EXPERIENCE FEEDBACK AT INDUSTRIALISED HOUSE BUILDERS

John Meiling[1] and Helena Johnsson[2]

ABSTRACT

In lean theories as in quality management, the notion of continuous improvement is strong. Experience from an earlier production cycle should be fed into the next cycle. The framework of lean production offers a structure for experience feedback to take place. The industrialised house builders would benefit more from experience feedback than traditional construction firms would, since the degree of repetitiveness of their work is higher. The degree of prefabrication in industrialised housing ranges from manufacturing open walls and floors up to producing entire volume modules with complete interior cladding. The higher the degree of prefabrication, the stronger is the clash between construction and manufacturing, since the traditional construction process does not cater for the need for early design decisions that are rigid throughout the building process. This paper aims at exploring the production process at three industrialised housing companies seeking feedback opportunities and implications. An explorative research method is used where interviews with the participating companies show that initiatives and opportunities exist, but not in a consistent way. The transformation of information and knowledge into useful design input could be seen as a bottleneck in production process.

KEY WORDS

experience feedback, industrialised housing, multi storey building, timber volume element prefabrication

INTRODUCTION

The construction industry is based on craftsmanship and the construction hero is someone who quietly handles every appearing situation with a sufficiently good result. If quality work in manufacturing relies on, e.g., repetition, standardisation, and follow-up, then construction is about uniqueness, responsiveness to problems, and flexibility in solutions. Therefore, the clash between the construction culture and the thought of quality management is large.

There is a category of construction companies that have met the contradiction between construction and manufacturing; the industrialised house builders, in this paper defined as those who produce houses in a closed factory environment with one evident process owner and a clear product goal of repetition in housing design and production where there is mostly assembly at the building site. Lessing et al. (2005) suggested eight characteristic areas that constitute the concept of industrialised housing namely: (1) planning and control of the

1 M.Sc. John Meiling, Division of Structural Engineering, Luleå University of Technology, 971 87 Luleå, Sweden, johnmeiling@ltu.se, +46 920 491818

2 Ph.D. Helena Johnsson, Div. of Structural Engineering, Luleå University of Technology, helena.johnsson@ltu.se.

processes, (2) developed technical systems, (3) off site manufacturing of building parts, (4) long term relations between participants, (5) supply chain management integrated in the construction process, (6) customer focus, (7) use of information and communication technology (ICT) systematic performance measuring, and (8) re-use of experience. In this paper the term *traditional construction* is understood as a construction project with low fulfilment of these eight characteristics. Thus, it is the authors' notion that industrialised housing companies have made an effort to distance themselves from the three interrelated peculiarities that distinguish construction from manufacturing, namely (1) site construction, (2) one-of-a-kind production, and (3) temporary organization (Vrijhoef and Koskela 2005). Industrialised house builders can be inspired by lean production theories within the company itself, but the construction site still functions according to traditional construction logic.

An extensive governmental evaluation (SOU 2000:115) of the Swedish construction industry states that knowledge in construction is fragmented, resulting in an inability to transfer knowledge from one project to another, and a similar investigation was conducted in England (Egan 1998). Yet another Swedish government report (Sigfrid 2007) calculates mistakes to have an extensive impact on the production price, the cost for correcting defects after moving in could be up to as much as 95 million euros. Defect examination in construction is not uncommon, e.g. Josephson and Hammarlund (1999) and Ilozor et al. (2004). Industrialised house builders in Sweden have chosen to address this problem through prefabrication in a controlled factory environment. One challenge, and opportunity, to becoming more industrialised is to change the company culture towards a process oriented production and work with feedback and reuse of experience (Lessing 2006).

This paper presents a case study of the construction process at three industrialised house builders, with a focus on practical feedback initiatives. The three companies use a timber volume element prefabrication method and cater to the Swedish market. This study does not comprise industrialised single family housing i.e. manufactured housing. The hypothesis to view houses as products instead of projects is based on the authors' understanding and view of how industrialised housing can benefit from lean and quality management theories.

THEORY

LEAN PRODUCTION

The basic idea of lean production is to reduce unnecessary operations, 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, i.e., 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. Perfection is the basic lean thinking principle meaning continually striving towards producing precisely what the customer wants and delivering 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 advanced when reached (Rother and Shook 2003).

