LEAN MODULAR DESIGN: VALUE-BASED PROGRESS OF INDUSTRIALISED HOUSING

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ABSTRACT

One of the core ideas of Lean Construction is that the process of designing and producing a construction product should progress continuously and create value for both the customer and the delivery team.

The hypothesis in this paper is that modularisation has potential as a method for value management. The aim is to describe how modularisation, in a lean context, can be used as a tool to facilitate the management of internal and external values in industrialised housing. The paper will explore the theory of modularisation and its drivers and examine how the method can promote value management.

Modularisation is then explored in practice, using empirical knowledge from the building service systems (HVAC, electricity, etc.) development process at five Swedish multi-storey timber housing producers. The analysis point out the importance of decomposing the modularisation process into a jointly performed industry phase where modules are designed, followed by a company internal product development process that complies to the modules. This paper concludes that it is not the product decomposition into modules that is of importance, rather the process that strives to balance internal and external values.

KEY WORDS

modular drivers, industrialised housing, building service systems, value management

INTRODUCTION

One of the core ideas of Lean Construction is that the process of designing and producing a construction product should progress continuously, from initial idea to finished product, creating value for both the customer and the delivery team. However, the construction process is often variable due to, e.g., actors with individual agenda, legislations, regulations, influential unions, strong wholesaler networks, etc., making production control difficult, in words of predictability, resulting in wasteful activities (see e.g., Forsberg and Saukkoriipi, 2007).

Lack of control is an issue in traditional site-based construction, which is evident from the continuous use and theoretical development of production control methods, such as Last Planner (see e.g., Knapp et al. 2006). Industrialised housing has been developed for many years in Sweden, with the salient idea of moving much

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of the work from the construction site to factories. By utilizing prefabrication and adding Lean Production practices to their factory based production systems (the entire process, from idea to product), Swedish housing companies are aiming to reduce variation and increase production control.

Ballard (2000) argues that production control intends to create reliable work flow between production units. Logic would thus indicate that production control is gained by thoroughly considering the production units, and the materials flowing through these units. Consequently, as Ballard argues, production control should begin with system design. Swedish industrial multi-storey housing producers are striving in this direction, towards improved production control by utilizing system design.

Björnfot and Stehn (2007a) called this the product offer, a theoretical construct that strives to increase value for both the delivery team (efficiency and profitability) and the customer (flexibility and quality). However, the production culture and business settings of traditional construction still remains, as industrial housing companies balance values from two disparate systems; traditional construction (on-site projects) and manufacturing (factory processes).

Methods, managing and balancing values, are used in construction research and applied practically, e.g., from quality management, TQM or QFD. Internal values for the delivery teams (expectations from stakeholders in design, the way projects are organised and managed in the construction phases, etc.) and external values for the customers (material and equipment quality, design quality and handovers, etc.) must be captured, realised and delivered. According to Kärnä and Junnonen (2005) lean construction (and lean thinking) lacks an adequate conceptualisation of value management, although they point out that Koskela´s third model of production – *production is value generation*, is near the concept of customer satisfaction.

The hypothesis put in this paper is that modularisation has potential as a method for value management; capture of customer needs (values), transformation into system demands, generation of physical products (transformations) and delivery to the customers. The core in modularisation is the division of a complex product into functional parts that are easier to manage individually than in relation to its whole, i.e. *"a module refers to a physical or conceptual grouping of components that share some characteristics"* (Jiao et al., 2007). Björnfot and Stehn (2007b) state that it is not the division into modules that is the essence of modularisation. Instead it is the providence of a standardised way of thinking throughout the production process.

The aim of this paper is to describe how modularisation, in a lean context, can be used as a tool to facilitate the management of internal and external values in industrialised housing. This paper begins by exploring the theory of modularisation and its drivers and examines how modularisation can promote the management (capture, generation and delivery) of value. Modularisation is then explored in practice, using empirical data from the building service systems (HVAC, electricity, etc.) development process at five Swedish multi-storey timber housing producers.

