INDUSTRIALISED TIMBER HOUSING: FROM TRIAL TO PRODUCTION

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Increased cost and declining quality within the construction industry has resulted in a growing interest in industrialised housing construction. During the past 15 years Swedish timber housing has been in a start-up phase where the frame system has been adapted to fulfil the demands of the building regulations. Still, potential clients and building owners are uncertain of long-term financial costs and functional performance of timber houses. To take timber frame housing from the level of unique experimental projects to competitive industrialised production, manufacturers will have to face the challenge of convincing the market that timber is an equally sufficient frame material as the more traditional concrete and steel. This paper presents a summary and analysis of the research conducted within the field of industrialised timber housing at Luleå University of Technology. The summary is made through a literature review of research reports, theses, papers and statistic references. The results are put in relation to lean theories and the development of industrialised timber housing in Sweden, with the aim of establishing current knowledge and identifying future research needs. Industrialised housing in Sweden is a growing market with good potential to provide low-cost housing of good quality. The results points out organising the design process to support production, working on customer interaction and to providing information that decreases the uncertainty for future customers as challenges for the industrialised house builders. Further research within industrialised housing should address the quality concept in housing, reduction of uncertainties in customer relations and new business models. Support of the technical development with efficient stabilisation methods for high-rise buildings and simple joining methods during assembly is another important issue.

Keywords: corporate strategy, housing, industrialization, prefabrication, standardization.

INTRODUCTION

The Swedish construction sector is currently undergoing great changes. To meet market demands the sector needs to become more efficient in several areas, with increased quality and reliability and decreased costs being the most prominent. Industrialised house builders have chosen to address this problem through prefabrication with varying degrees of specialisation in their product (Lessing, Stehn and Ekholm 2005). Recent years have seen an increasing degree of prefabrication and companies involved in modular house prefabrication gain market in the U.S. (Nasereddin, Mullens and Cope 2007), while deemed a low potential in the U.K. (Pan, Gibb and Dainty 2007). The prefabrication strategy changes construction companies from object-oriented builders that focus on on-site construction to process-oriented manufacturers taking greater control of the value chain with reduction of workflow

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variability due to repetition in operations (Höök 2008). Another move is to streamline on-site construction through better planning and control, as expressed in e.g. the Last Planner method (Ballard 2000). There is an interest to transfer methods and tools developed in the manufacturing industry e.g. lean principles. These principles can be applied to any type of production, but have to be suited to the cultural context where they are to be applied (Koskela 2000). Industry specific differences between manufacturing and construction retain ad-hoc type transfer of competitive management principles (Diekmann *et al.* 2004). By using lean principles, which are applied both in manufacturing and construction, industrialised house builders become an interesting case to study. Ever since 1996, industrialised housing has been a core interest in research for the Timber Structures research group at Luleå University of Technology. During the past 15 years Swedish timber housing has been in a development phase, where the frame system has been adapted to fulfil functional code requirements. Still, potential clients are uncertain of long-term financial costs and functional performance of multi-storey timber houses (Höök 2008). This paper presents a summary and analysis of the research conducted within the field of industrialised timber housing at Luleå University of Technology. The results are discussed in relation to lean theories and the development of industrialised timber housing in Sweden, with the aim of establishing current knowledge and identifying future research needs.

LEAN THEORIES

Lean production

Stemming from the development of the Toyota Production System (Liker 2004), lean production as a philosophy for organisational development has gained acceptance in the industry (Womack, Jones and Roos 1990). The basic idea is simple; reduce unnecessary operations (waste) with simple methods to promote increased flow targeted at creating customer value, Fig. 1.

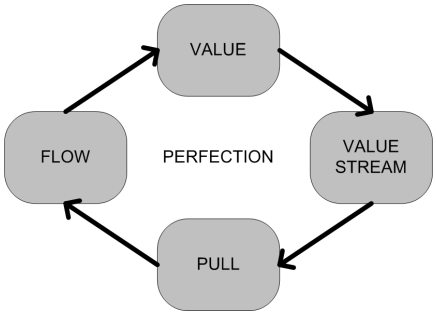

Figure 1: The principles of lean production, simplified from Womack and Jones (2003).

Instead of producing to stock, the concept of pulling (manufacturing when the need arises) creates a flow through the production system. Value is created by the flow, both for internal and external customers. Value streams through the process, both within the process itself but also from supply chains. The aim for perfection is the foundation of lean production. Waste elimination is a method aimed at amplifying value, while just-in-time is focused on flow generation. Central to the lean production approach is the involvement of personnel, which are encouraged to see mistakes as possible points of improvements. Lean production is a never-ending quest where constant improvements towards perfection are focused.