In 1992, one of the first parallels were drawn between manufacturing industry and construction when (Koskela 1992) defined the principles that laid the foundation to what is known as lean construction. In lack of an industrial manufacturing process Koskela (1992) issued the TFV framework, referring to 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 not necessarily organised in a flowing manner. Production has to be performed using transformation of inputs into outputs where materials, and information, flow through value and non-value adding activities with value for the customer as the end goal.

Björnfot (2006) argues, from an industrialised construction perspective, that lean production management is restrained by the project-oriented construction process, and thus obstructing perfection. Bertelsen and Sacks (2007) is making a historical survey, arguing for a new understanding of construction and proposes construction projects to be linked in a complex network, constituting a web of flow. The development of industrialised construction is an ongoing process, in close relation to the development of Lean Construction. Höök (2008) states that industrialised culture changes focus from organizational- and project learning, towards building in knowledge into the process instead of in the people, and hence facilitate knowledge feedback in a consistent way. The importance of a cultural change and a top-down strategy combined with bottom-up tools of lean manufacturing is also supported by Liker and Lamb (2002). A key element in the pursuit of perfection is learning and feedback (Liker 2004).

ENGINEERING KNOWLEDGE AND KNOWLEDGE BASED ENGINEERING

There are several initiatives in the area of knowledge management (KM) through information technologies, e.g., KM systems using *blogs* and *wikis* for capturing best practice and enabling information pull (Ahn et al. 2007, Egbu and Botterill 2002, Shelbourn et al. 2006). This is understood as answering the question: What is the design rationale and what are the requirements for how the building system and its basic technical solutions should be chosen in order to meet performance requirements? Improved design decisions are bound to product knowledge, thus the capture of information for later use in the design process is vital for fulfilling requirements. Knowledge based engineering (KBE) is a manufacturing industry life cycle approach to knowledge management (Egbu and Botterill 2002, Stokes and MOKA Consortium 2001). The KBE methods/approach is initiated in order to enhance the effectiveness and efficiency of engineering design, normally by creating design support tools in a CAD environment. The product knowledge, i.e., configuration and engineering knowledge, is formalised into design rules available in the CAD environment. The KBE design process is denoted a *product model* and the actual information is referred to as a knowledge base (LaCourse 1995). Information such as geometry, material type and performance as well as process information can be stored. The KBE knowledge base, is what could be defined as an active design procedure manual, with the ability to improve through feedback from production, tests, and quality audits (LaCourse 1995). The KBE product model, unlike an engineering team, never forgets; it computes numerous design models in a short time and thus reaches buildable designs with fewer resources. In construction, a theoretical framework for learning through project feedback was presented by Kärnä and Junnonen (2005). They state that learning takes place on four different levels, (1) organisational, (2) individual, (3) construction and (4) relationship learning, and they conclude that learning is a key ingredient with successful companies in terms of value creation.

ISO STANDARDS AND QUALITY WORK

The Quality management system is the part of an organisations management system that is focused on achievement of results, in relation to quality objectives, to satisfy needs, expectations and requirements of interested parties, as appropriate (ISO 9000:2000). It is defined as (ISO 9000:2000 3.2.3) "*the management system to direct and control an organisation with regard to quality.*" Product quality is defined as (ISO 9000:2000 3.1.1) "*degree to which a set of inherent characteristics fulfils requirements.*" Thus the characteristics and the requirements chosen are what makes the product and the management system is only a framework. The most widely used standard for implementing such a quality management system is the ISO 9000 series. This set of standards is implemented mostly because of customer requirements and the ISO certificate is the most desired outcome (Poksinska 2006). It is clear that the outcome of the implementation reflects the reason for applying and the most decisive means for successful outcome, when implementing ISO 9000, is a will to manage the company regarding quality (Gustafsson et al. 2001). Lean theory offers a management foundation for implementing continuous improvement initiatives expanding the governing construction logic domain, without life cycle considerations, into a Lean service life domain, see figure 1.

