Continuous Improvement and Experience Feedback in off-site Construction
Timber-framed Module Prefabrication

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CONTINUOUS IMPROVEMENT AND EXPERIENCE FEEDBACK IN OFF-SITE CONSTRUCTION

TIMBER-FRAMED MODULE PREFABRICATION

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Luleå, November 2010

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“I hear and I forget, I see and I remember, I do and I understand”

Confucius
The PhD project this thesis is based upon spanned a period of almost five years, from February 2006 to May 2010. During this time the author was a member of the Timber Structures Research Group, Luleå University of Technology, Sweden. A major aim of the group is to develop an understanding of the design, production and business processes involved in off-site methods for constructing timber structures. The group, which currently consists of 18 people, is part of the Structural Engineering Division of the University’s Department of Civil, Mining and Environmental Engineering. The group is the largest academic group focusing on off-site construction in Sweden. The research project presented in this thesis was based on the hypothesis that off-site construction of timber-framed buildings could increase efficiency and control, reduce costs and enhance quality in housing production in Sweden. The work was conducted with support from the Swedish competence platform Lean Wood Engineering (LWE) and the SkeWood programme, initiated by the Swedish Governmental Agency for Innovation Systems (VINNOVA). A significant contribution was also made by the Trelleborg AB’s foundation for research and education at Luleå University of Technology. All of these contributors are gratefully acknowledged.

The five years I have been involved in PhD studies represents a period of intense personal and academic development. I would like to express my gratitude to the people who have helped me on the journey to completing this thesis. My supervisors Helena Johnsson for guiding me in the academic universe and for valuable scholarly scientific mentorship as well as personal support in my struggle to believe in the process of becoming a researcher. Professor Lars Stehn for an inspiring attitude, and for providing a working arena characterised by an atmosphere of trust and common strive at the department. I would like to acknowledge Markus Sandberg for helping me to navigate in the abstract world of knowledge engineering. Dan Engström directed me towards vital improvements regarding the thesis structure and is greatly acknowledged. My profound gratitude is directed to co-supervisor Fredrik Backlund, your positive attitude and guidance made a huge difference.
I would also like to express my gratitude to the companies and their representatives who provided the financial support and empirical material used in the case studies, without which the work would have been impossible to complete. The following persons are particularly acknowledged: Stefan Lindbäck and Per Burström (Lindbäcks), Mikael Hedtjärn and Mårten Dahlqvist (Moelven Byggmodul).

Thanks to my colleagues and friends at Timber Structures for keeping my ego in check, my spirit high, and engaging in fruitful discussions.

Finally, I would like to thank: my family and friends for their love, tolerance and patience; my father for support and encouragement; my brother Pär for access to the Chalmers library; my beloved daughter Sara for grasping each new day with curiosity and energy; Olov and Johan for inspiration in life and for sharing your mother with me; and finally but not least Lisa, who brought love, kindness and patience into my everyday life, always inviting me to bring out my best. The journey continuous “what happened next?”

Luleå, November 2010

John Meiling
ABSTRACT

Continuous improvement implies an incremental, ongoing effort to improve products, services or processes. Some construction companies have chosen to face competition by adopting an off-site construction strategy, one form of which is timber-framed module prefabrication. These housebuilders strive to transform their activities from conventional, loosely controlled construction into tightly controlled, continuously improved production processes.

The rationale for developing and implementing methods for continuous improvement is well documented. Regardless of the choice of production strategy common denominators are needs to recognise problems and a continuous quality improvement program that incorporates learning from mistakes and success. There is greater scope for such experience feedback in off-site module manufacturing than in on-site construction, because there are higher levels of repetition and process control. The purpose of adopting a continuous improvement strategy is to create knowledge that results in improvements aligned with company vision and goals. This thesis presents and discusses a series of studies intended to elucidate the role and status of continuous improvement in Swedish off-site construction.

Quantitative and qualitative data have been gathered in six studies of timber-framed module prefabrication companies: three multiple case studies, two questionnaire-based surveys, and one archival analysis. The six studies have investigated building inspection defects, current practice of experience feedback, application of stepwise problem-solving, and Lean management in an off-site construction context.

The results show that application of a continuous improvement strategy through stepwise problem solving enables pull for experience feedback in the studied companies. Furthermore, stepwise problem solving can reduce defects, enhance learning and target accuracy when solving problems in module prefabrication. The investigated problems acted as vehicles for experience feedback for both internal and external customers, in a feedback generating loop. Communication was improved as it was demanded by the problem-solving activity.
Further work is needed to understand how continuous improvements and the stepwise problem solving methodology could be fully implemented and integrated in working processes in the off-site construction context, in terms of supporting leadership, ensuring availability of resources, building trust among employees, providing challenging work and thus attaining sustainable quality advantages in contrast to short-term benefits. In addition, a sufficient level of standardisation must be applied in off-site construction to gain the benefits of systematic problem solving.
Sammanfattning (Abstract in Swedish)


Kvantitativa och kvalitativa data har samlats i sex studier utförda på företag som tillverkar prefabricerade moduler med trästomme: tre multipla fallstudier, två enkätbaserade studier, och en arkivbaserad analysstudie. De sex studierna har undersökt felnoteringar från byggbesiktnings, tillämpningen av erfarenhetsåterföring, stegvis problemlösning, och Leant ledarskap inom industriellt byggande.

Resultaten visar att tillämpning av ständiga förbättringar och stegvis problemlösning medför ett dragande system för erfarenhetsåterföring. Det innebär också att antalet fel kan minskas, medan lärandet och precisionen i problemlösningen kan ökas. Problemen som undersöckes i fallstudierna var bärare av erfarenheter från externa och interna kunder. Kommunikationen förbättrades eftersom det inbegrips i de aktiviteter som följer av problemlösningen.
Mera forskning behövs för att till fullo förstå hur ständiga förbättringar och stegvis problemlösning kan införas och integreras i industriellt byggande. Flera faktorer påverkar hur man kan uppnå långsiktig framgång med detta arbete: stödjande ledarskap, resurstilldelning, förtroende bland medarbetarna och en upplevelse av utmaning i arbetet. Ständiga förbättringar är starkt beroende av standardiserat arbete, där graden av standardisering bör utforskas bättre.
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LIST OF APPENDED PAPERS


**Paper V:** Meiling, J., Backlund, F., Sandberg M., and Johnsson, H. (2010). Continuous improvements through stepwise problem solving; a study within off-site construction. *Submitted for publication in Journal of Construction Engineering and Management (ASCE)*

**Paper VI:** Meiling, J., Backlund, F., and Johnsson, H. (2010) Managing for continuous improvements in off-site construction; An assessment of Lean management principles. *Submitted for publication in Engineering, Construction and Architectural Management (Emerald)*
RELATED PUBLICATIONS (not appended)


LIST OF APPENDICES

*Appendix 1* Stepwise problem-solving methods

*Appendix 2* Questionnaire; experience feedback practice

*Appendix 3* Questionnaire; Lean principles – management

*Appendix 4* Questionnaire; Lean principles – production personnel
Chapter 1: Introduction

This chapter sets the context of the research area and discusses the proposed problems regarding continuous improvement in off-site construction. The aim and research questions are presented and the demarcations are stated. Finally, the structure of the thesis is outlined.