A VALUE MANAGEMENT PERSPECTIVE ON MODULARISATION

Ballard and Howell (1998) stated that the general idea of production control is to first stabilise work flow by shielding production against uncertainty. This has to be made before other improvements are possible. However, sources of uncertainty and variety in production are plentiful, e.g., project uncertainty, project complexity, type of contract, production control methods, project typology, space availability on site, risk, technology, tasks interrelationship, decision-making, etc. (Henrich et al. 2006).

Adding to the uncertainty and variation in construction, customers are different entities (persons, companies or organisations) depending on the used perspective, or at what stage in the construction process, work is performed (Björnfot and Sardén 2006). According to Burati et al. (1992) every party in the construction process has three roles: supplier, processor, and customer. Value satisfaction for each of these parties must be fulfilled. As summarised in Björnfot and Sardén (2006), value generation in construction can be classified in two types:

- External value is the clients' value and the value which the project should end up with. External value can be divided into product value (the finished building) and process value (provides customers with an excellent experience during the construction process).
- Internal value is the value created by, and between, the participants (client, contractors, suppliers, etc.) of the delivery team. Internal value strives for an economically efficient production process generating high quality products.

The product offer, viewed from a value management perspective is a well-defined and standardised building system (a product based technical platform) developed from the theoretical principles of lean thinking and the practical value views of specific customers, illustrated in Figure 1. The product offer implies a cultural change in industrialised housing, where value conceptualised into a *product* (house) is central, while keeping the view on production as a critical aspect of value generation.

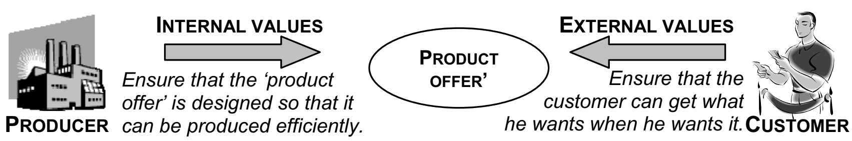

Figure 1: Simultaneous consideration of internal and external values in product offer development. Modified from the originally published figure in Björnfot (2006, p.46)

Value management in construction is an on-going research area within the Lean Construction community (e.g., Kärnä and Junnonen, 2005; Emmitt et al., 2005). It is in this paper argued that modularisation has characteristics that can facilitate the management of value in construction. In this sense management implies capturing, generating and delivering external and internal value.

VALUE MANAGEMENT THROUGH MODULAR DIVISION

Bertelsen (2005) argued that the purpose of modularisation in construction is to reduce the complexity of production, i.e., its variability. According to Bertelsen, modularisation has the purpose of reducing production variability by turning the building into a product that can be prefabricated in permanent facilities using established methods and tools for Lean Production.

Modularisation can thus be seen as both a process and a product discipline offering multiple advantages in the whole process. Modularity offers improvements for construction throughout the entire lifecycle of a building, from development to "after-sale" (Björnfot and Stehn, 2004). Consequently, modularisation has potential to improve process control and lower construction variability. However, viewed as a method the scope is much wider, for example Brookes (2005) argues that modularisation in construction helps to:

- Reduce critical points in assembly occurring from 3D-interrelations, i.e. avoid the peril of misfit between component parts.
- Avoid misunderstandings between construction participants (architects, designers, manufacturers and contractors), i.e. reduce risk of ambiguous detailing on drawings, specifications, etc.