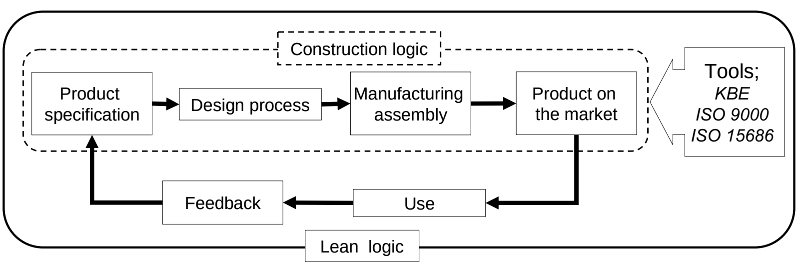

Figure 1: Theoretical model of a life cycle product approach to industrialised housing.

A key difference between manufactured products and housing is the view of product quality being decisive of service life and of maintenance costs required to attain intended service life. The general concept service life (ISO 15686-1, 3.1.1) is defined as "*the time after installation during which a building or its parts meets or exceeds the performance requirements*." Service life planning through the ISO standard portfolio (ISO 15686) is suggested to contribute to enhanced building quality, strengthened collaboration between actors, and minimised life cycle costs (SIS HB 2005). Emphasis on Service Life Planning (SLP) as an effort to ensure building performance was initiated when the Construction Product Directive (CPD) was issued in 1988 (The Construction Products Directive 1988). Sjöström et al. (2002) states that SLP was identified as a guiding concept regarding durability of buildings, that should be of help in implementing CPD. Estimating service life should be done through feedback of actual performance measurement. Service life planning could be considered a complementary framework for life cycle approach, also supported by KBE, offering a quality approach to product enhancement in construction.

METHOD

The multiple case study involves three companies utilizing industrialised prefabrication production. The companies are medium-sized, counting approximately 100-150 employees, with around 20% of their staff working in design and administration, and the remaining staff engaged in production. All three companies use timber for the load-bearing structure and have chosen to manufacture modular houses (volume elements) inside a factory, reducing the building site to final assembly. With the modular technique buildings can be up to five stories high. The prefabricated timber volumes consist of four load-bearing walls enclosing the volume. The size of the volume elements is limited to an outer width of 4.15 meters, an outer length of 13.00 meters and an internal height of the volume element up to 2.60 meters as illustrated in figure 2.

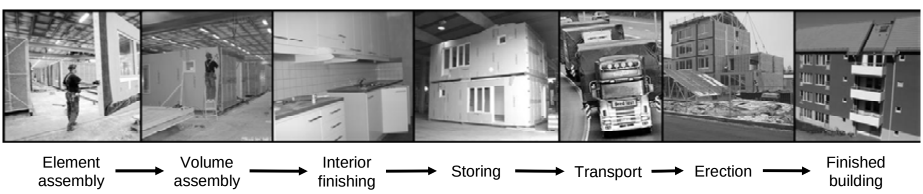

Figure 2: Industrialised Volume element prefabrication process.

Empirical findings are based on data gathered through interviews, observations and archival studies in order to understand the industrialised production process. Interviews were conducted with key persons representing management (3 companies), factory production (3 companies) and assembly (site managers of 5 assembly teams). Five different field trips to building sites were conducted. Semi-structured, in-depth interviews were performed with the head of quality work at one company, two site managers at one company, the head of sales at two companies and two production managers at one company.

CASE STUDY

The organisation of production in the studied companies is quite clear, however not process-oriented in any formal way. Building projects follow predefined paths, which involve multiple activities, see figure 3. The figure also illustrates how manufacturing- and construction logic meets in the industrialised building process. The process of producing a house has a long start-up phase, where communication with the client and authorities dominate the activities to eventually reach a product definition for the building. The company often runs everything in-house, using a design-build contract, i.e., they design the building according to customer demands, they produce prefabricated volumes in their factories, and they assemble and finish them on the construction site. Design, manufacturing, and erection, takes respectively 12+4+4 or a total of 20 weeks. Most activities remain in-house, while some are performed by external consultants. Building- and guarantee inspections, see figure 3, are both compulsory through contract, in Sweden regulated and formalised, through a non-profit-making association of influential actors in the construction industry, and presented in two regulations; one is general regulations for construction, AB04, and the other is specialised for design build contracts, ABT94. Regulations stipulate the guarantee limit to two years for material and inventory.

