FEEDBACK IN INDUSTRIALISED HOUSING: WHY DOES IT NOT HAPPEN?

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The construction industry is based on craftsmanship and the construction hero is someone who handles every appearing situation with a somewhat good result. Quality work in manufacturing relies on repetitiveness, standardisation and follow-up, whereas construction is about uniqueness, responsiveness to problems and flexibility in solutions. A category of construction companies have met the contradiction between construction and manufacturing – industrialised house builders. This category of companies work with the prefabrication of building parts for later assembly at the building site. The degree of prefabrication ranges from manufacturing open walls and floors up to producing entire volume modules with complete interior cladding. In lean theories as well as quality management, the notion of continuous improvement and experience feedback is strong. Yet, why is this mechanism almost non-existent with traditional construction companies? Industrial house builders benefit more from experience feedback than traditional construction firms, since the repetitiveness is higher. This paper aims to explore why experience feedback, in Sweden, does not function in today’s industrialised building process. The manufacturing process of four industrial house builders in Sweden was studied and mapped. The results show that much focus was put on streamlining the production process at the factory, but that experience feedback between departments at the company was small and non-existent from quality audits within the company. A change in company culture and leadership is needed to start addressing this problem.

Keywords: feedback, industrialised housing, quality management.

INTRODUCTION

Industrialised housing in Sweden is identified to have the potential to increase efficiency and control, lower costs and increase quality (SOU 2002, 2000). The emerging industrialisation in construction is following an international trend (Apleberger, Jonsson and Åhman 2007) e.g. the Egan Report (1998) argues that construction must turn into a manufacturing process in order to become more efficient. The development of timber frame prefabrication on the multi-storey market was enabled through the introduction of functional building codes in 1994. The high strength/weight ratio for wood implies the possibility to handle prefabricated units over large transportation distances (Höök 2006). The degree of prefabrication ranges from manufacturing open walls and floors up to producing entire volume modules with complete interior finishing. The method of using volume-based timber construction moves 90% of the work to factories (Ibid.). Höök (2006) states that industrialised housing, when aiming for standardized and predictable processes,
changes the company culture from organizational learning and learning between projects, and will develop towards building in knowledge into the process instead of in the people, thus facilitating knowledge feedback in a consistent way. Liker and Lamb (2002) also support the importance of a cultural change and a top-down strategy combined with bottom-up tools for lean manufacturing.

Sigfrid (2007) calculates mistakes in construction to greatly impact the production price, i.e. the cost for correcting defects after moving in could be up to €95 M. Josephson and Hammarlund (1999) calculate the cost for defects during a project to 6% of the production cost. In an average building project the cost of poor quality is 15% (Josephson and Saukkoriipi 2005). Hence, feedback and re-use of experience is an urgent field that causes both monetary and product quality implications.

Industrialised house builders could benefit more from experience feedback than traditional construction companies, due to the higher repetitiveness and one process owner taking responsibility for the product.

This paper presents a case study of the construction process at four industrialised house builders using timber volume element prefabrication on the Swedish market. The analysis is made with a focus on scrutinizing feedback possibilities. The research question is the following: If industrialised house builders have control over large portions of the process, why does experience feedback not function?

INDUSTRIALISED HOUSING

A prefabrication strategy changes construction companies from object-oriented builders focusing on on-site construction to process-oriented manufacturers taking larger control of the value chain with the reduction of workflow variability due to repetition in operations (Höök 2006). Theoretically, such companies have all the prerequisites to control the processes and the resources used, moving value-added activities up the supply chain and into a controlled environment (Nasereddin, Mullens and Cope 2007). Lessing et al. (2005) suggested eight characteristic areas that constitute the concept of industrialised housing: (1) planning and control of the processes, (2) developed technical systems, (3) offsite manufacturing of building parts, (4) long-term relations between contractors, (5) supply chain management integrated in the construction process, (6) customer focus, (7) use of information and communication technology (ICT), (8) systematic performance measuring and re-use of experience. Diekman (2003) presents a set of characteristic lean principles: standardisation, culture/people, continuous improvements/built-in quality, eliminate waste and customer focus.

