction; one producer of timber elements, one producer of timber volumes, and a fresh Swedish endeavour combining timber elements and volumes in an industrialized construction process. Albeit being a limited study in size and scope, the results are clear and indicate that the Swedish construction industry is slowly changing from the traditional project based generation of customer value to offering a specific product that the customer can adapt to suit his or her perspective of value. The results also indicate that a prefabrication strategy where a well defined and tested product is offered to customers has the additional effect of redistributing resources from the design process to the value stream and its associated supply chain. Such redistribution enables companies with a well developed prefabrication strategy to better control its value stream and to implement new and better ways of meeting customer demands while continuously improving their work and eliminating waste. This value generating process is in stark contrast to today's construction process where value is built up from scratch and only realised, if at all, when the customer receives admission to the building.

The notion of precisely specifying value for the customer (the first principle of Lean Thinking) seems to have been partially forgotten in academic Lean Construction management research; more specifically the question of how construction should be structured to best generate value for the customer is rarely dealt with. This is surprising since Lean Thinking is about finding root causes to problems – value generation is an issue that so far remains unsolved in construction. From a critical perspective, the project organization so common in construction is merely a means to an end of producing a construction product. By means of offering a well developed and specified product, the one-of-a-kind nature of the construction product and the use of temporary organizations for its design and production are efficiently managed, instead value generation emerges as the main concern of companies. Lean Construction should therefore strive towards new forms of project organizations better suited to the product under consideration and better suited to the generation of value for all involved stakeholders. Prefabrication strategies' offering specific products (albeit adaptable) to specific customers is such a Lean Construction strategy. Prefabrication in this fashion frees resource and opens the door for additional improvements within value streams (the second principle of Lean Thinking).

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