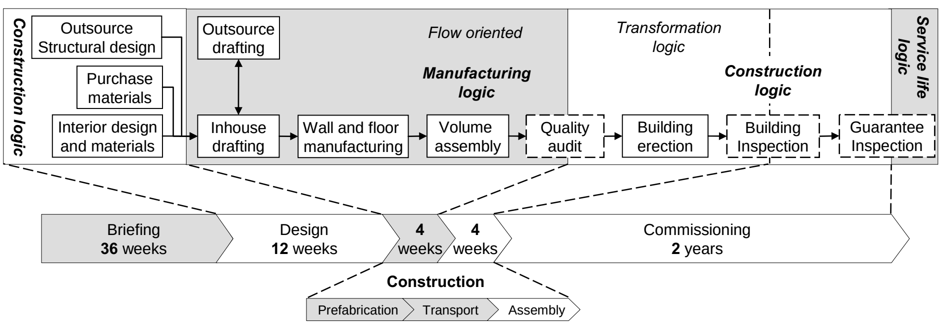

Figure 3: Time frame for the typical building project with a simplified model of activities during design, manufacturing and commissioning.

BRIEFING

Briefing consists of 4 weeks to allow for early client contacts, 12 weeks receiving a building permit, 8 weeks for design for tender, and 12 weeks tender negotiations and acceptance. During this period both economical and technical design issues are addressed as well as architectural aspects. The sales department consists of 2 to 3 individuals of which one person is assigned to support long-term customers. Architectural work is done both in-house and with customer-selected external architects, both of which are skilled in the volume element prefabrication system. After sales, a start meeting is initiated where sales, design, purchase, production and assembly are represented. This is where the object specific demands are investigated; this is also when the project leader is appointed.

All of the investigated companies try to promote early customer choice of standardised design solutions. Two companies have assigned the work of documenting such a company standard, i.e., technical platform. Early design work is organised under the sales department, and is supposed to be supported by a skilled senior design employee, but due to capacity problems this designer is occupied with design- and production.

THE DESIGN PROCESS

The same kind of 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 affects the manufacturing to a large extent, 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 handled by external consultants to a varying extent.

Common for the companies is that building design and HVAC installation is performed in two stages: first, the building envelope is divided into modules suitable for manufacturing; second, the detailed design where the elements building up each module are drafted on manufacturing drawings. Standard CAD software for construction is used to produce drawings printed on paper. A bill of materials in Excel is produced as by performing a quantity take-off directly from drawings. Ordering of materials is done manually, based on the bill of materials. Communication is done mainly via e-mail or phone. There is no visualisation of design activity progress. Quality control of drawings are scheduled but not executed in order to save time and not causing any manufacturing delay.

THE MANUFACTURING PROCESS

Data from design is transferred in printed format, and sometimes even re-organised or re-drafted before being directly applicable in manufacturing. None of the studied companies have automised their production plants, but plans exist to do so. The factory seems to work as a stand-alone production unit and the drawings produced have a strong resemblance to those used for on-site construction. The capacity of the production plants vary, on average 150 m2 of finished modules are produced daily.

Rules and limitations regarding volume assembly exist at different levels in the organisation, but they are not documented consistently. Many of these rules have not been documented at all and exist only in the minds of the employees. The rules are therefore not transparent in design, creating unnecessary rework between design and manufacturing. Once the wall elements are manufactured and assembled to volumes, internal cladding, painting, and decoration starts. The workers use printed drawings to keep track of work tasks for each module.

Before storing finished volumes, an inspection is done and deviations are reported. All missing equipment or undone work is listed; documentation is done in different software, including Excel, Outlook, and company-developed software. This documentation is not used for any other purpose than as a check list for ordering material or assigning labour to correcting defects, there is no practice of follow-up after closing the issue. Data and experience from projects are kept in archives related to a specific project, but they are not related to the production process. There is no clear process orientation or process leader, which can disturb co-operation between departments. The ownership of improvements in activities or product development does not have an appointed function. No person is working fulltime on quality issues or product development.