Continuous improvement (hereafter CI) implies an incremental, ongoing effort to improve products, processes and services (Imai, 1986). CI can be regarded as a simple concept with a low entry barrier for even small-scale enterprises (Bessant et al. 1994). The core principle is self-reflection on business processes, i.e. continuous feedback in order to identify, reduce and eliminate sub-optimal processes. Thus, CI should be viewed as a “process intended to achieve improvement” rather than a series of isolated improvement activities (Jha et al. 1996).

The combination of terms continuous and improvement has highly positive nuances in this context, involving learning from previous experiences and the acquisition of knowledge that can be realised in improvements on a continuous basis. At a personal level, the willingness to improve could be argued to derive from basic human desires to experiment and improve things. On a company level, when times are good, the driving force for improvements in regard to efficiency is to make better use of resources and enhance profits, while in times of recession the driver for improvements is to survive in the marketplace.

In Sweden, 11% of all employees were engaged in the construction sector in 2008, the sector contributed almost 8% of the gross domestic product.

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1 Efficiency in this thesis refers to the ratio between value-adding activities and waste, while effectiveness refers to the ratio between created value and consumed resources. The term value is within this thesis restricted to activities aiming to satisfy customer requirements, the ambiguity of the term is acknowledged but not investigated per se, see for example Erikshammar et al. (2010).
product, and the total value of all construction investments amounted to €28 billion (SBI, 2009). The implementation of approaches to ensure that the construction process is efficient and effective is a challenge for the sector, and failure to develop (and implement) appropriate approaches will adversely affect wider economic development since it makes a vital contribution to the economy in most European countries (Barker, 2003; EC, 2009).

Improvements are being made in construction projects as new or improved technical solutions are introduced, and new working methods are applied with the intention to increase efficiency. These are characterised of being a series of isolated improvement activities. Sustained improvements are often obstructed as innovative solutions to problems that arise at the construction site are not systematically transferred to the next project (Carrillo et al., 2003; Knauseder, 2007). The construction sector is known for its ability to tackle severe problems in complex, large-scale projects, but many times with delays and cost overruns (Assaf and Al-Hejji, 2006). During the last decade several national and international government initiated investigations have raised critiques regarding the construction sector’s ability to deliver cost-efficient and high quality projects (Egan, 1998; SOU, 2000; CIRC, 2001; Hampson and Brandon, 2004; Van Boxtel and Driessen, 2005; DTI, 2009). In Swedish housing production, costs arising from defects, mistakes and deviations from client requirements are estimated to amount to 10-15% of total construction costs (SOU, 2002; Josephson and Saukkoriipi, 2007). A study by Sigfrid (2007) indicates that the costs of correcting defects after project delivery in Sweden could amount to €1.3 billion per year (based on housing production data for 2005).

Defects are prominent drivers for experience feedback, learning and improvements since they provide clear proof that construction processes are flawed. Hence, there is a profound need for change and the sector is striving to apply new improvement methods. However, there are obstacles hindering the implementation of CI in the construction sector connected to the current nature of construction projects, characterised by Vrijhoef and Koskela (2005) as being one-of-a-kind production (e.g. design to order and order-based production), by temporary organisations (with, inter alia, fragmented supply chains) and on-site production (which is dependent, inter alia, on outdoor conditions).
1 Introduction

These characteristics inevitably also have impact on the learning ability (Table 1).

Table 1. Construction projects’ characteristics effects on learning.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Effects on learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-of-a-kind</td>
<td>Technical solutions are unique for one project, solutions are not transferred between projects which prohibits CI application.</td>
</tr>
<tr>
<td>Temporary organisations</td>
<td>The learning transfer, i.e. experience feedback, is obstructed as teams, and subcontractors differ from one project to another.</td>
</tr>
<tr>
<td>Site production</td>
<td>Working conditions at the building site do not enable a process orientation where tasks can be standardised.</td>
</tr>
</tbody>
</table>

Thus, the very nature of the construction projects (particularly their transient, and dispersed organisation) limits opportunities for learning (Styhre et al., 2004). Hence, interest has grown in modern, alternative construction methods, e.g. off-site construction techniques using various forms of prefabrication, such as closed panel and modular-based construction, see Figure 1. This way of working is suggested to have the potential to increase efficiency, control and quality, while reducing costs.

![Figure 1. Choice of fabrication strategy: on- vs. off-site work. The focus in this thesis is on modular construction.](image)

The possibilities of off-site construction methods have been considered by several authors, e.g. (Gann, 1996; Gibb, 2001; Blismas et al., 2006; Tam et al., 2007; Pan et al., 2008).
The adoption of off-site methods has been promoted in studies initiated by governments of several countries and territories, e.g. the UK (Egan, 1998), Sweden (SOU, 2000; SOU, 2002), Australia (Hampson and Brandon, 2004) and Hong Kong (CIRC, 2001). Similar conclusions have also been reached by Dutch authors (Van Boxtel and Driessen, 2005).

There appears to be an almost implicit idea that indoor construction alone may solve quality and productivity problems. However, it should be recognised that off-site construction is not a panacea that inevitably leads to effectiveness in terms of client satisfaction, and production efficiency (Gibb, 2001). Clearly, on-site work must eventually be undertaken in any construction project, hence off-site construction can be regarded as lying at an intersection of the construction and manufacturing industries, see Figure 2.

![Figure 2. The off-site construction industry at an intersection of the construction and manufacturing industries, adapted from Meiling (2008).](image)

The intersection position could be regarded as a strategic advantage, since it provides enhanced possibilities in regard to process control, quality management, standardised work, efficiency and effectiveness. However, among British housebuilders Pan et al. (2007) have documented a number of perceived barriers for choosing off-site construction strategies, including a lack of trust in the off-site construction methods. In addition, Levander et al. (2010) identify lack of trust among clients towards off-site construction in terms of high perceived life cycle costs, implying that construction firms need to develop a robust production strategy incorporating CI to capture clients’ trust.
1 INTRODUCTION

1.1 Timber-framed module prefabrication
Timber-framed module prefabrication is one kind of off-site construction that has several distinct characteristics that make it suitable for investigation from a CI perspective, see Table 2.

Table 2. Characteristics and possibilities regarding timber framed module prefabrication.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Perceived possibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>A focus on in-door production with on-site activities limited to assembly</td>
<td>Implicit scope to apply established quality management strategies, CI and experience feedback.</td>
</tr>
<tr>
<td>A single, distinct process-owner handling all aspects from procurement to assembly of buildings on-site</td>
<td>Implicit scope to trace and identify root causes of defects through application systematic problem-solving.</td>
</tr>
<tr>
<td>A goal to incorporate repetition in design and production</td>
<td>Greater Implicit possibilities to adopt standard solutions via continuous improvement.</td>
</tr>
</tbody>
</table>

Companies engaged in this activity have explored ways to enhance repetition in processes, although the scope for standardisation varies depending on the chosen client segment. Use of module-based timber construction, as a prefabrication strategy, moves 80% of the work to factories (Höök, 2008). Such companies need to control the processes and the resources used, as they shift value-added activities up the supply chain and into a controlled environment (Nasereddin et al., 2007). They currently have a 9% share of the Swedish market for producing multi-storey houses and commercial buildings (Stehn, 2008). A timber-framed module is a closed, three-dimensional structure with floor, roof and wall elements. The off-site production phase for a single module is divided into three main stages (element production, module assembly and module completion; see Figure 3) and completed modules are covered with moisture-proof tarpaulins before transport by truck to the construction site.