Lean construction

Following the development of lean production, the ideas were brought to the construction industry by Koskela (1992). Typical for construction (site) work is the lack of a flowing production that can be measured and improved. Lean production principles do not transfer exactly to the world of construction. Instead, Koskela (2000), issued the TFV-theory; transformation, flow and value, Fig. 2. The introduction of transformation as an element in lean theory reflects the construction industry's idea of an object being gradually enhanced by craftsmen not necessarily organised in a flowing manner. Being a project-oriented framework, lean construction lacks the long-term strive for perfection. Project organisation is not the best way of delivering value facing the difficulty of having temporary organisations cling to value generation (Winch 2006). Transformation differs from value stream, since transformation occurs only once, making it a process difficult to gradually improve. The emergence of lean construction led to the development of new tools suitable for the construction industry. One of them is the Last Planner system, which reduces waste time in planning efforts by postponing planning activities until the need arises (Ballard 2000).

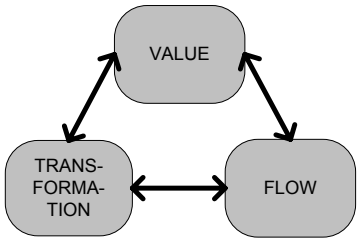

Figure 2: Transformation, flow and value, Koskela (2000).

METHOD

This paper presents a summary and analysis of the research conducted, during the past 12 years, within the field of industrialised timber housing at Luleå University of Technology. The summary is made through a literature review of research reports, theses, papers and statistic references. The results are put in relation to lean theories and the development of industrialised timber housing in Sweden, with the aim of establishing current knowledge and identifying future research needs.

INDUSTRIALISED HOUSING

Industrialised housing is about moving parts of the building process into factories, typically design and production of elements. A definition of industrialised housing was developed by Höök (2008).

> *Production in a closed factory environment where only assembly is performed at the construction site, with one evident process owner and a clear product goal of repetition in housing design and production.*

There is a variation between companies in how large a portion of the building process is internalised. The choice of degree of prefabrication affects the corporate strategy. In Fig. 3, the production of volume modules is presented as an example.

Industry setting

Sweden has had the lowest house building activity within the EU during the 10 past years (Antoni and Tilly 2004). A comparison of the number of completed apartments per one million inhabitants shows an average within the EU around 6.000 while the

corresponding number for Sweden is 1.500 (ibid.). This situation has led to housing shortage in many Swedish municipalities (Johannesson *et al.* 2007). Traditionally, public tenancy has held a strong position on the Swedish housing market. This has secured the supply of housing for those who have limited economic means. However, during the latest years a debate on introducing market prices on public tenancy has been raised. According to the prognosis the winners would be couples without children, living in private houses and the losers would be single parents living in tenancy rights (Gustafsson and Henriksson 2007). The consensus is that the need for a differentiated supply of apartments is curtail (Johannesson *et al.* 2007). In this context, together with a situation of increased competition, the construction companies have been forced to more effectively address customer demands (Brege and Överberg 2001). The need for lowering costs and shorten building time for housing is great (Sou 2000:44). It is believed that this issue can be handled through the use of prefabricated systems for housing with a higher degree of industrialised production.

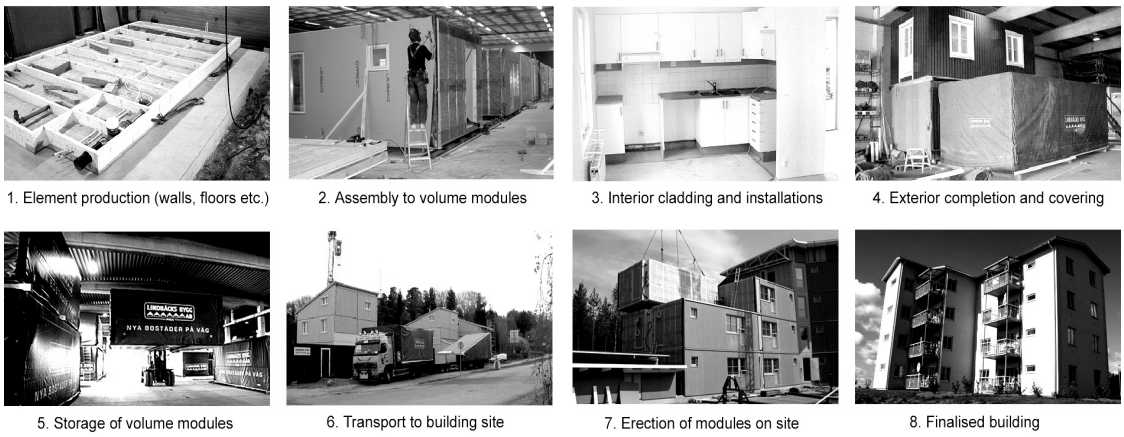

Figure 3: Industrialised housing through volume module production.