The decomposition of a product into *suitable* modules is a more complex undertaking than it may seem. What is a *suitable* module and how are the interfaces to other modules defined? Blackenfelt (2001, pp.8-10) presented a number of module drivers (characteristics that can be used to define and divide a product into *suitable* modular components) and grouped these drivers based on, as Blackenfelt stated: *"the three main problems approached by modularity"*:

- **Variety versus commonality**. The problem of having a large set of product variants and at the same time standardised production process. Associated drivers are, planned or driven change, upgrade ability, reconfiguration ability etc.
- **Organisation of development and production**. Relates for strategic decisions of how product development and production should be organised and managed. Associated drivers are separate or parallel development processes, in- or outsourcing, use of preassembly, etc.
- **After sale of product**. After sale of product deals with modular decisions concerning the use of products, supervision of products in use and the disposal of products. Associated drivers are ability and need of repair, ability to reuse components and recycling of materials, etc.

From a theoretical viewpoint, modularisation seems to be a method for value manage-ment, where internal (production) and external (customer) values are balanced. From a value perspective, modularisation is also a step towards an open building platform (Veenstra et al., 2006) where internal and external values come together.

DEVELOPMENT OF MODULAR INDUSTRIAL SERVICE SYSTEMS

The qualitative and preliminary findings presented in this paper are results from an on-going research and development project. Empirical data is collected from participation at workshops, interviews with industry representatives, observations at production units and construction sites, as well as the study of multiple design and construction documentations (and other literature) detailing the building systems of five Swedish industrialised housing producers (see Table 1).

The participating companies produce a total of 3 500 apartment units annually, which correspond to a share of nearly 20 % on the Swedish market. The incentive for this R&D project originates in the development initiated by the steadily increased use of industrialised timber housing in Sweden. The participating companies produce a total of 3 500 apartment units annually, which correspond to a share of nearly 20 % on the Swedish market.

Table 1: Overview of the five involved housing manufacturers. More information about the structural systems are presented in e.g. Björnfot and Sardén (2006)

Company	Turnover (MEUR)	Building system	Product strategy
1	42	Volume building system based on a light timber frame system	Student-dwellings, apartment buildings
2	42	Volume building system based on a light timber frame system	Apartment buildings, offices, schools and mobile sheds
3	7	Volume building system based on a light timber frame system	Single family residences, schools, prisons and mobile sheds
4	18	Volume building system based on massive timber slabs	Student-dwellings, apartment buildings
5	14	Element structural system (integrates installations and finishing)	Multi-storey residential housing

The industry now begins to coordinate the service systems (HVAC, electricity, etc.) into their industrialised building systems, that is also composed of the production and structural systems.

- **Production system**. The process, which produces the product from initial idea to a finished product (building), thus includes the design and production phases, formed to maximise value and minimise waste (Ballard et al., 2001).
- **Structural system**. The construction platform (volumes, elements, etc.) on which the studied companies base their production systems. See further in, e.g., Björnfot and Stehn (2007).
- **Service systems**. Comprise the necessary services in a building (HVAC and electricity) and the

coordination and canalisation of pipes and wires into the production and structural system.

From the perspective of value generation, the current focal point of all industrialised housing companies is to increase internal values, such as production efficiency and profitability. However, much work is still based on traditional construction principles, especially concerning the design, sub-contracting and the purchase of service systems that so far have not seen much adaptation towards an industrial practice. The production process in industrialised housing is based on a fixed, and in many cases, inflexible structural system, which means that the supporting systems such as the service systems have to adapt to the limitations of the production and structural system in the completion of the building (product) (see Figure 2a).

However, alterations in customer values and environmental regulations (leading to demands on energy savings) result in new demands for the housing producers and particularly their service systems. To be able to cope with the current and future development needs, the service systems have to be better coordinated into the building (see Figure 2b). In other words, the services systems should be optimised individually rather than to the existing production system and structural system.

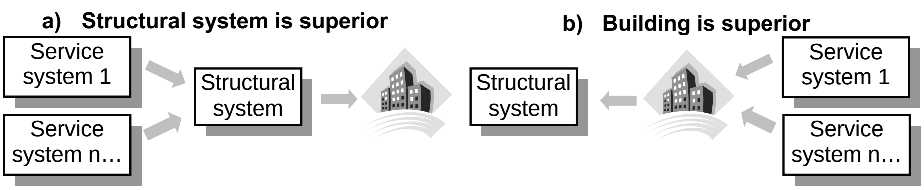

Figure 2: Rethinking industrialised timber housing construction; a) Current state, with superior structural system. b) Desired state, building is superior and value is in focus.