ASSEMBLY ON SITE

The modules are delivered to the building site by truck and their delivery time is set scheduled to minimise site work. The work on site is carried out by small, tight, groups of both in-house teams and external carpenter firms. These teams are moving from building site to building site, and have inherent knowledge about the practical aspects of the building platform. At the building site, information flow is a problem. This is addressed by meetings and short education sessions but these do not take place on a regular basis. A common problem is the lack of detailed standards for specific work task; all teams have their own solutions, when it comes to e.g., edging, carpet joints, and doors. All companies rely on a few long term relations with skilled workers. One company has a newly formulated imperative: when a new group is accepted for assembly work at least one skilled worker, appointed by the company, is required to participate in the erection of the first three buildings.

FEEDBACK INITIATIVES

Data is organised with building projects as the base, which is natural while the project is current, but difficult when the project has become an experience. Product development is not a separate process within the companies, but rather an activity that arises in project after project. Information is dependent on individuals, there is no central management system that controls the progress of the house production process; therefore it is difficult for individuals to keep track of the progress. All of the investigated companies have initiated meetings, with staff from design, prefabrication and assembly, at least once, where discussions have been documented in the intention of further feedback analysis. One company has appointed groups, representing assembly, for contributing feedback and reporting on new solutions. But no body is dealing with the incoming information, from these initiatives, and transforming it to engineering knowledge and changing the platform – the building system. One company working with long term commissioned assembly crews have had some projects with zero defects at delivery; this is somewhat of a record in the construction industry, but there is no investigation connected to this achievement. External quality audits are made on the finalised building at delivery and after a guarantee period of two years (in Sweden). There is no existing link between these audits and no model is established for traceability of quality problems backwards in the manufacturing process. The analysis of the audits is absent. The action process for correcting defects is fast and nonreflective about the characteristics of the notification in the audits. Feedback through quality audits among current house stock is unfortunately absent.

DISCUSSION

The prefabrication of timber frame volumes, as one form of industrialised housing, has improved since well over 50 years in Sweden. Timber volume element prefabrication, as a concept for multi-storey construction is a novel production form in Sweden since 1994. Recent prefabrication initiatives gaining much attention on the Swedish market, for its high degree of completion are the two systems NCC Komplett (concrete elements) and Open House (steel frame volumes). Recently they shut down their factories, NCC (2007) and Open House (2008). Both argue they advanced too fast with too many technical solutions. The timber volume producing companies represents a stable and competitive actor on the market when it comes to simple, repetitive houses as sheds, student homes, etc. These companies are rather small and do not invest in radical changes. The industrialised house builders would benefit more from experience feedback than traditional construction firms would, since the degree of repetition of this work is higher also in the sense that the process owner takes responsibility for the entire product. Thus of the five hindrances for comparing houses and cars, listed in the ISO user guide for service life planning (SIS HB 50, 2005), (1) Complexity, (2) Service life, (3) Environment, (4) Product uniformity and (5) Production uniformity, only the first three are applicable as products and production is uniform in industrialised housing production. Even if houses are not cars, a comparison Gibb (2001) and others have argued should be treated with caution, the industrialised companies are closer to industrialised production and thus have possible a greater opportunity to take responsibility of long term quality and feedback. All three companies in the case study are working with design-build contracts, and long term relations with suppliers. Individuals and construction teams are organised according to industrialised construction conditions where relations remain the same from project to project. This implies that in the perspective of learning, these companies will gain advantage of organisational and construction team learning (Kärnä and Junnonen 2005) due to less implications from individual and relationship learning.

If a service life approach was applied during briefing and design this could facilitate the utilisation of existing quality audits and inspections, creating value from defect notations in the inspection documents. As the designers are pressed for time they instead choose to rely on personal experience rather than facts originating from detailed examination of the inspection protocols. The transformation of information, into product knowledge and then reuse, could indeed be considered as a bottleneck in production. In timber element prefabrication companies, KBE could serve as a model in order to formalise solutions and to ensure the capture of building system knowledge in a systematic and sustainable way by starting to find ICT solutions. KBE is not utilised within timber volume element prefabrication. This is in part due to the small series of houses and partly due to the product and its interfaces not being defined. Furthermore a product development process appears to be non existent with the observed timber volume element prefabrication companies. A clear receiver for KBE efforts is therefore lacking. The importance and difficulty of capturing, structure, and transforming information within the company for sustainable use in a continuous process is not given enough resources. A product development approach to construction recognises the importance of feedback to satisfy the customer (Ulrich and Eppinger 2004). This is adopted by the European community through the CPD directives and the service life planning standards (Trinius and Sjöström 2005).