The focus of this thesis on applications of quality management strategies in construction is reflected in use of the term client (rather than customer), referring to an organisation or “professional customer” procuring multi-storey buildings. The term customer is used hereafter when referring to internal or external receivers of goods or services connected to the off-site construction process, internal customers being the receivers of goods and services between sub-processes within a specific firm.
1 Introduction

Meiling and Johnsson (2008) found that off-site module manufacturing would benefit more from experience feedback than traditional construction, since higher levels of repetition and control are already required in production. The importance of the latter regarding the defect recovery process and learning is also emphasised by Love and Josephson (2004). Feedback of experience data can nurture improvements, and simultaneously support learning in organisations as described by, for instance, Kärnä and Jumonen (2005).

1.2 Continuous improvement

The overall aim of CI is to develop learning capabilities among all employees (Liker, 2004). The learning procedure within CI is formalised in problem-solving settings and executed through various applications of the PDCA (Plan, Do, Check, Act), learning cycle (Deming, 1986). The PDCA-learning cycle implies the application of experience feedback in order to grasp problems, find root causes, suggest solutions, make implementation and evaluate results (Deming, 1986; Garvin, 1993). Execution of PDCA cycles involves stepwise problem-solving (hereafter SWPS), targeting the improvement of products and processes (see for instance (Ishikawa and Lu, 1985; Deming, 1986; Imai, 1986). CI is described both as a process within more comprehensive quality improvement strategies, e.g. Total Quality Management (TQM) or Lean production, and as a management strategy itself (Bessant and Francis, 1999). TQM is defined by Hellsten and Klefjö (2000) as an overall management...
system consisting of values, techniques and tools intended to increase external and internal customers’ satisfaction using reduced amounts of resources. The Lean production strategy stresses the importance of human and cultural aspects, together with quality tools and methodologies, focusing on even production flows, targeting value-adding activities from customer pull\(^3\), while continuously eliminating waste. Both TQM and Lean production share a focus on improving production processes through CI. From a TQM perspective, Love et al. (2000) argue that CI can be used as a vehicle to lead construction companies into learning from their mistakes and becoming learning organisations. The CIRC report (2001) states that CI is a vital means of reaching new levels of efficiency and effectiveness in the construction sector.

1.3 Problem description

To stay competitive, a firm needs to improve faster than its competitors. Effective execution of CI methodologies is identified as important as the rate of optimisation of processes determines the survival of firms (Salah et al., 2010). Although off-site construction is an established technology, it is not (in isolation) a source of sustainable advantage. Clients are seeking clearer evidence of quality enhancements in order to suppress uncertainties. However, the conditions for utilising experiences and learning from mistakes are more favourable in off-site construction than in on-site construction. Thus, learning to continuously improve is vital for the construction trade in general and the off-site construction niche in particular, raising questions about how CI should be applied in off-site construction as a means to ensure sustained and improved performance by means of experience feedback. The current state is characterised by scattered knowledge, information and data that are difficult to attain why feedback is obstructed, see Figure 4. Reasons for why experience feedback and CI are obstructed within the construction sector have been presented in the introductory part of this thesis. Strategies for implementing CI have been introduced. However, strategies regarding

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\(^3\) *Pull*, within this thesis, refers to activities initiated from internal or external customer needs, opposed to *push* where no request is activating the conducted activity. *Push* is within Lean production theory related to overproduction (Womack and Jones, 2003).
experience feedback and improvements are obviously not sufficient if execution fails. It is reported that 70% of CEO failure is due to bad execution, not bad strategy (Charan and Colvin, 1999).

\[ 
\begin{align*}
\text{Construction} & \quad \text{Company} \\
\text{projects} & \\
\text{P1} & \quad \text{Scattered:}
\end{align*}
\]

\[ 
\begin{align*}
\text{P2} & \quad \text{knowledge} \\
\text{P3} & \quad \text{information} \\
\text{Pn} & \quad \text{data}
\end{align*}
\]

\[ 
\begin{align*}
\text{Time} & \\
\text{Learning by doing} & \\
\text{Obstructed feedback}
\end{align*}
\]

**Figure 4. How can scattered knowledge within a company, at a larger extent, be feedback into new construction projects?**

This thesis is focused on the company level of CI, i.e. how it can be managed and organised in the construction phase of the off-site construction company (factory production and assembly on site).

### 1.4 Aim and research questions

The overall aim of the studies this thesis is based upon was to describe and understand how CI, including experience feedback, can be applied in off-site construction. To fulfil the aim three research questions were formulated, see Table 3.

<table>
<thead>
<tr>
<th>Research questions (RQs) and anticipated contribution to meeting the aim.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RQ 1:</strong> How can experience feedback support continuous improvement?</td>
</tr>
<tr>
<td><strong>RQ 2:</strong> How can stepwise problem-solving promote continuous improvement?</td>
</tr>
<tr>
<td><strong>RQ 3:</strong> How can overall improvement strategies support continuous improvement?</td>
</tr>
</tbody>
</table>
1.5 Demarcations

According to Imai (1986) improvements can be divided into Kaizen and innovation. Kaizen refers to maintaining and improving the work-standard through small, gradual improvements; the term innovation means improvements as a result of large investments in a separate process prior to design. This thesis is focused on small incremental improvements mainly in the production and assembly phases of timber-framed module prefabrication, see Figure 3.

The described theoretical approach is based on the chosen research method, i.e. the construction firm is here regarded as a system that aims to produce structures efficiently, according to client demands. Application of CI constitutes a sub-system within the construction process that interacts with, and is affected by, its overarching context. Accordingly, studies of quality methods intended to support improvement activities in off-site construction involve depiction of the system wherein they are active. The timber-framed module prefabrication building system is not analysed in this thesis, but the business concept is identified as a well-defined form of construction that would be amenable for implementing CI and experience feedback.

The theoretical framework is outlined under three related headings: Learning and knowledge, continuous improvement, and overall improvement strategies. A theoretical understanding of learning and knowledge is used to understand the practical implications of CI. Both TQM and Lean production are relevant to the construction trade, and thus examined as examples of overall improvement strategies incorporating similar methods and tools. Lean production is the preferred overall strategy among the off-site construction companies investigated in this thesis, however it is considered to have valuable relations to TQM, hence TQM (and its relationship to Lean philosophy) is also discussed in the thesis.

TQM and Lean production practice, as it is communicated within this thesis, reflects what is described as the second generation of quality management (Bergquist et al., 2006). This perspective has a clear focus on satisfying internal and external customer requirements and expectations. A growing critique of this perspective, and indeed the lack of supporting theories, has led to formulating the third generation of quality management. According to Bergquist et al. (2008) there are three features distinguish the third generation quality management
from its predecessors: (1) a stakeholder perspective (identification of the customer as a stakeholder rather than the stakeholder), (2) an identified need for explicit, unambiguous and empirically supported theory, (3) a distinction between quality management as a whole-of-the-company strategy, and the methods and techniques of quality management. The implications these three features are not included in this thesis.