To establish service system limitations and demands, as well as to find a suitable modular division for the service systems, the R&D project runs in two parallel processes; an industry and an academic led process. The task for the industry development process is to facilitate an advance in general knowledge about building and product development of service systems (technical possibilities, limitations and practical use). The goal of the academic research process is to map the current application of building service systems (system possibilities and limitations, as well as potential module drivers), illustrated in Figure 3.

Figure 3: The two processes and the main activities in developing common industrial service systems

THE INDUSTRY DEVELOPMENT PROCESS

To manage the industry development process, a group of senior Swedish construction and technical installation expertise was assigned. They began to work on a roadmap for technical development of the service systems within industrialised housing. The industry development process has three joint objectives:

- **Production system**. Confirm that the production process (and support systems) is designed to maintain the new service systems.
- **Structural system**. Identify critical interfaces between the service and the structural system, and find new technical solutions for these interfaces.
- **Service system**. The main focus; identify new designs and technical solutions for a service system supporting industrialised housing construction.

An open call went out to all Swedish technical consultants, contractors and designers to develop service systems suited for industrial house production. The most prominent *ideas* (about five to ten) will be further developed into concepts and tried out in actual projects. This process is an ongoing activity.

THE ACADEMIC RESEARCH PROCESS

The first step in the academic research process was to get a firm understanding of the service systems used by the involved companies and the underlying strategy for their developed systems. Therefore an arduous process began of gaining knowledge of the building service systems. The mapping method *Design Structure Matrix* (DSM), used in Björnfot and Stehn (2007b), was utilised to support the mapping of the building service systems. All five companies were studied using this method.

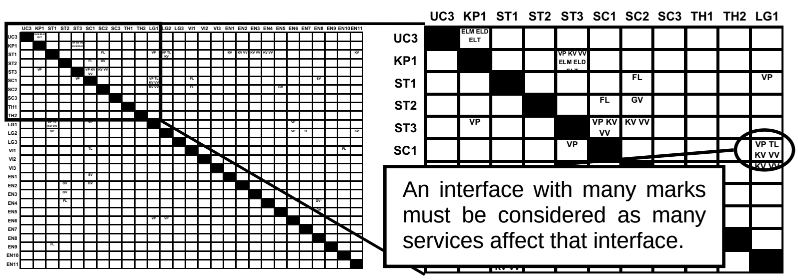

Figure 4: Excerpt from the DSM modeling of the service systems at Company 4. The matrix is designed to follow the different services, (e.g. heat & ventilation) through out the building system.

Figure 4 illustrates an excerpt from the mapping process of the service systems at *Company 4* (Table 1). The row and column entries represent different parts of the service system. By comparison of the DSM for the companies, common technical solutions (and variances) across different building service systems and company practices were identified (Figure 4 illustrate how the DSM was used in this analysis.

During this phase in the project, a set of module drivers have also been developed. They have been detected from the DSM analyses, as well as from workshops, interviews and observations at the participating companies.

- **Flexibility to changes in regulations**. Soon a priority will be to address the issues concerning environmental and energy efficiency, as changes in regulations are expected, which will result in altered service systems.
- **Independence from market forces**. Ability to gain control over diversity in products and material, leading to independency from, for example the influence of wholesalers.
- **Ability for external product development**. Possibility to develop modules individually so they can be outsourced (Lau and Yam 2005). The producer then has the choice to focus on the core processes.

