INDUSTRIALISATION AS A TOOL FOR REDUCING UNCERTAINTY IN CONSTRUCTION

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Construction projects are complex and have become more so during the late 20th century. This complexity is due to the failure of planning mechanisms and the apparent inability of plans to represent the reality of on-site construction. The occurrence of unpredictable events disrupts site processes and site conditions sometimes approach that of chaos. One strategy to deal with chaotic site conditions is to increase industrialisation, i.e. a controlled construction process following a predicted plan. The Swedish government suggests that increased competition could be obtained by an augmented use of timber in housing construction through developed building systems for multi-storey houses, and by using the knowledge of single family house manufacturers as catalysts for increased industrialisation in housing. Timber is a relatively "new" frame material in Swedish multi-storey housing. Hence, the knowledge, techniques and business relations needed for timber housing are lacking in many aspects. The increased competition and the absence of knowledge, techniques and business relations, together with a focus on industrialisation, gives the construction sector a great opportunity to develop general construction activities by engaging in timber frame projects. The case study results presented in this paper provide a broad view of the use of different prefabrication strategies used in the Swedish timber housing market and how these strategies decrease the uncertainty experienced by many stakeholders when choosing a "new" material such as timber for their facilities. The aim was to examine the possibility to use industrialisation as a tool for reducing uncertainty in construction. To manage this, three Swedish, multi-storey timber projects that have adopted a high degree of industrialised production were studied. The conclusion is that the novelty, and uncertainty, of Swedish, high-rise timber housing do not lie in the material, but in the new products, new techniques and new actors. Introducing prefabricated system components with a high degree of built-in knowledge concerning design and assembly may reduce uncertainties. If these components can be industrially produced, e.g. controlled and standardised, the uncertainty can be reduced even further.

Keywords: industrialisation, lean construction, prefabrication, project management, solid timber frame housing

INTRODUCTION

Bertelsen and Emmitt (2005) promote construction as a complex system by arguing that the prevailing understanding of construction as an ordered process is wrong and that such a delusion may be the reason for many of the problems encountered by construction managers. Under complex circumstances, unforeseen events that completely invalidate the project's target, planning and approach may occur. These events force the project team to frequently redefine the project's basic premises and to make decisions based on incremental learning (De Meyer *et al.* 2002). This introduction of complexity into construction vocabulary indicates a belief that the nature of construction is beyond understanding and therefore beyond management,

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especially for on-site construction where complexity seems to be due to the apparent inability of plans to represent reality (Kenley 2005).

A possible strategy to control unpredictable site conditions is the introduction of an industrialised construction process utilizing prefabricated components (Björnfot and Stehn 2005). Prefabrication, i.e. the making of construction components at a place other than the point of final assembly, may lead to better control of the inherent complexity within the construction process (Höök and Stehn 2005). The Swedish government suggests that this could be obtained by increasing the use of timber in housing construction, since Swedish single family housing manufacturers that have adopted a very high degree of industrialised production can act as catalysts for an increased industrialisation in multi-storey (> 2 storeys) housing. An increased knowledge of timber housing construction among construction actors and more developed building systems for timber frame houses have the potential to make general housing construction more effective.

The aim of this paper is to examine the possibility of using industrialisation as a tool to reduce uncertainty in construction. To accomplish this, the authors have studied three Swedish multi-storey timber projects where a high degree of industrialised production has been adopted.

THE SWEDISH CONSTRUCTION SECTOR

The construction, housing, and property sectors play an important role in the Swedish economy. The market value of the country's houses and constructions is estimated to more than double the GDP, and the construction sector is responsible, directly or indirectly, for 13% of the Swedish employment. The rate of construction increased during the late 80s only to experience a radical decrease during the 90s. Contractual forms incorporating a larger piece of the construction process, like build-operate/own-transfer and a responsibility to fulfil performance requirements, have become trends in Swedish housing construction. This could indicate a change from the traditional project orientation towards a more process oriented and industrialised approach in markets other than single family house construction, which in many ways is already industrialised (Bergström 2004).