Six Sigma is an overall improvement strategy originating from the Motorola company. Its aim is to enhance company profits by reducing variability in production processes to increase quality. The name Six Sigma reflects a process goal of almost defect-free operation (Pyzdek, 2001). Six Sigma is focused on advanced, process-related, statistical analysis, therefore not included in the theoretical framework. However, it should be noted that some authors suggest that Lean production philosophy and the Six Sigma steps are essentially the same, and both have developed from the same root – the Japanese TQM practices (company-wide quality control) (Dahlgaard and Dahlgaard-Park, 2006).

Consequences of the demarcations presented above are further discussed in Chapters 2 and 6 regarding validity and generalization. Demarcations, choice of theoretical concepts, and consequences of these choices are discussed in Chapter 3.
1.6 Disposition

This thesis comprises six chapters and six appended papers.

Chapter 1: Introduces the reader to the research area, presents the research aim and research questions and describes the structure of the thesis.

Chapter 2: Presents the methods chosen for collecting the empirical results related to Papers I-VI.

Chapter 3: Describes the theoretical framework and presents an analytical model.

Chapter 4: Presents a summary of empirical results from Papers I-VI.

Chapter 5: Analysis of the results in relation to information presented in Papers I-VI and theoretical considerations.

Chapter 6: Presents conclusions based on findings related to the research aim and answers the research questions.

Appended Papers I – VI:

I: Feedback in industrialised housing – why does it not happen?
   (Awarded best Ph.D. student paper at the ARCOM conference in Wales.) By John Meiling and Helena Johnsson, published in the Proceedings of the 24th ARCOM Annual Conference, September 1-3, 2008, Cardiff, Wales. My contribution was in formulating fundamental ideas, planning and conducting interviews, co-planning and performing process mapping. I also processed, categorised and analysed the empirical input, and wrote the paper under supervision of Helena Johnsson.

II: Defects in offsite construction: timber module prefabrication
   By Helena Johnsson and John Meiling, published in Construction Management & Economics (Taylor & Francis), 2009. My contribution to this paper was to conduct a literature study regarding defects in construction, and gather, categorise and display data from audits for statistical analysis. Helena Johnsson conducted the statistical analysis, both authors wrote the paper.
1 INTRODUCTION

**III:** *Towards a feedback model for off-site construction*
By John Meiling and Marcus Sandberg, published in the Proceedings of the 25th ARCOM conference, September 7-9 2009, Nottingham, UK. My contribution was in formulating fundamental ideas, conducting the literature study, planning and performing the case studies, and writing the paper under supervision of Marcus Sandberg.

**IV:** *Digitalisation of inspection data: A means for enhancing learning and continuous improvements?*
(Awarded best Ph.D. student paper at the ARCOM conference in Leeds.)
By Robert Lundkvist, John Meiling and Anders Wennström, published in the Proceedings of the 26th ARCOM Annual Conference, September 6-8, 2010, Leeds, UK. My contribution was in co-planning and performing the survey. All authors contributed to conceptual ideas for the paper, and I co-authored it with Robert Lundkvist under supervision of Anders Wennström.

**V:** *Continuous improvements through stepwise problem-solving – A study within off-site construction.*
By John Meiling, Fredrik Backlund, Marcus Sandberg, and Helena Johnsson. Submitted for publication in Construction Engineering and Management (ASCE), 2010. My contribution was in formulating fundamental ideas, conducting the literature study, planning and performing interviews, planning and performing the case studies. I also wrote the paper with assistance of Fredrik Backlund and Marcus Sandberg, under supervision of Helena Johnsson.

**VI:** *Managing for continuous improvements in off-site construction: An assessment of Lean management principles.*
By John Meiling, Fredrik Backlund and Helena Johnsson. Submitted for publication in Construction Management & Economics (Taylor & Francis), 2010. My contribution to this paper was in formulating fundamental ideas, conducting the literature study, planning and performing the survey. I also co-authored the paper with Fredrik Backlund under supervision of Helena Johnsson.
2 METHOD AND RESEARCH PROCESS

This chapter describes the research and data collection methods. The first section presents the chosen research strategy and design, then describes how the six studies relate to the research questions and appended papers. This is followed by a discussion of the validity and reliability of the conducted studies. The chapter ends with a description of the case companies.

A system view is applied in this thesis for investigating how continuous improvement (CI) can be applied in off-site construction. In a system approach attempts are made to observe and elucidate patterns in complex courses of events, and it is recognised that the sum of the parts of the investigated system amounts to less than the whole (Skyttner, 2005; Arbnor and Bjerke, 2009). Therefore, a system view requires understanding of the context in which the studied phenomena occur (Conti, 2006; Arbnor and Bjerke, 2009). The fact that the author has an engineering background is reflected in the way the system is explained and illustrated, i.e. mainly as a mechanistic system, but affected by non-mechanistic aspects of learning and knowledge. Thus, learning and knowledge are described, but not studied per se. A mechanistic approach can be an effective way to explore complex systems, as explained by Johnson (1998). Deming (1993) describes a system, from a quality management perspective, as a man-made network of processes intended to work cooperatively to accomplish targeted aims. Accordingly, a construction firm is here regarded as a system that aims to produce structures efficiently, according to client demands. Application of CI constitutes a sub-system within the construction process that interacts with, and is affected by, its overarching context. Accordingly, studies of quality methods intended to support improvement activities in off-site construction involve depiction of the system wherein they are active.
2.1 Choice of research strategy

The presented research related to the overall aim of the thesis and the three research questions is based on qualitative methods, relying on the premise that qualitative methods are suitable for studying a phenomenon in its natural context, targeting rich descriptions of the phenomenon (Miles and Huberman, 1994). In addition, according to Merritam (1998) qualitative methods provide the ability to elucidate the whole context of an apparent phenomenon. It should be noted that qualitative methods yield information only on the particular cases studied, and any more general conclusions drawn from them are merely hypotheses (Denzin and Lincoln, 2005). However, the choice of a qualitative approach does not exclude use of quantitative analysis of empirical material (Miles and Huberman, 1994; Yin, 2003). Indeed, it is recommended in order to increase the validation of sampled data, and according to Miles and Huberman (1994) the ongoing debate regarding the relative merits of qualitative and quantitative approaches is unproductive.

Yin (2003) lists five major qualitative research strategies (experiments, surveys, archival analyses, histories and case studies) and states that the optimal strategy depends on three conditions: the nature of the research questions posed, the extent of control the investigator has over actual behavioural events, and the degree of focus on contemporary events. Thus, the nature of the research project will determine which of the strategies is most suitable, and is linked to the optimal choice of a wide variety of data collecting methods, e.g. interviews and group discussions, observation and reflection, field notes, and use of various texts, pictures, and other materials (Fellows and Liu, 2003). Further, it is often valuable to apply multiple data collection methods, since this enables general conclusions to be drawn from a limited number of cases (Gummesson, 2000), and triangulation to strengthen the validation of case studies (Jick, 1979).