Swedish timber housing

In Sweden, timber was the dominating construction material for a long time. As urbanisation developed, houses of wood with highly flammable roofing were built closely together in cities, which made large city fires more frequent. As a consequence, the usage of wood as a frame material was regulated in the first Swedish building code from 1874 and was prohibited from use in house frames higher than two stories. This is the reason why timber in housing has been utilised and developed on the single-family housing market (~90% of single-family dwellings in Sweden have timber frames).

However, after a change of the Swedish building code in 1994 that allows timber frames in multi-storey buildings, a specialization towards increased use of prefabricated and industrially produced timber framed, multi-storey, houses has developed. An example is timber volume element (TVE) prefabrication, Fig. 3.

The presumed beneficial effects of industrialisation does, however, seem to be limited for TVE prefabrication due to; the client lacks knowledge or trust about the TVE's life cycle performance two combined effects and, the fact that, the clients feel that there are too few actors to make the TVE system reliable compared to other building techniques (Stehn and Levander, 2007).

To reduce the degree of uncertainty the construction process should be well planned and predictable. Decreasing the number of involved participants, the amount of on-site

production and the number of possible variations, as well as increasing the time and effort of pre-production activities such as design and cost estimations will accomplish a reduction in the perceived uncertainty among clients (Sardén and Stehn, 2006).

This is exactly what is being obtained by industrialisation of the construction process. So, where does the effort fail?

Industry logic

Building projects in industrialised housing follow predefined paths, Fig. 4. In the start-up phase, communication with the client dominates to eventually reach a product definition for the building. From the order point, it takes minimum 24 weeks (10+10+4) until the building is designed and manufactured. Erection adds another 3 weeks after manufacturing. Drafting of the building envelope is handled by the company itself, while HVAC drafting, structural design, electrical drafting and life-cycle costing are conducted by external consultants to varying degrees. There is no clear process leader which means that the ownership of improvements of/in activities or product development does not "belong" to a specific, appointed function or person.

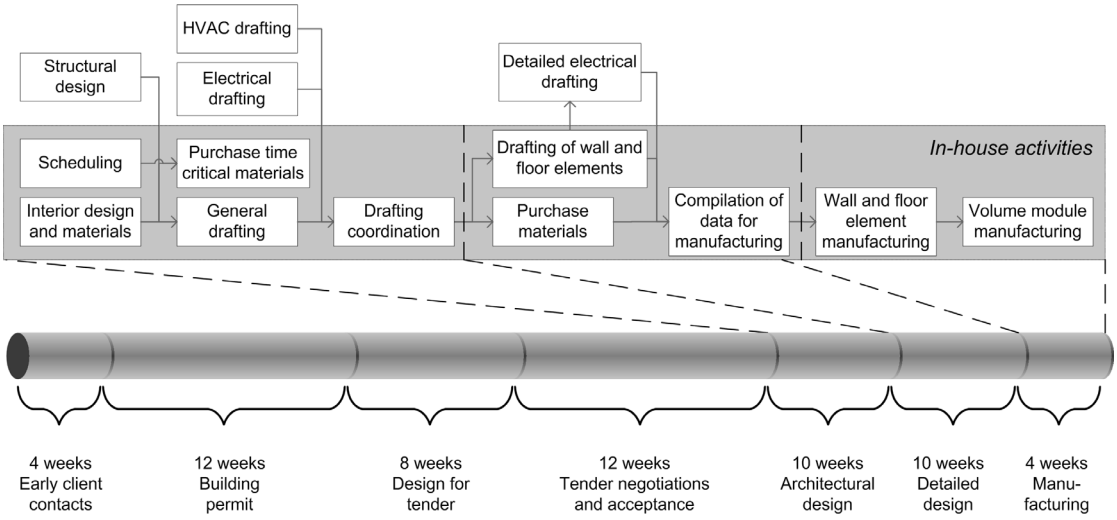

Figure 4: Schematic process for industrialised housing.