UNCERTAINTY IN CONSTRUCTION

The construction sector is characterized by complexity factors due to industry specific uncertainties and interdependencies and an inefficiency of operations (Dubois and Gadde 2002). The more uncertain the task, the greater the quantity and quality of information processing required during the task activity to generate the necessary knowledge to complete the task (Tatikonda and Rosenthal 2000). A greater task uncertainty implies a high variability in and unpredictability of the exact means to accomplish the task, in turn leading to poorer task outcomes. One component that contributes to construction uncertainty is the degree of novelty of the technology used. Tatikonda and Rosenthal (2000) define technology novelty as: *"the newness, to the development organisation, of the technologies employed in the product development effort"* .

There are four types of uncertainty, each with specific consequences for the project team (De Meyer *et al.* 2002).

- *Predictable variation*: Cost, time and performance levels vary randomly, but in a predictable range. A linear flow of coordinated tasks represents the critical path toward project completion. Variation in task times will cause the path to shift, but building in buffers will help the team complete the project within a predictable range. Managers must plan for buffers and use disciplinary executions.
- *Foreseen uncertainty*: A few known factors will influence the project, though unpredictably. Major project risks, or "chance nodes", can be identified and contingent actions can be planned depending on actual events and desired outcomes. Managers must identify risks, prevent threats and develop contingency plans.
- *Unforeseen uncertainty*: One or more major influence factors cannot be predicted. The project team can still formulate a decision tree that appropriately represents the major risks and contingent actions, but it must recognize an unforeseen chance node when it occurs and develop new contingency plans midway through the project. Managers must solve new problems and modify both targets and execution method.
- *Chaos (incremental learning)*: Unforeseen events completely invalidate the project's target, planning and approach. The project team must continually redefine the project's basic premises and create new decision trees based on incremental learning. Managers must repeatedly and completely redefine the project.

To reduce the degree of uncertainty the project team should try to make the process as well planed and predictable as possible. 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 this. The more complex the project is, e.g. the more possible variations that can occur, the higher the risk that unpredictable events occur and that the project's target, planning and approach becomes completely invalid. These events force the project team to redefine the project's premises and to make decisions based on incremental learning; hence, they increase the degree of uncertainty.

INDUSTRIALISATION IN CONSTRUCTION

Although innovation in construction takes place incrementally (Arditi *et al.* 1997), technological and organizational changes have led to transformations of the Swedish construction sector, including changes in materials, development in prefabrication and more extensive factory production of subsystems and components. Despite these changes and the developments that have taken place, the Swedish construction sector still fights the challenges of low profits and low market activity.

To overcome some of the difficulties regarding traditional, crafts-based on-site housing and improve the housing construction process, an industrialisation of housing inspired by the possibilities to apply mass production to housing construction has emerged (Winch 2003). Initiated during the first half of the 20th century, this early industrialisation of housing influenced the evolution of systems building (Gann 1996).

The beneficial effects of the industrialisation changes seem to be limited due to three reasons:

- The effects of organizational (e.g. partnering, design/build contracts) and technological (e.g. prefabrication) changes can be undermined by conflicts introduced in the relations between the different parties, because they demand a new way of working.
- New management practices place greater demands on the coordination between different organizations, and new technologies require enhanced precision in assembly. This contributes increased complexity in an environment already characterized by fragmentation in responsibility, adversarial labour relations, safety considerations and a range of regulations, standards and codes (Thompson and Sanders 1998, Conley and Gregory 1999).
- The conflicts between different parties in the sector and the problems that ascend from increased complexity may worsen by the nature of the skills profile, where the delineation between different skills are very unyielding, and by the employment conditions (many persons having seasonal employments) of the Swedish construction workforce.

Failures in the industrialisation of housing, prefabrication and systems building led to a return to traditional housing during the 1970s (Winch 2003).

Since then, industrialised housing has evolved through customer orientation and construction process developments. Japanese industrialised housing companies have successfully adopted and adapted the lean production concept through balancing customisation and standardisation, while developing efficient production processes (Gann 1996). The standardisation of processes and products can improve the construction process, prefabrication can improve safety, productivity and quality, and customisation is efficiently achieved by combining standardisation and prefabrication (Gibb 2001). Lessons from attempts to industrialise construction show the possibility and advantages of using a lean and responsive production approach to handle the interface between process and project orientation on the company and the industry level (Höök 2005).

More and more Swedish producers (contractors, manufacturers, etc.) of multi-storey timber houses have increased their awareness of these possibilities, resulting in an increased level of prefabrication in their production.