According to various authors, e.g. Yin (2003), when behaviours cannot be manipulated “why” and “how” questions concerning contemporary events (i.e. aspects of various functions and their temporal connections) are best addressed using exploratory or explanatory case study techniques. A case-study generally comprises three phases of research: descriptive, explorative, and explanatory. When an exploratory case study design is applied data are collected before theories or specific
research questions are formulated (Yin, 2003). The aim of descriptive case studies is to record, systematically, the object(s) of study, while explanatory study implies hypothesis testing (Fellows and Liu, 2003). However, an explanatory case study is described by Yin (1981) as having three parts: accurate rendition of the facts of the case, some consideration of alternative explanations of these facts, and drawing of conclusions based on the single explanation that appears most congruent with the facts. According to Fellows and Liu (2003), a large number of studies fall between the two extremes of exploratory and explanatory, e.g. field investigations of the effectiveness of decisions.

The extent of control over behavioural events in the case studies presented in this thesis was considered to be low, so experiments were not regarded as a viable research strategy. In addition, the studies focused on contemporary issues: how feedback, problem-solving, and Lean production relate to CI, particularly in the off-site construction industry. For reasons stated above a case study approach appeared to be suitable for addressing these issues. This choice is also supported by Merriam (1994), who states that case studies can be considered the best research strategy when the aim is to solve a problem that requires profound understanding of the context and its practice, i.e. real events and complex phenomenon. A drawback of case studies is the inherent difficulty in making distinct demarcations, as they can convey non-manageable data quantities (Denzin and Lincoln, 2000). Case studies can be categorised and designed as single or multiple. The former may be used to study whether a theoretical proposition is in accordance with practice, while multiple case studies provide wider-ranging information and greater scope for generalisation (Miles and Huberman, 1994), since they should (theoretically) yield similar, corroborative results (Yin, 2003).

### 2.2 Choice of research design

According to Yin (2003), the research design forms an action plan describing how empirical data connect to the study’s initial research question and its conclusions. Crabtree and Miller (1999) state that the research design is shaped by the research aim, “analysis goals”, and research questions. To fulfil the aim of the doctoral project three questions were identified and formulated (see Figure 5), all of which are “how” questions intended to probe the relationships between
experience feedback, stepwise problem-solving and Lean production related to CI. The chosen research design, regarding all three questions, constitutes a chain of action that incorporates both descriptive and explanatory case study techniques. The first research question was the project starting point. The question evolved from consideration of an industry-based problem, i.e. the inability to learn from mistakes in off-site construction. The aim of RQ1 was met by performing research in four steps, presented in Figure 5, involving all four companies listed in Table 4.

Figure 5. Research questions related to the chosen research design and papers.

Timber-framed module prefabrication was chosen as a building system representing off-site construction that has a 9% share of the multi-storey and commercial buildings market in Sweden (Stehn, 2008). The companies selected all have long experience of off-site construction and hence were considered good choices to represent this niche (see Table 4). Clients purchasing the multi-story buildings or

4 Commercial buildings is a term used to refer to such buildings as nursing homes, schools, and office buildings.
2 METHOD AND RESEARCH PROCESS

commercial buildings they construct are mostly real estate trustees and municipalities.

In the following section sampling methods connected to each research question are justified and described. The six conducted studies have resulted in six papers (I-VI). Findings from the appended papers have been subjected to cross-paper analysis, applying an analytical model presented in Chapter 3.

2.3 Studies and information collecting methods

As mentioned above, several methods can be used to collect information in a case study, e.g. interviews, direct and participant observations, archival studies and questionnaires, all of which can provide useful evidence to explore relevant phenomena and draw conclusions. Hence, case studies are powerful means for examining contemporary problems (Yin, 2003), provided of course that the data collection methods selected are suitable for addressing the stated research question(s).

2.3.1 Experience feedback (RQ1 step 1)

An explanatory multiple case study was chosen to fulfil the first step towards addressing research question one. The study was conducted from October 2007 to February 2008 and is presented in Paper I (Meiling and Johnsson, 2008). The manufacturing processes at four Swedish house manufacturers (see Table 4) were described and documented (Johnsson, 2006). Feedback management activities and overall quality management in the companies were documented, then their production processes were mapped and probed for feedback initiatives and/or lack of feedback practice. Multiple sources of evidence were utilised, including personal interviews, observations and examinations of defects and inspection protocols. Crabtree and Miller (1999) state that use of multiple sources of information and collecting methods enables researchers to validate each individual set of information, i.e. to triangulate sampled data. All the conducted interviews were semi-structured, in-depth interviews, which are particularly useful for obtaining contextual details related to participants’ experiences (Kvale, 1996). Interviews were not always transcribed, so the acquired information was validated by sending summaries of the conclusions to the interviewees. When visiting a
construction site, interviews were often recorded in notes and photographs, and thus were unstructured. During the mapping of processes at the four companies, relevant personnel involved in each phase of the construction process were questioned. This gave the researchers a broad understanding of the investigated context. The actual processes were documented, first with post-it notes and later transcribed into Microsoft Visio and sent back for validation.

The author also attended several on-site building inspections (and off-site inspections in the factory units), during which participant and direct observations were compiled. Such observations enable the development of close and intimate familiarity with pertinent groups of individuals (Patton (1990), and provide the researcher(s) opportunities to compare answers and statements given by the respondents to real-life situations. According to Yin (2003), such observations give researchers opportunities to perceive reality from “within” the context and to participate in observed events. A combination of qualitative observations and interviews is considered the best method available for studying processes. Both the building inspections and factory visits were documented in notes and photographs.

Step 1 also incorporated the retrieval of a large number of inspection protocols from archives. Inspection protocols were identified as existing experience material, thus investigating their potential utility was seen as important. Recorded defects were categorised and counted, enabling validation of statements by personnel regarding the frequency of defects. Statements regarding the origins of defects and their severity were validated through personal visits to design, factory production, transport and on-site assembly points.

Interviews were conducted with individuals representing management (at all four companies), factory production personnel (at all four companies) and assembly staff (site managers of five assembly teams at two companies). Five field trips to building sites were conducted, and semi-structured, in-depth interviews with the quality manager at one company, two site managers at one company, the sales managers at two companies and two production managers at one company. The interviewees all had knowledge regarding inspections and defects in their respective company’s products. Building inspections from 16 building projects undertaken by case companies A and C were examined, covering 958 prefabricated volume modules. A total of
2.829 defects were sorted by their origin. Participating in one building inspection regarding a project with 40 apartments, made it possible to learn about the inspection procedure and acquire knowledge about the actual defects and the corresponding notation. To evaluate the possibility of using existing inspection records, a population representing 20% of the total production of case company A was explored, and guarantee inspections from nine projects were examined, documenting 909 modules and 490 defects.

2.3.2 Defect information (RQ1 step 2)

To fulfil the second step towards addressing research question one it was seen as vital to understand what the defects and problems recorded from inspections revealed concerning the current quality level in the investigated companies. For this purpose it was considered appropriate to broaden the archival study. This strategy is preferable when there is no need to control behavioural events. However, the retrieved documents could be considered to reflect contemporary events and thus provide an opportunity to generalise towards current events. To obtain a broader understanding of defects in construction a literature study was also undertaken, and a statistical analysis was applied to structure information from the inspections.

The study was conducted from July to September 2008 and is presented in Paper II (Johnsson and Meiling, 2009). The aim was to characterise defects in off-site construction, and thus assess the current quality of timber-framed module prefabrication. Two companies were chosen for investigation, case companies A and C, which were identified as representing the existing range of module configuration and variety of clients. Every recorded defect was coded and entered in SPSS statistical software for analysis.