Ironically, one obstruction towards lifecycle approach seems to be working with ISO quality management systems. The system is being mistaken for implementing a feedback system. A quality management system, according to ISO 9001, only offers a framework for enhancing the level of quality on both processes and products and it should not be implemented in fear of losing business or considered a maximum achievement vs. quality management (Dale 1999). This is a common case in the SME business (Gustafsson et al. 2001). The basic thought is to actively prevent, change, and improve rather than control and repair (Bergman et al. 2003). Routines within a quality system, as practised in construction, is not used for feedback unless defects or mistakes have an economical implication with other stakeholders (Persson 2006).

CONCLUSIONS

Industrialised housing companies have the opportunity to apply a life cycle approach to their products because:

- They own a significant part of the construction process, i.e., the processes of briefing, design, fabrication, and construction.
- They are striving to achieve a product standard and thus gaining a repetitive effect.
- They utilise indoor production in a controlled environment.

The transformation of information and knowledge is a bottleneck in production because;

- Data and experience from projects are kept in archives related to a specific project; experience should rather be stored in a database, where improvement suggestions from each project are linked to a production process.
- Industrialised housing companies utilise experience on an individual basis without allocated resources.

FUTURE WORK

Feedback between the instances of design, factory, building site and commissioning through operation and maintenance could be done using key ratios and data rather than information hidden in building inspections or in the head of a construction worker. Further investigations should explore transformation of feedback initiatives and traceability of defects through the building production process.

ACKNOWLEDGEMENTS

I would like to express my gratitude towards the three companies involved, the SkeWood research programme in Skellefteå, Sweden, and the competence centre Lean Wood Engineering in Luleå, Sweden.

REFERENCES

Ahn, C., Park, M., Lee, H-S., and Roh, S. (2007). "Project Based Knowledge Management System For Lean Construction." *Proceedings IGLC-15, 2007*, Michigan, USA.

Bergman, B., Klefsjö, B., and Ashing, K. (2003). *Quality from customer needs to customer satisfaction*. Studentlitteratur, Lund, Sweden.

Bertelsen, S., and Sacks, R. (2007). ”Towards a new understanding of the construction industry and the nature of its production.” *Proceedings IGLC-15, 2007,* Michigan, USA.

Björnfot, A. (2006). *An exploration of Lean thinking for multi-storey timber housing construction, Contemporary Swedish practices and future opportunities*. Ph.D. dissertation 2006:51, Luleå University of Technology, Luleå, Sweden.

Dale, B. G. (1999). *Managing quality*. Blackwell, Oxford.

Egan, J. (1998). *Rethinking construction: The report of the construction task force*. Department of Environment, Transport and Regions. Available at www.constructingexcellence.org.uk.

Egbu, C.O., and Botterill, K. (2002). "Information Technologies for Knowledge Management: Their use and Effectiveness." *ITcon*, 7 (2002), 125-136.

Gibb, A. G. F. (2001). “Standardization and pre-assembly, distinguishing myth from reality using case study research.” *Construction Management & Economics*, 19, 307-315.

Gustafsson, R., Klefsjö, B., Berggren, E., and Granfors-Wellemets, U. (2001). “Experiences from implementing ISO 9000 in small enterprises.” *TQM Magazine* 13/4/2001, 232-246.

Höök, M., and Stehn, L. (2008). “Lean Principles in industrialized housing Production.” *Accepted for publication in Lean Construction Journal in April 2008.*

Ilozor, B. D., Okoroh, M. I., Egbu, C. E., and Archicentre. (2004). "Understanding residential house defects in Australia from the State of Victoria." *Building and Environment*, 39(2004), 327-337.

ISO 15686-1. (2000). *ISO 15686-1:2000 Buildings and constructed assets – Service life planning, Part 1*, *General principles*. ISO, Geneva.

ISO 9000:2000. *Quality Management systems – fundamentals and vocabulary*. ISO, Geneva.