DESIGNING FOR MODULARITY IN INDUSTRIALISED CONSTRUCTION

The qualitative based results in the R&D project show that external value (to offer more and improved values for the customer) becomes more important in the product offer development. This is a shift from the single company's focus on product offer development to a situation where the companies are willing to collaborate in order to achieve a common platform for the service systems. The management of external values has become so important, that the housing companies are ready to break the restraining impact of their rigid production systems to a situation, where individual modules are more important, as illustrated in Figure 2b. Also evident from the R&D process is that the companies are confident in modularisation as the working method to reach the goal of an improved industrialisation process.

The most important challenge of a modularisation initiative in industrialised housing becomes the undertaking of a common industrial development, performed as a joint venture. In other words, the establishment of standards across the industry in order to improve production control (reduce variation in used resources).

In the modularisation process, it is central that the structural and production system of the companies become subordinate to the modular division. Consequently, it is important to divide the modularisation process into a joint industry development phase, followed by a company internal product development. In the second phase the generic modular system is adapted and fitted into a specific structural system and concurrently into the production systems. The employed strategy is illustrated in Figure 5. The management through modularisation yields a value generation not solely based on internal values but also on external customer values (a systems view on value).

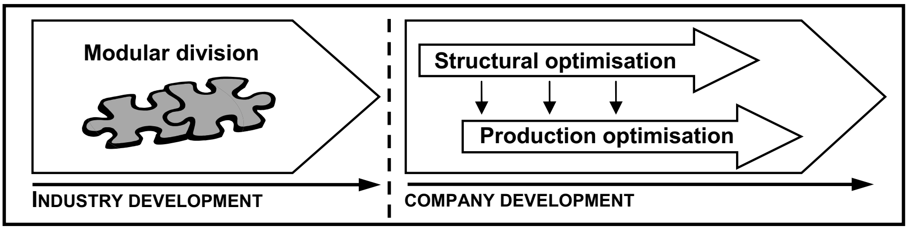

Figure 5: Illustration of the modularisation process structured into development of internal (industry) and external (company) value.

DISCUSSION AND CONCLUSION

In this paper, a modularisation initiative was advocated to be a *method* that can unite the construction industry towards common interests; i.e. reducing variation in order to gain control and obtain increased predictability. As a consequence, process efficiency and quality will improve. This paper argues that it is not the commission to actually divide the product into modules that is important, rather it is the process of modularisation that strives to balance internal and external values.

Common applications of modularity usually start with transferring customer needs into product demands, using for example QFD. This paper indicates that to take advantage of modularity, at least initially, a generic standardised construction platform is required; following this, individual companies can build independent and robust product platforms.

Why is the industrialised housing industry in need of modularisation? In their advance, the companies have encountered barriers to their expansion, which in all likelihood is related to the culture of traditional construction (Höök and Stehn, 2008). Two examples of progress obstacles specifically concerning technical installations are the influence of unions (leading to competition and individualism, instead of unification and shared goals) and the wholesaler market with a large material and product diversity leading to high costs, instead of standardisation that will result in cost reduction for the companies.

It is assumed that the traditional construction culture is the largest obstacle to the acceptance of industrialised housing construction. Evidential proofs from the on-going R&D project indicate that single actors within the construction industry are not able to carry the development forward. The companies have realised that they must cooperate in order to take charge of the process and change the culture towards an environment with industrial practice in house manufacturing.

In connection with a modularisation initiative, issues concerning manufac-turability can emerge (Jiao et al., 2007). This is part of the problem with v*ariety versus commonality* (Blackenfelt, 2001). In lean construction this problem is related to work structuring. Tsao et al. (2004) state that work structuring includes concerns of how operation and process design align to product design, supply chain structure, allocation of resources and design for assembly. An incentive from properly defined modules is outsourcing (ability to develop modules individually) and also improved production control. In this regard work structuring might be interesting to investigate further as the R&D process progresses.

The authors emphasise that the project is at an initial stage, where actual modules have not yet been developed. However, the conviction is that the modularisation strategy is sustainable, proved by the fact that five competitors concur to cooperate and develop a common platform that can work as a foundation not only to themselves but also to other actors in housing construction.

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