The main interest was to quantify data in each coded group in order to characterise the defects. The only qualitative work conducted was the sorting of defects through coding into six different groups before analysis. To establish an overview of the type of defects, when they occurred and their causes, audits from three control points were gathered: factory, building and warranty. Eight projects undertaken by companies A and C were selected, for which complete data were available (i.e. factory, final and warranty audits). In total, 443 modules were included in the analysis of the quality audits, and a grand total of
2713 defects across all projects were identified: 1234 defects in the factory audits, 1147 in the final audits and 332 in the warranty audits. Defects are recorded in reports (the results of quality audits) and stored in text format in the companies’ archives. The reports were reviewed and all defects coded using six categories: where, what, type, measure, why and when. Each category was associated with a nominal scale.

During this work several visits were made to the factory plant of case company A, to verify that each defect notation and its origin were correctly understood. Some defect notations called for extensive investigation, notably the propagation of cracks. This type of defect was documented during all three factory, transport and assembly stages.

2.3.3 Feedback model (RQ1 step 3)

The third step towards addressing research question one was fulfilled through theoretical studies to identify the actual constituents of a feedback model. A case study was performed to verify the findings. Arranging focus group meetings was seen as an effective method for presenting the ongoing work and receiving feedback in real problem settings, since they allow participants’ views and opinions regarding broad and wide-ranging topics to be explored (Patton, 1990). Thus, during this work the author made several visits to various construction sites to sample information that could be processed in a focus group meeting. The study was conducted from May to August 2009 and is presented in Paper III (Meiling and Sandberg, 2009). Desired criteria for the sought model were that it should include techniques for prioritising experience that should be fed back and help to identify people that experience should be fed back to. The constituents of the feedback model were based on the contextual evidence acquired in the two previous studies, and the cases were validated through meetings with relevant production personnel at company A.

2.3.4 Inspection data (RQ1 step 4)

The last step towards addressing research question one required discovery of the extent to which various sources of experience feedback and knowledge were utilised among a broader group of on- and off-site construction companies. A survey was conducted through a web-based questionnaire. A survey was chosen partly because it enables rapid data collection and partly because the researcher has
restricted influence on respondent behaviour (Denzin and Lincoln, 2000). The survey was set up through a common web survey service, using individual participants’ links to the survey website, which enabled reminders to be easily sent to candidates who had not yet responded, and provided a certain level of confidence that selected company representatives were the actual respondents. It also provided a possibility for respondents to voluntarily enter contact data at the end of the survey, giving further proof that selected representatives were the actual respondents. Questionnaires have several advantages, e.g. they are cheap, do not require as much effort from the questioner as verbal or telephone surveys, and often offer standardised answers that make it simple to compile data (Trost and Hultäker, 2007). However, such standardised answers may frustrate users, if they do not understand them or feel that none of the offered alternatives are really applicable (Brace, 2004). Therefore, both open and closed questions were formulated. The questionnaire used was constructed during a PhD course at the University, with the assistance of a trained questionnaire expert, which promoted validity of the questions. Answers were anonymised before data analysis, and the study was conducted from May to August 2010.

The questionnaire consisted of several groups of questions concerning general quality strategies, current practice for acquiring new knowledge, current practices regarding storing knowledge and information from projects, and more specific questions about inspections. Validation of the inspection-specific part of the questionnaire was improved by observations made during participation in the building inspections of 25 apartments. The inspection-specific part of the questionnaire consisted of nine Lickert-scaled statements and two open-ended questions. The answers from the open-ended questions were analysed and categorised/codified to enable conclusions to be drawn from the data.

Prior to distribution of the questionnaire it was validated by two test groups. One group consisted of 23 employees at two divisions of the Luleå University of Technology: Construction Engineering and Management, and Structural Engineering — Timber Structures. The second test group was chosen from employees of one off-site construction company, consisting of two management representatives, and one management representative from an on-site construction
company gave feedback regarding the questions. In a first round, the survey was sent to 66 site/production managers and project/factory managers in both medium-sized and large construction contractor companies in Sweden, all of which were members of the Swedish Construction Federation. The companies were on-site producing contractors, and members of the off-site segment, mostly multi-storey housing producers. The authors indentified these as two separate populations, which were sampled by selecting site managers and project managers from every company. More than two participants were selected to represent each of the larger companies. The samples were randomised as far as possible, but overall the respondents were sampled with a convenience approach. For some companies it was possible to obtain a random selection from a company-supplied list of all their available personnel in the population. However, for larger companies with subsidiaries operating in local markets in several regions, pairs of participants were selected for every region. One reason for this was to capture possible differences in ways of working between different parts of the country in the same company, and another was to obtain a better balance in the sample between the large and medium-sized companies. It was assumed that regionally organised divisions were of approximately the same size in every such company, but no attempt was made to check the validity of this assumption. During the survey design process it was initially decided to apply a probability (stratified) sampling approach, in which the researchers should randomly select participants for the samples from company-provided lists of their total records of site/production and project managers. However, that approach proved too difficult to follow, since many of the smaller companies had only a few persons in the requested positions, so there was little scope for randomisation, while other companies were not eager to hand out lists of their employees, claiming privacy reasons. Therefore, the only choices in such cases were to exclude the company completely, or to accept the few names provided. Thus, a non-probability, convenience sampling approach was applied.

Questions regarding inspections are presented in Paper IV (Lundkvist et al., 2010). The response rate was 65 % (43 respondents), of whom 62 % (41) completed the survey. The complete questionnaire, which is presented in Lundkvist and Meiling (2010), yielded a response rate of 70% (50 respondents), of whom 67% (48) completed the survey.
2.3.5 Stepwise problem-solving (RQ2)

The research conducted in case study I resulted in the formulation of research question two, aimed to investigate how stepwise problem-solving could be applied in an off-site construction context. Multiple (three) case studies were conducted, all focused on well-defined phenomena in a single company, since extensive information handling was involved. The information collecting methods applied in this case study were identical those used in RQ1-step1, i.e. interviews, focus group meetings, direct participation and visits to factory plant and on-site assembly points.

The study was conducted from January to May 2010 and is presented in Paper V (Meiling et al., 2010a). The aim was to investigate how SWPS methodology can support continuous improvement in the off-site construction sector. The three case studies were based on three different applications of a SWPS method. In each study one of the authors acted as a SWPS facilitator and was in charge of communicating activities and documentation. Empirical results are based on data gathered through interviews and observations from September 2009 to February 2010. In total, 14 semi-structured interviews were conducted with seven on-site managers and seven group managers, at case companies A and B, see Table 4. Both studied companies had adopted Lean production as their overall improvement strategy.

Assembly on-site was identified as the main point at which the quality of upstream processes could be empirically recognised. In order to probe existing problems the on-site assembly of modules was studied during nine field trips to the building sites. During these visits a series of activities was conducted, including interviews with site managers and personnel, and inspection and documentation of the frequency, context and technical aspects of problems.

A list of problems was compiled from the interviews with on-site managers, reflecting the quality of upstream processes, i.e. how well the design and factory production processes fulfilled client requirements. The list consisted of approximately 50 problems that were considered to reoccur. Photographs illustrating all of the problems were taken and presented at focus group meetings, where the problems were prioritised. In order to manage the problem-solving
process a series of meetings was set up. In total 12 focus group meetings were conducted with varying participants in the three case examples.