A timber volume element is a closed three-dimensional structure built up by timber framed elements completed in a factory. The timber volume element contains four load-bearing walls (exterior walls or volume separating walls), a system of joists, interior roof and partition walls, each representing an element. The size of a volume element is limited to an outer width of 4.15 meters and an outer length of 13 meters. The production is managed in eight main stages - element production (walls, floors, etc.), assembly to volume modules, interior cladding and installations, exterior completion and covering, storage of volumes, transportation to building site, erection of modules on site, and finalised building.

QUALITY MANAGEMENT

Total Quality Management (TQM) is defined as both a philosophy and a set of guiding principles (Dale 1999, Bergman and Klefsjö 2003). Quality work at a
company is often connected to a routine exercise without any thoughts of implementing a system for enhanced product quality, such as with ISO 9000 standards (Nee 1996). The result is then to manage documentation aspects of getting or maintaining the ISO certificate rather than reaching desired quality goals (Gustafsson et al. 2001, Lam and Ng 2005).

The values of TQM is summarized in five cornerstones; (1) focus on the customer, (2) base decisions on facts, (3) focus on processes, (4) improve continuously, and (5) let everybody be committed (Dale 1999). The cornerstones are supported by a set of tools, values and methodologies (Bergman and Klefsjö 2003), many of which are also used within the Lean production system (further discussed in the following chapter) (Arnheiter and Maleyeff 2005). The formalisation of continuous improvements is often demonstrated by the PDCA (Plan, Do, Check, Act) learning cycle and by improvement tools and methods, such as root cause analysis (RCA), (Wilson, Dell and Andersson 1993, Jones et al. 1999, Arnheiter and Maleyeff 2005), and techniques like cause-and effect- and tree diagrams. Low and Peh (1996) suggest a framework for implementing a TQM quality system in construction, though the impediments are also summarised by Low and Teo (2004), who state that the success of TQM is yet to be proven in construction. When learning about improvement systems it is difficult not to mention yet another quality management system originating from TQM and Motorola Corporation in 1985, i.e. Six Sigma. A customer focus is again emphasised, recognising that quality is the responsibility of all employees and that employees must be trained to achieve (Pyzdek 2001). In Six Sigma, initiatives similar to learning cycles in TQM are used to improve the existing business process and new product or process designs for predictable, defect-free performance. Six Sigma is associated with defects and quality, and Lean production is linked to speed, efficiency, and waste (Hahn, Doganaksoy and Hoerl 2000). Both are production oriented, but because Six Sigma is a disciplined and a highly quantitative approach (Hahn, Doganaksoy and Hoerl 2000), it could be argued premature to use in construction with undefined and shifting processes. However, Abdelhamid (2003) and Arnheiter and Maleyeff (2005) argue for Six Sigma to be transforming from a highly developed technical, statistical system that only focuses on minimising variations and defects to a management program in pursuit of customer satisfaction.

LEAN THINKING

Lean Production

The basic idea in lean production is to reduce unnecessary operations and waste with simple methods to promote increased flow targeted at creating customer value (Womack and Jones, 2003). Instead of producing to stock, the concept of pulling or manufacturing when demanded creates a flow through the production system. Value is created by the flow for both internal and external customers. Value streams within the process itself and from supply chains. Perfection is the basic lean thinking principle, meaning to continually strive towards producing precisely what the customer wants and deliver the product when expected while eliminating waste (ibid.). Perfection is a way not the means through identification of a future improved state that will always be renewed when reached (Rother and Shook 2003). The elimination of waste is pursued through continuous improvement of the production system by using the same tools and methods as in TQM, such as root cause analysis and the technique of asking five whys (Jones et al. 1999). To achieve this, Toyota has implemented so-called quality circles (Shingo 1986) consisting of cross functional groups of operators from
different functions. Everyone is involved and responsible to come up with suggestions for improvements. In addition, everyone is empowered to stop the production line if mistakes are detected.