CASE STUDIES

The first two case studies are part of ongoing research projects with results and analysis presented in other academic publications; Case study 1: Björnfot and Stehn (2005), Sardén (2005); Case study 2: Höök and Stehn (2005), Olofsson *et al.* (2004); Case study 3: Björnfot and Sardén (2006). The 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 prefabricated products and the prefabrication decision in each case.

Case study 1 – Element prefabrication

Case study 1 concerns a supplier of prefabricated solid timber floor and wall elements, Figure 1. The supplier is a large Swedish sawmill owner, whose aim is complete prefabrication of the elements, which generally include surface finishing, façade and installations. All work is performed at the supplier’s factory where automated machinery is utilized. The elements are completed are then delivered to the construction site and assembled to a complete structural system. The goal of the supplier is to provide a complete system for prefabricated elements, i.e. design, manufacturing, delivery, and guidance for on-site assembly.

The prefabricated element system was recently tested in practice in a multi-storey timber housing project consisting of five houses with six floors each. The structural system was procured under a design-build contract with a fixed price and the element supplier promised the contractor full responsibility for the design and assembly, even though this particular system was used for the first time. As a result, the system was continuously developed during the project, resulting in wasted time due to rework and delays.

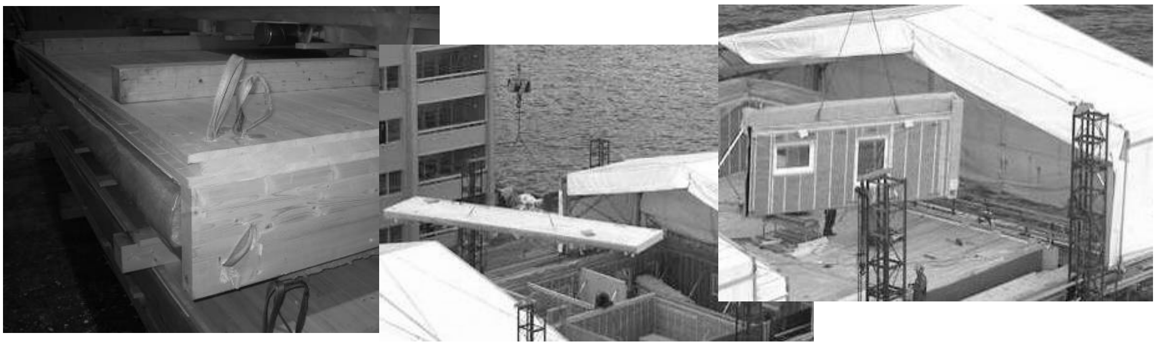

Figure 1: Prefabricated timber floor and wall elements used for multi-storey housing**.**

A prefabricated structural system with the installations integrated during manufacturing was chosen mainly because of a desire to increase the productivity of site assembly and guarantee a high quality. Since timber is generally susceptive to weather, a “dry construction” process was aimed through the use of a covering tent (Figure 1), and 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, and not surprisingly, this decision resulted in an inability to apply surface finishing and major installations at the factory, which were later identified as one of the main reasons for the problems in structural and internal finishing work observed during site production.

The supplier also had to take on the role of a contractor, rather than being a traditional supplier of construction components, and the elements were continuously being redesigned. Clearly, all project stakeholders would have been better off if the prefabricated element system had been fully developed before the project start. Despite all of these problems, it was agreed that the assembly of the prefabricated system was advantageous and it progressed according to schedule.

Case study 2 – Volume prefabrication

Here, a Swedish company produces volume timber frame multi-storey houses. The company’s projects are run with everything in-house, i.e. they procure property, design the building according to the customer’s demands, produce prefabricated volumes, and assemble and finish them on site, Figure 2. The company has focused on customisation, while keeping a straightforward design and production process. Only minor changes in the principle design are allowed to maintain a highly, cost efficient production. This is possible because the company own the major parts of the value stream, e.g. they hire subcontractors for in-house installations and uphold long-term relationships with suppliers.

Figure 2: Prefabrication and site assembly of volumes including finishing.

The company product offer of prefabricated volumes governs their marketing, manufacturing, client negotiations, and on-site production. The volumes are produced through a standardised 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 and 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. Only minimal finishing work is required on site through this work, which is often performed with a minimum amount of wasted effort.