The Design Process

Some companies work with sales agents and use standard type houses on drawings as templates for drafting. The typical customer is a private individual seeking a single-family home. Other companies work directly with professional customers (B2B) and do not use standard type houses, since the customer defines the main characteristics of the building. Because the layout of the building greatly affects manufacturing, strategic alliances with architects and customers are sought to streamline the design process. In industrialised housing, building design is performed in two stages – the architectural design that defines the building envelope and divides it into modules suitable for manufacturing and the detailed design where the elements that build up each module are drafted in manufacturing drawings. HVAC installations are likewise designed twice.

The Manufacturing Process

The design process results in numerous manufacturing drawings and lists that are used as steering documents for manufacturing. Data from design are transferred in printed format, and occasionally re-organised or redrafted before being directly applicable in

manufacturing. Some of the studied companies have automated their production plants, mainly through automated wall element production. Remaining work is based on craftsmanship with handheld tools. The factory seems to work as a stand-alone production unit using drawings that resembles on-site construction documentation. The capacity of the production plants varies; an average of 150 m2 finished volume modules can be produced each day. Manufacturing follows the logic in Fig. 3. Late changes in drafting significantly disturb the flow and might lead to re-work. The modules are delivered to the building site by truck and their delivery time optimised to minimise site work.

Building System Documentation
The technical platforms, i.e. the building systems, build upon the same principles for many industrialised timber housing companies. Parts can be categorised in two main groups – detail and type solutions.

- Detail solutions describe meetings between components, e.g. a joint between two wall segments. Detail solutions can also encompass specific methods e.g. for mounting kitchen assemblies.
- Type solutions describe general solutions for elements with a cross section, but not their geometrical length, only their layer constitution.

Rules regarding limitations exist on different levels in the organisation. Many of these rules have not been documented at all, existing only in the minds of the employees, and are therefore not transparent in the design situation. Data is organised with building projects as the base, which is normal when the project is in effect, but difficult when the project becomes a memory. No specific person is assigned the function of managing the building system.

ICT Tools
Standardisation has inspired some industrialised house builders to invest in enterprise resource planning (ERP) systems for economical follow-up and material and resource planning (MRP). Unfortunately, standard construction CAD software and existing ERP systems do not communicate with each other, resulting in the product (the building) being defined in two different ways, often with discrepancies. ERP systems developed directly for the construction sector seem non-existent. Individual solutions with Excel and VB-scripts are extensively used to automate smaller sub-tasks. This data is not migrated into any receiving system. Information is dependent on individuals and the lack of an overall process management is evident. It is difficult to keep track of the project progress. Projects are defined in the early stages through CAD-drawings and PDF-documents. CAD data is seldom reused in the following detailed design, merely as printouts. Quantity take-off is not performed with CAD data as the basis, but with Excel lists enhanced with a VB-script to automate the process. Scheduling for manufacturing is done by the plant manager, who also controls the supply of materials. The work is manual with standard tools. Redrafting and recalculation are common activities.

REVIEW OF RESEARCH WITHIN INDUSTRIAL TIMBER HOUSING AT LULEÅ UNIVERSITY OF TECHNOLOGY

In 1996, the first project within industrialised housing in timber started at Luleå University of Technology. The goal was to enhance a TVE building system and streamline the mounting of installations as well as addressing customer needs and looking into ICT support. The need for a structured information handling was identified. The industrialised manufacturing process inspired contacts with the

manufacturing industry and the thoughts of Goldratt and Cox (1993) laid the foundation to research within modularisation and information management with ERP systems by Bergström (2004). As a result the important balance between customisation and internal factory efficiency was described. Single-family house manufacturers use a "car-selling" strategy in this case; a range of different models are offered to the customer. The range is predefined to fit the manufacturing equipment. With professional clients the situation is altered and production efficiency must be enabled through modularisation and a consistent building system. The importance in this context of an ERP system in terms of organising information and act as a driver for product development was identified by Bergström and Stehn (2005).

As the relation between the building system owner and his client defines the possibility for an industrialised house builder to make business, a project around uncertainties and complexity for new building systems was started. Through a single case study following a pilot project of a 5-storey building with a massive timber frame, it was concluded that reduction of uncertainties is the most important factor to handle in the investment situation (Sardén 2005). Complexity was handled through contractual agreements in the case study, but also through generous time planning throughout the building process.