**Lean Construction**

In 1992, one of the first parallels was drawn between the manufacturing industry and construction when Koskela *et al.* (1992) defined the principles that laid the foundation for what is known as lean construction. In lack of a flowing manufacturing line, Koskela (1992) issued the TFV - framework; transformation, flow and value, with a base in production and operations management. The introduction of transformation as an element in lean theory reflects the construction industry’s idea of an object being gradually enhanced by craftsmen, though not necessarily organised in a flowing manner. Production has to be performed using transformation of inputs to outputs, where materials and information flow through value and non-value adding activities with customer value as the end goal. Being a project-oriented framework, lean construction so far lacks the long-term strive to perfection. To improve performance a new understanding of construction and its product is proposed (Bertelsen and Sacks 2007), though for now project organisation is not the best way to deliver value (Winch 2006), particularly when facing the difficulty of having temporary organisations cling to value generation. Kärnä and Junnonen (2005) present a theoretical framework for learning through project feedback. They state that learning can be divided in four dimensions i.e. (1) organisational, (2) individual, (3) construction and (4) relationship learning, and conclude that learning is a key ingredient within successful companies in terms of value creation. The difficulty with learning in construction projects is documented by e.g. Anheim (2001), Persson (2006), Shelbourn *et al.* (2006) and Ahn *et al.* (2007). Vrijhoel (2005) blames the three peculiarities of production in construction, i.e. site construction, one-of-a-kind production and temporary organization, as obstacles. A joint venture of Six Sigma and Lean in construction projects has recently been proposed (Abdelhamid 2003, Arnheiter and Maleyeff 2005).

**METHOD**

The manufacturing process at four Swedish house manufacturers is described and probed to document the feedback management regarding the technical solutions utilised as well as the overall quality in the product. The companies are small and medium sized (see Table 1).

<table>
<thead>
<tr>
<th>Case</th>
<th>No of employees</th>
<th>Main products</th>
<th>Turnover (MEuro)</th>
<th>No. of storeys</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>220</td>
<td>Schools- and office buildings</td>
<td>38</td>
<td>Mainly 1-2</td>
</tr>
<tr>
<td>B</td>
<td>135</td>
<td>Multi family- and student dwellings</td>
<td>42</td>
<td>Mainly 4-5</td>
</tr>
<tr>
<td>C</td>
<td>300</td>
<td>Multi family- and office buildings</td>
<td>42</td>
<td>Mainly 1-4</td>
</tr>
<tr>
<td>D</td>
<td>35</td>
<td>Schools- and office buildings</td>
<td>7</td>
<td>Mainly 1-2</td>
</tr>
</tbody>
</table>

Empirical results are based on data gathered through interviews and observations from October 2007 to February 2008, along with archival studies to understand the industrialised production process. Interviews were conducted with individuals representing management (four companies), factory production (four companies) and assembly (site managers of five assembly teams). Five different field trips to building sites were conducted. Semi-structured, in-depth interviews were performed with the
quality manager at one company, two site managers at one company, the sales manager at two companies and two production managers at one company. Building inspections from 16 building projects were examined representing 958 prefabricated volume modules. A total of 2,829 defects were sorted by their origin (see Figure 1). To evaluate the possibility of using existing inspections, a population representing 20% of the total production was explored. Also, guarantee inspections from 9 projects were examined, representing 909 modules and 490 defects.

Building and guarantee inspections, compulsory through contract in Sweden, are regulated and formalised through a non-profit association of influential actors in the construction industry. A rigorous set of rules is presented in two regulations, i.e. general regulations for construction, AB04 (AB 2004), and design build contracts, ABT94 (ABT 1994).