Even though it seems as if the company is strict on maintaining its volume production system, they are actually keen on meeting customer demands. However, client involvement is very much limited to interior and façade design, and add-ons such as balconies. This may seem to severely limit meeting customer demands, though the customers generally know what to expect and how much involvement they are allowed in design. The volume system has been perceived as limited in flexibility and customisation and has been mostly used for repetitive standardised housing projects such as student dwellings. 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 platform initiative
Case study 3 concerns an innovative effort in the Swedish construction market where the supplier in case study 1 and the company in case study 2 have joined together with an architect and suppliers of construction components. The aim of this initiative is to produce cheaper houses to a larger market segment than the companies can do individually and thus increase the involved companies' shares of the multi-storey housing market. Even though the case has not yet been seen in practice, a discussion of its prefabrication strategy 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, i.e. timber element prefabrication (Figure 1) and volume prefabrication (Figure 2). The main idea of the initiative is to use timber elements (Figure 1) and timber volumes (Figure 2) where they are best suited. In the design of the concept, the finishing of "wet areas", such as bathrooms and kitchens, was identified as the most difficult part of site-production. Therefore, an attempt to prefabricate such areas as volumes to better control the difficult on site finishing work was suggested. It was also decided to include as much of the installations in the volumes as possible, since experience from case study 2 showed that site production of installations is a common source of waste.

The layout of the houses is based on volumes, though to achieve a higher degree of flat layout flexibility, prefabricated timber elements are used to complement the volumes. By using elements, almost any kind of building can be produced. Great efforts to standardise the elements and simplify the manufacturing and site assembly processes have been made. This design effort has significantly reduced the number of different elements used. The involved companies have also attempted to pinpoint and simplify the supply chain by reducing the number of suppliers for construction components.

Although this company endeavour seems to have all the possibilities of success in a fragmented construction market, it will be interesting to see if the ideas are adoptable in practice.

REDUCING UNCERTAINTY THROUGH PREFABRICATION

Prefabrication from a value stream perspective
A general, material related value stream for a multi-storey timber housing project could be depicted as in Figure 3. This value stream can be used to relate the prefabrication strategy in the cases (c.f. Björnfot and Sardén 2006). The decoupling point (DP) between factory and on-site production can be used to exemplify each cases prefabrication strategy, e.g. a prefabrication strategy where more and more factory produced construction components are used would result in a decoupling point further to the right (downstream) (Björnfot and Stehn 2005).

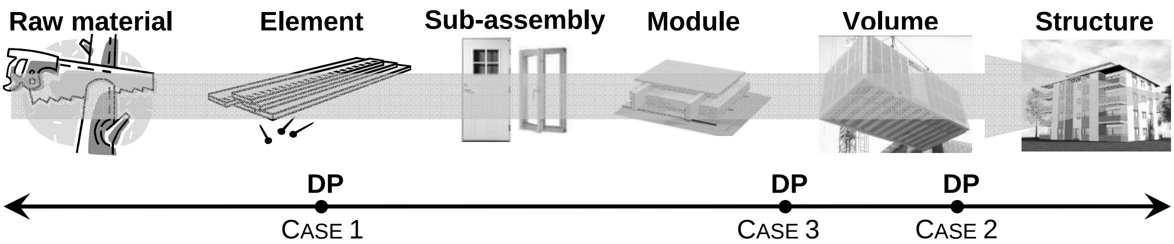

Figure 3: The case study product offers related as a decoupling point between factory and site production.

The company in Case study 1 has a strategy to produce prefabricated elements. However, a lack of time or deficient knowledge of the construction process has so far resulted in a system that is too undeveloped for practical usage, leaving the DP relatively high upstream in the value flow. In the second case, the company's strategy is to produce a complete volume system (depicted as the decoupling point furthest downstream in Figure 3). Development of this volume system has led to an increased control of factory and on-site variability through better control of the customer value generation process (Björnfot and Sardén 2006). The product in case study 3 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 previously unattainable housing market segments can be reached. From the case study results, the case companies seem to utilize different prefabrication strategies to reach diverse segments of the housing market. Nevertheless, the strategies aim to facilitate on-site production and minimise the product and process variation in common.