Josephson, P-E., and Hammarlund, Y. (1999). "The causes and costs of defects in construction, A study of seven building projects." *Automation in Construction*, 8, 681-687.

Koskela, L. (1992). *Application of the new production philosophy to construction*. Technical report #72, CIFE, Stanford University. England.

Koskela, L., Ballard, G., and Howell, G. (2003). “Achieving Change in Construction." *Proceedings IGLC- 11*, Virginia, USA.

Kärnä, S., and Junnonen, J-M. (2005). “Project Feedback for Learning.” *Proceedings IGLC-13*, Sydney, Australia.

LaCourse, D. E. (1995). *Handbook of solid modelling*. McGraw-Hill, New York.

Lessing, J., Stehn, L., and Ekholm, A. (2005). "Industrialised Housing: Definition and Categorization of the Concept." *Proceedings IGLC-13, 2005,* Sydney, Australia.

Lessing, J. (2006). *Industrialised house-building: Concept and processes*. Lic. Thesis. Department of Construction Sciences, Lund University, Lund, Sweden.

Liker, J. (2004). The Toyota Way – 14 Management Principles. McGraw-Hill, New York.

Liker, J., and Lamb, T. (2002). “What is Lean Ship Construction and Repair?” Journal of Ship Production, 18 (3), 121-142.

NCC Komplett (2007). (In Swedish) Press release, http://www.ncc.se.

Open House (2008). (in Swedish). Press release, http://www.openhouse.se.

Persson, M. H. (2006). Lessons learned in knowledge management: the case of construction. Ph.D. Diss., Dept of Construction Sciences Lund University, Lund.

Poksinska, B. (2006). ISO 9000: business as usual or radical change? Experiences from Swedish organisations. Ph.D. Diss., Linköping University, Linköping, Sweden.

Rother, M., and Shook, J. (2003). Learning to See – Value Stream Mapping to add Value and Eliminate Muda. Version 1.3. The Lean Enterprise Institute, Cambridge MA, USA.

Shelbourn, M. A., Bouchlaghem, D. M., Anumba, C. J., Carillo, P. M., Khalfan, M. M. K., and Glass, J. (2006). "Managing Knowledge in the context of Sustainable Construction." ITcon , 11 (2006) 57-71.

Sigfrid, L. (2007). “Fel och brister i nya bostäder - vad kostar de egentligen, (The cost of defects in new residences).” Boverket (In Swedish), Publikationscentrum, Karlskrona, Sweden.

SIS HB 50. (2005). SIS HB 50 User’s guide to ISO 15686-1, Building and constructed assets – Service life planning. SIS, Stockholm, Sweden.

Sjöström, C., Jernberg, P., Caluwaerts, P., Kelly, S., Haagenrud, S., Chevalier, J-L. (2002). “Implementation of the European Constructions Products Directive via the ISO 15686 Standards.” *Proceedings of the 9th International Conference on Durability of Building Materials and Components*, Vol.1, CSIRO, Australia.

SOU. (2002:115). *Skärpning gubbar! Om konkurrensen, kvaliteten, kostnade och kompetensen i byggsektorn*, *(Competition, quality, costing and knowledge in Swedish construction)*. 2002:115 (In Swedish). Byggkommissionen. Stockholm, Sweden.

Stokes, M., and MOKA Consortium. (2001). *Managing engineering knowledge : MOKA: methodology for knowledge based engineering applications*. Professional Engineering Publ., London, England.

The Construction Products Directive. (1988). *Council Directive 89/106/EEC of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products* (89/106/EEC). Brussels, Belgium.

Trinius, W., and Sjöström, C. (2005). "Service life planning and performance requirements." *Building Research and Information*, 33(2), 173-181.

Ulrich, K. T., and Eppinger, S. D. (2004). *Product design and development*. McGraw-Hill, Boston, USA.

Vrijhoef, R., and Koskela, L. (2005). “Revisiting the Three Peculiarities of Production in Construction.” *Proceedings IGLC-13*, Sydney, Australia.

Womack, J., and Jones, D. (2003). *Lean thinking: Banish waste and create wealth in your corporation*. 2003 edition (originally published 1996). Simon & Schuster Ltd, London.