TIMBER VOLUME ELEMENT PREFABRICATION CASE

The organisation in the studied companies is not process-oriented in any formal way. Building projects follow predefined paths involving multiple activities (see Figure 2). The companies often run everything in-house, seeking a design-build contract. During design, manufacturing and erection, the building is thoroughly defined, manufactured and erected. Most activities remain in-house, while some are performed by external consultants.

Briefing

Briefing includes 4 weeks of early client contacts, 12 weeks for the building permit and 8 weeks to design tender and 12 weeks for tender negotiations and acceptance. Financial and technical design issues as well as architectural aspects are addressed during this period. The sales department consists of one person in company D and two to three persons in companies A, B and C. The architectural work is conducted in-
house and with external architects, both of which are experienced in the volume element prefabrication system. After sales, a start meeting is initiated where object specific demands are investigated; this is also when the project leader is appointed. Two companies are assigned the work of documenting a company standard, i.e. technical platform, as part time work. Early design work is organised under the sales department and is supposed to be done by a skilled senior design employee, but due to capacity problems this person is often occupied elsewhere.

The Design Process

Standardisation appears for these companies in the design process, by defining standard joints, standard stairwells, standard wall and floor sections, etc. Since the layout of the building greatly affects the manufacturing, strategic alliances with architects and customers are sought to streamline the design process. Drafting of the building envelope is handled by the companies themselves, while HVAC drafting, structural design, electrical drafting and life-cycle costing are done by external consultants to varying extents.

Common to all the companies is that building design and HVAC installations are performed in two phases. The building envelope is first developed and divided into modules suitable for manufacturing, followed by the detailed design where the elements building each module are drafted on manufacturing drawings. Standard CAD software for construction is used to produce the drawings. A bill of materials is produced as quantity take-off directly from drawings. Based on the bill of materials the ordering of materials is made as a manual action. There is no active process support to follow up the progress of an activity. Quality control of drawings is scheduled, but not executed.

The Manufacturing Process

The capacity of the production plants vary, where an average 150 square meters is finished modules are produced each day. Rules and limitations regarding volume assembly exist on different levels in the organisation, but are not documented with any consistent method. The rules are therefore not transparent in the design situation, and create much of the unnecessary rework between design and manufacturing.

Once the structure of the module is complete, internal cladding, painting and decoration begin. The workers use printed drawings to keep track of work tasks for a particular module. Before storing the volume, an inspection is conducted and any deviations are reported. All missing equipment or incomplete work is listed. This material is not used for any other purpose than as a memory list for ordering material or assigning labour to correct defects; there is no follow-up practice after closing the issue. Data and experience from projects are archived according to a specific project, and not related to the production process. The ownership of improvements in activities or product development does not have an appointed function.

Assembly on site

The modules are delivered to the building site by truck and their delivery times are optimised to minimise site work. The work onsite is done by small and tight groups of in-house teams and external carpenter firms. These teams move from building site to building site and have inherent knowledge about the practical aspects of the building platform. At the building site, the information flow is addressed through meetings and short instructions, but not on a regular basis. A common problem is the lack of detailed standards for a specific work task. All teams have their own solutions concerning, e.g. edging, carpet joints and doors.
Feedback initiatives

Data is organised with building projects as the base, which is natural while the project is ongoing, but difficult when the project becomes an experience. Product development is not a separate process within the companies, but rather an activity that arises from project to project. Information is dependent on individuals and no central management system controls the progress of the process; therefore, it is difficult for individuals to keep track of the project progress.

External quality audits are done on the finalised building at delivery and after a guarantee period of 2 years (mandatory in Sweden). No link exists between these audits and no model is established for traceability of quality problems backwards in the manufacturing process. Today, the action process for correcting defects is fast and non-reflective. The prevailing procedure with obvious defects, i.e. when clients demonstrate a demand for action, is to initiate immediate actions, but without follow-up of solutions. This could be described as a fire extinction approach to defects and problems.