Prefabrication as a way of reducing uncertainty

The company is case study 1 offers a prefabricated element system that is undeveloped, but has the potential to be a system with built-in installations and built in knowledge of how to decouple and assemble the elements. In this case, most major influence factors, such as the weather and on-site logistics needed for structural finishing work, cannot be predicted or may at least unpredictably influence the project. Still, most project risks, i.e. limiting the height of the timber elements, can appropriately be identified and planned for depending on actual events and desired outcomes, though the project team must recognize unforeseen risks when they occur and re-plan the project, considering these risks. The system offers a customisable, yet defined and industrial solution to be used in residential and office buildings. The solution decreases the uncertainty for both the client and the contractor, as the on-site activities are limited to assembly and structural finishing. Therefore, the majority of activities vary foreseeable, though unpredictably. This result in a production uncertainty with a focal point that moves from unforeseen to foreseen and further towards a predictable variation, Figure 4, but the uncertainty still contains some elements of chaos.

In case study 2, the company offers prefabricated volumes produced by a well-developed and highly industrialised process. The company has all the needed sub-contractors to complete the volumes as well as the finished buildings tightly connected to them through long-term contracts. Therefore, cost, time and performance levels will vary randomly, but predictably. The variation in task times will cause production to fluctuate, though these fluctuations may be handled by building in buffers. A few known factors, such as the weather, will influence the project unpredictably, but the major chance nodes can be identified and planned for. The fact that all activities, except the assembly of the volumes, are preformed in-house and that the volumes are quite standardised, rendering the activities both foreseeable and predictable. Hence, the uncertainty in the construction process becomes very low, Figure 4, almost only containing almost only predictable variation, but with also some foreseen uncertainty.

The group in case study 3 and their integrated system is very new. Hence, it is impossible to say anything about the real performance of the system, but we think that it has the potential to increase the flexibility and the degree of customisation of the volume based system than to actually decrease the uncertainty in construction. This means that the amount of unpredictable events that may occur will increase compared with the “pure” volume prefabrication case, Figure 4.

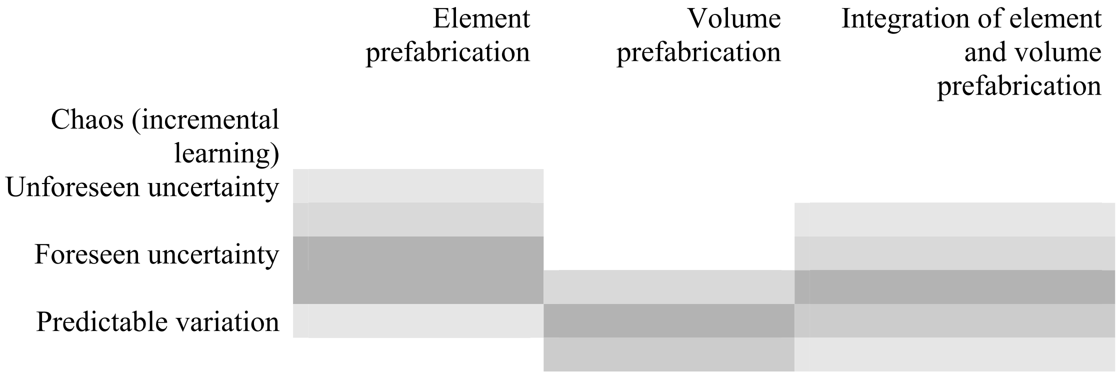

Figure 4: Degree of uncertainty as a result of the prefabrication strategy.

The darker grey areas in Figure 4 represent the main type of uncertainty created by the prefabrication strategy in each case. The lighter grey areas illustrate the presence of other types of uncertainty.

DISCUSSION AND CONCLUSIONS

The case study results presented in this paper provide a broad view of the use of different prefabrication strategies used in the Swedish timber housing market and how these strategies decrease the uncertainty experienced by many stakeholders when choosing a "new" material such as timber for their facilities. The aim was to examine the possibility to use industrialisation and prefabrication as tools for reducing uncertainty in construction. To manage this, three Swedish multi-storey, timber projects where a high degree of industrialised production was adopted were studied.

The novelty and uncertainty of high-rise timber housing does not lie in the material itself, but in the new products, new techniques and new actors. The introduction of prefabricated system components with a high degree of built-in knowledge concerning design and assembly may reduce these uncertainties. Since these components can be industrially produced, e.g. controlled and standardised, the uncertainty can be reduced towards predictable variation, as shown above.

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