2.3.6 Lean management and continuous improvement (RQ3)

This question was formulated after conducting multiple case studies I and II, which identified that overall improvement strategies could possibly enable utilisation of CI by means of SWPS. Several off-site construction companies in Sweden have introduced Lean production as a means to gain structured improvements, with CI as a major element. Thus, a study was set up to explore current use of Lean management in off-site construction companies. The study was conducted in the form of a survey (survey II), via a questionnaire. All of the management and production personnel at two companies with similar production strategies were chosen for the investigation.

The study, conducted from July to September 2010 and presented in Paper VI (Meiling et al., 2010a), measured the extent to which off-site construction firms practice and implement Lean management via the 14 principles stated by (Liker, 2004). A survey seemed to be the most suitable research method. Questionnaires were developed (Appendices 3 and 4), based on the 14 management principles, formulated in accordance with the authors’ perceptions of best practices regarding each principle.

Two questionnaires were constructed: one for management and one for factory production personnel in order to enable gap analysis. A five-point Likert scale was used to measure the extent of respondent agreement to each statement, ranging from 1 (“do not agree”) to 5 (“fully agree”). Questions regarding how long the respondent had been employed, company vision, and working tasks were formulated as open answers. The Likert scale is easy to use and understand, but there will always be some degree of uncertainty in that the respondents do not perceive the distance between the five steps as equally great. Populations were chosen from case companies A and B (Table 4), both of which use Lean production as their overall improvement strategy. To assure that the questions were valid, the questionnaires were initially tested on one management representative and a small group of employees at one of the companies. The adjusted questionnaires were
distributed, under the supervision of one of the researchers, to 19 (out of 19) management and 146 (out of 189) production workers, covering 100 % of management and 77 % of the production personnel. The personnel who did not receive a questionnaire were absent because of vacation, sickness or other reasons.

2.4 Validity and reliability
To ensure validity of the case studies, multiple case studies were conducted within the same line of business. The overall validation, through e.g. triangulation, was obtained using multiple sources of evidence, collected by the multiple data collection techniques, i.e. case studies, archival analysis, focus group meetings, questionnaires and statistical analysis. Participation on-site and in the factory production enabled the researcher to compare the answers given by the respondents to the real-life situations and is considered to have increased the construct validity of the results. All interviews were semi-structured in-depth interviews, and the respondents subsequently had the opportunity to verify the correctness of the interview records, which should strengthen the internal validity of the results. The focus group meetings were performed in a problem-solving setting, where documentation was displayed to (and thus validated by) all the participants. The meeting notes were printed out by the researcher and then discussed and validated through focus group meetings and informal discussions with the concerned parties. The reliability of the questionnaires was verified by a pre-test of the actual data collection. However, it is possible that some respondents did not understand the questions properly and thus only answered the questions arbitrarily.

When a questionnaire is used the researcher’s control over the environment is somewhat limited, hence the validity of the results depends on how the respondents perceive the questions and their honesty. Hence, questionnaires cannot be claimed to provide complete objectivity. In addition, a five-point scale was chosen, since it has a middle value that could indicate that the respondents only half-agree with the statements, but in retrospect use of a seven-point scale could have provided more information because the larger response range might have led respondents to answer more accurately. A seven-point scale would also probably have yielded a wider span in the collected data. Hence, a criticism of the results of the questionnaire is that the
data may not be sufficiently spread to indicate the individual experiences in the case companies. However, the results of the pre-tests indicate that the questionnaire was understood.

The documentation studied in the archival analysis consisted of complete sets of records of inspections performed by a certified third party. Studying these documents is considered to have strengthened the internal validity as well as the construct validity, and the information acquired from them is certainly of high reliability.

### 2.5 Case companies

The studies were conducted in close cooperation with off-site construction companies involved in the Lean Wood Engineering competence centre and SkeWood programme. Four companies were involved from project start to licentiate thesis, and two companies from licentiate to PhD thesis. All companies use timber-framed module prefabrication as their building system, and strive to control production processes through continuous improvement and experience feedback. Summary statistics for the case study companies are presented in Table 4.

**Table 4. Summary statistics for the case companies.**

<table>
<thead>
<tr>
<th>Case company</th>
<th>No of employees</th>
<th>Main products</th>
<th>Turnover (€ M)</th>
<th>No. of storeys</th>
<th>Production (Modules/ yrs)</th>
<th>Contract type</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (Lic. and PhD)</td>
<td>150</td>
<td>Multi-family and student dwellings</td>
<td>34</td>
<td>Mainly 4-5</td>
<td>1400</td>
<td>Design build</td>
</tr>
<tr>
<td>B (Lic. and PhD)</td>
<td>99</td>
<td>Multi-family and office buildings</td>
<td>18</td>
<td>Mainly 4-5</td>
<td>900</td>
<td>Design build and general</td>
</tr>
<tr>
<td>C (Lic.)</td>
<td>253</td>
<td>Nursing homes, schools, office buildings</td>
<td>43</td>
<td>Mainly 1-2</td>
<td>1500</td>
<td>General</td>
</tr>
<tr>
<td>D (Lic.)</td>
<td>35</td>
<td>Schools and office buildings</td>
<td>7</td>
<td>Mainly 1-2</td>
<td>-</td>
<td>General</td>
</tr>
</tbody>
</table>

The four companies represent the majority of the Swedish market for timber-framed module prefabrication for recurrent professional clients.
2 Method and Research Process

Case company A is a fourth generation, family-owned company group with one production plant located in the north of Sweden. The company group is divided into a real estate branch and an off-site construction branch, and focuses on producing multi-family and student multi-storey dwellings. The stated company vision is to become the leading Scandinavian off-site producer of timber-framed, multi-family houses. At the time of the survey this company had been implementing Lean production as their overall improvement strategy for a year. A holistic implementation approach is used in cooperation with an external consultant company providing education, support and on-site management. In addition a part-time improvement and implementation leader supervises and supports the continuous implementation of 5S (sort, straighten, shine, standardise, sustain) throughout all parts of the construction process, i.e. sales, purchase, design and on-site assembly of units.

Case company B is part of a larger company group with four production plants located in the south of Sweden. Its products range from movable personnel booths for construction sites, to offices, schools, day-care centres, student dwellings and multi-storey family dwellings. The four divisions all specialise in different types of products, although the main focus of the investigated company is on multi-family, multi-storey buildings. This company has an improvement strategy that is inspired by Lean production, focusing on continuous improvement. At the time of the survey 5S had been implemented in the factory production plant for two years and the company was focused on improving efficiency in design and the work flow in factory production, but without a clear goal to standardise the work.

Case company C is part of a larger company group focusing on development, sales and rental of movable buildings for professional clients. The company group is divided into three branches: sales, rental and leasing. Case company C has three factory plants in central Sweden. The main products are official and commercial buildings, e.g. schools, group dwellings, social service and office buildings. It offers standard concepts for some of the product types, but most of the buildings are still customised. The company group vision is to develop the Nordic market for movable off-site construction of modular
solutions, and become a natural alternative and complement to traditional real estate and on-site construction.