Exploring feedback data from building inspections

Building inspections from 16 building projects and guarantee inspections from 9 projects were explored (see Table 2). Within the inspections only indoor building protocols were chosen, based on earlier studies from Sigfrid (2007), Persson (2006), and Josephson and Hammarlund (1999), implying the urgency in this area. From the investigated building inspections, 66% of defects originate mostly from factory production, followed by 21% from erection. The 11 projects from company B include 457 apartments with 7.3 defects per habitat with a maximum of 14 and minimum of 1 defects. Repairing simple defects at the building site constitutes 63% of 2,415 defects, followed by replacements at 31%, which is more severe.

Table 2: Summary of inspection protocols.

<table>
<thead>
<tr>
<th></th>
<th>Projects (no.)</th>
<th>Defects (no.)</th>
<th>Modules (no.)</th>
<th>Mean value (Def./Mod.)</th>
<th>Std. dev. (%)</th>
<th>Max/min (Defects)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building</td>
<td>A 5</td>
<td>414</td>
<td>81</td>
<td>6.1</td>
<td>66</td>
<td>1/11</td>
</tr>
<tr>
<td>Guarantee</td>
<td>B 11</td>
<td>2415</td>
<td>877</td>
<td>3.1</td>
<td>63</td>
<td>1/7</td>
</tr>
<tr>
<td>Building</td>
<td>A 5</td>
<td>66</td>
<td>81</td>
<td>1.1</td>
<td>81</td>
<td>0.4/2.4</td>
</tr>
<tr>
<td>Construction</td>
<td>B 4</td>
<td>424</td>
<td>828</td>
<td>0.9</td>
<td>70</td>
<td>0.3/1.6</td>
</tr>
</tbody>
</table>

DISCUSSION

Findings from the case study reveal that many of the defects occurring in newly produced houses are generated during the early stages of the construction cycle, i.e. originating mainly from design and factory production. Little is done regarding the use of information captured in the building inspection. The timber volume element house manufacturer, rather than builder, is often responsible for both design and production, giving the opportunity of seeking and promoting early design decisions compatible with production capability. This is imperative to attain a cost effective product, and demonstrates the contradiction between manufacturing and construction. When manufacturing prefabricated volumes, the number of participating companies is less, resulting in enhanced possibilities concerning learning from experience, e.g. feedback, and thus finding connections to improvement possibilities within the company. This in turn could present a competitive edge towards other building systems and promote long-term quality.

The analysis of defects could give information about the most common defects, and an opportunity to trace defects back to production and design. The purpose of building
inspections is to determine whether the contractor fulfilled what the customer has procured. Using building inspections for evaluation, and as a bearer of information, is not recognised by the companies.

From a Lean perspective defects represents waste. and is a way of gaining perfection, though within the investigated manufacturers, defects are an obstacle for closing projects. A strive for customer value is noticeable in the companies, together with a focus on streamlining production and minimising waste. Without feedback management it is not possible to close the Lean circle of value, pull, flow and value stream, and reach perfection as described in Womack and Jones (2003). Sigfrid (2007) investigated building inspections from 6 traditionally built projects and found 9.3 defects per habitat, implying that industrialised housing with 7.3 defects achieves the same level of quality.

The investigated companies do not have a strategy for handling knowledge connected to the correction of defects, knowledge is often connected to individuals or filed in a specific building project. The companies in the case study are mostly sole process owners; thus, in a learning perspective, these companies will benefit more from organisational (company) learning (Kärnä and Junnonen 2005) as individuals, teams and customers are more stable and thus controlled. Relations remain the same from one project to the next.

The companies are still rooted in the construction culture without any implemented quality culture based on a belief of continuous improvements and follow ups, as described by e.g. Bergman and Klefsjö (2003). The construction worker is paid to solve problems and is not instructed to stop production when serious problems occur. The cost of not implementing a wider and deeper quality approach should be prohibitive (Juran and Gryna 1993), but at best, one company has one person responsible for maintaining a quality management system such as the ISO9000; this is hardly sufficient for a €42 M turnover company.

REFERENCES


Meiling and Johnsson