In conjunction with the work on manufacturing logic, lean production became the focus of attention. The proposed TFV framework (Koskela 2000) provided the grounds for a project based on lean thinking in timber volume element prefabrication, Fig. 3. A theoretical effort was made to explore lean construction and its usefulness in industrialised housing i.e. to look at lean construction and its ingredients in the light of contemporary multi-storey building projects in wood (Björnfot and Stehn 2005). Complicated design decisions, poor design documentation and deficient production planning are seen as obstacles on the way towards lean construction. A consistent product offer is suggested as a possible solution. The product offer must be based on customer value and endorse value stream management in the production chain.

Market acceptance for industrialised timber housing was measured and showed a need for stronger information flow to potential customers combined with possibilities to experience the building system in reality (Höök 2008). The work was supported by the active support from four industrialised housing companies, all working with the technique showed in Fig. 3. Furthermore, the transfer of manufacturing principles to construction was studied and the need for a stronger structure in construction was identified. Industrialised housing is seen as a possible change agent towards an increased structure of construction with a higher degree of predefinition.

The efforts within industrialised housing was canalised by the start of a competence centre, Lean Wood Engineering. Twelve companies joined forces with three academic departments to address industrialisation through process, production, market and structural engineering aspects. The centre enables research across disciplines as e.g. when addressing the need for a stronger structure in construction, which calls for good documentation that lead to a demonstration of ICT solutions in Johnsson (2004). Product models combined with life-cycle data could be a good support in documenting a building system.

From a process viewpoint, separating product development from the building projects is seen as necessary to increase the product focus in industrialised housing (Johnsson 2004). As of today, the design process at industrialised housing companies is the bottleneck in the overall process, which has spurred interest to study the design

process. Notably, the design process is seemingly alike between industrialised house builders, but when it comes to human resource management it becomes clear that differences are large and affect the overall efficiency of the design process (Bergvall and Jansson 2008). Once the product is in focus, experience feedback becomes a natural activity in improvement work, the prerequisites of which is studied by Meiling and Johnsson (2008).

ANALYSIS

Many industrialised house builders use design-and-build contracts in the vast majority of their projects and take the overall responsibility for delivering a complete house. This is different from regular construction as industrialised housing takes control of a larger portion of the building process. This process oriented view has inspired the application of lean thinking to industrialised housing. The companies themselves view their production of building houses as manufacturing and several companies have invested in automation of their production. The link between design and production is unfortunately weak, the overall rate is too slow and current lead times from order to delivery exceed one year (2008). Therefore, it is crucial that the companies work with the bottlenecks in their entire process.

As of today, stronger ICT support in industrialised housing is needed to eliminate rework, increase design quality and strengthen the link between design and production. Many clients in construction view the possibility to make late changes as a source of great value. This is problematic since delivering customer value, according to lean thinking, should be in focus, but allowing late changes obstructs the flow and creates waste activities through rework.

Industrialised house builders would like to define the interface and interaction with their customers to a few, predefined points during the project realisation. This is not an easy task given that the customers are professional actors which are used to the construction culture, where everything is subject to change until it is built. The success of lean production in the production process at industrialised house builders have been tested (Höök 2008) but to transfer this knowledge to the design phase is a much bigger challenge.

Another category of companies are the industrialised element producers. They often serve as sub-contractors to a construction firm and deliver their products directly after the first step in Fig. 3. Therefore, they do not encounter the same problematic situation with the customer as the industrialised house builders. Element producers have problems that are more technical, related to documentation and technical performance of their products.

What the industrialised house builders could learn from the element producers is their information strategy. Element producers define their product very thoroughly and provide their customers with in-depth information on how to design, buy and handle their products. The same effort on information is not present with industrialised house builders and customers therefore feel a great deal of uncertainty concerning the product (Sardén 2005), a sense of lost control is common according to Höök (2006).

CONCLUSIONS AND FURTHER RESEARCH

Industrialised housing in Sweden is a growing market with good potential to provide low-cost housing of good quality. Still, there are some issues unsolved if industrial housing is going to evolve from trial to full production.

The challenges for industrialised house builders are:

- to organise their design process to fully support their production process,
- to work on their customer interaction to define the limits for changes vis-à-vis the internal process efficiency, and
- to provide information and quality data that decreases the uncertainty with future customers.

To provide support for this development further research within industrialised housing should address:

- quality management and the quality concept in housing
- reduction of uncertainties in customer relations, and
- new business models (contractual agreements).

Another line of future research, that needs attention if industrial timber housing is going to develop to a competitive alternative on the Swedish housing market, is the technical issues of efficient stabilisation methods for high-rise buildings and simple joining methods during assembly.

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