Case company D has one factory plant situated in the north of Sweden, which was incorporated into a larger company group in 2008. The factory unit is now producing detached houses for private clients. Prior to this their products consisted of official and commercial buildings, e.g. schools, pre-schools, office buildings, and dwellings. It was a small company that solely worked with highly customised projects. All products were fundamentally unique, but the building system was always the same, e.g. the company had a standard design for walls.

2.6 The author’s involvement in the case companies

From project start to licentiate thesis, 2006-2008, the author, management representatives from each of the four studied timber framed module prefabrication companies, and other representatives from the timber structures research group have met and participated in various research projects, meetings and seminars. The frequency of these meetings where once each quarter of a year. This has provided increased understanding of the companies involved in this research project, their production and products and the context in which they work. These empirical findings are not documented and have essentially tacit nature. However, this understanding has influenced the analysis of the results and the overall understanding. As a result of these meetings, the author was involved in the realisation of a common web-service involving four companies (www.travolym-byggnad.se), launched in 2007. The home page is a development forum for timber-framed module prefabrication. It provides information about the different stages in the construction process, technical aspects of fire resistance, noise mitigation, and moisture resistance in regard to the building system. The ongoing and finished research projects are also presented as well as news fregarding related subjects. This work further contributed to a broader understanding of the building system and the involved companies. Throughout the whole Lean production implementation in case companies A and B the researcher has been able to visit the factories on a regular basis. These visits, often combined with meetings related to the research project, also included updating of current enhancements in improvement projects. As an example, the researcher initiated, planned and participated in a project
aimed to evaluate methods for geometric control of complete factory-produced modules. Set of four modules were measured at case company A using three close-range devices: (1) an electronic theodolite (yielding discrete point measurements), (2) a terrestrial laser scanner (yielding surface point clouds), and (3) a hand-held laser scanner (yielding delimiting geometry), see Figure 6.

Measurement results will be analysed through 3D models and virtually compared to design CAD models, see Figure 7. The geometry of the modules in the CAD models will be compared to measured 3D models, revealing deviations between design intentions and production outcomes. This analysis has not been conducted yet, and hence is not included in this thesis.

The project aim is to identify where and how design and factory production could be improved through introduction of measurement methods that could provide common metrics. This project involved repeated visits to factory plants and discussions with factory personnel; these discussions are not recorded but have contributed to a deeper understanding of the building system.
3 THEORETICAL FRAMEWORK

The chapter aims to explore the theoretical fields that explain how application of continuous improvements could be understood. The outlined fields are aspects of learning and knowledge, continuous improvements and improvement strategies. The chapter ends with a model of analysis explaining how theory is connected to the investigated problem of how continuous improvement relates to improvements in off-site construction.

The focus in this thesis is on continuous improvement and the methodologies and techniques supporting systematic incremental improvements that enhance performance and quality in off-site construction. The theoretical framework is outlined under three related headings: aspects of learning and knowledge, continuous improvement, and overall improvement strategies. In relation to these headings the following subjects are theoretically considered: experience feedback, defects in construction, stepwise problem-solving, total quality management (TQM) and Lean production. Both TQM and lean production are relevant to the construction trade, and are thus examined as examples of comprehensive overall improvement strategies incorporating similar methods and tools. Lean production is the preferred overall strategy among the off-site construction companies investigated in this thesis. However, its relation to TQM is considered to be valuable, and thus TQM is also considered.

The theoretical framework reflects the author’s notion of how to gain increased understanding of a system. Therefore, when investigating continuous improvement in the off-site construction context touching upon parts of other applied research areas is seen as essential. The chosen theoretical areas are related to more overarching theories of learning organisation, knowledge management and quality management, see Figure 8.
Figure 8. Theoretical frameworks selected from three interrelated management fields.

The chapter ends by presenting an analytical model that visualises how the various theoretical aspects interact.

### 3.1 Learning and knowledge

Improving quality in production processes is inherently a learning and knowledge-based activity (MacDuffie, 1997; Osterloh and Frey, 2000). According to Lee et al. (2005), learning can assist an organisation to continuously improve by helping it avoid to repeat the same mistakes, and by improving operations and activities. Ackhoff (1989) states that learning and adaption to new conditions take place either through trial and error, or by systematic exploitation of experience. Garvin (1993) connects knowledge management and organisational learning through the following definition:

> “A learning organisation is an organisation skilled at creating, acquiring, and transferring knowledge, and at modifying its behaviour to reflect new knowledge and insights.”

Thus, a key attribute of a learning organisation is an ability to exploit created knowledge in improvements. The importance of managing the learning process is emphasised by the cited author, utilising what he describes as building blocks in the learning organisation.

Yeo (2005) states that the learning ability of an organisation depends on the ability to improve with regard to problem-solving and involves continuous improvement.

In this thesis, two complementary views have been selected to explain how organisational learning can take place, supported by systematic problem-solving and continuous improvement. Firstly, the notion that organisational learning occurs via close and interactive relationships between people, as explained by Murray (2002). This view incorporates the idea that learning take place at individual, group and
organisational levels (Argyris, 1993; Kärnä and Junnonen, 2005; Yeo, 2005; Senge, 2006). Secondly, Flood and Romm (1996) describe and distinguish three types of organisational learning: single-, double-, and triple-loop learning. Single-loop learning occurs when an organisation responds to an alteration in its environment by detecting and correcting errors without changing its norms (Argyris and Schön, 1978). Double-loop learning occurs when the detection and connection of errors leads to a change in an organisation’s standards or objectives (Argyris, 1999). Finally, triple-loop learning occurs when an organisation realises that opportunities should be grasped, and known problem tackled, even when this is difficult, so it starts to fundamentally re-examine itself and the context in which it is active (Flood and Romm, 1996). The learning climates within firms that promote single-, double-, and triple loop learning are described by Snell and Chak (1998) and summarized in Table 5.

Table 5. Type of learning and corresponding characteristic company climates, developed from (Snell and Chak, 1998).

<table>
<thead>
<tr>
<th>Learning type</th>
<th>Learning climate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-loop:</td>
<td>Personnel work together as best they can to fulfil a set of tasks efficiently</td>
</tr>
<tr>
<td>Double-loop:</td>
<td>Expectation of continuous improvement based on common mental models and personnel creativity, e.g. positive brain storming.</td>
</tr>
<tr>
<td>Triple-loop:</td>
<td>Established structure to promote creativity and sharing of experience at all levels (personal, team and organisation) based on extensive self-criticism.</td>
</tr>
</tbody>
</table>

According to Schein (2004), the fostering of a learning culture must promote reflection and experimentation, by allocating time and resources to these activities. In this way the learning task will eventually become a shared responsibility. Keys to learning, according to Schein (2004) are:

- Feedback.
- Time to reflect, analyse, and assimilate.
- Ability to generate new responses.
- Trying new ways of doing things and generating feedback from the new behaviour.
Best practice exists in every learning organisation and it will change as the shared knowledge changes. Garvin (1993) lists five activities that a learning organisation must master, see Table 6.

Table 6. Five activities and connected methods that a learning organisation must master.

<table>
<thead>
<tr>
<th>#</th>
<th>Activities</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Systematic problem-solving</td>
<td>Scientific method driven by difficulties: PDCA, simple statistical tools (histograms, Pareto charts, cause-and-effect diagrams)</td>
</tr>
<tr>
<td>2</td>
<td>Experimentation with new approaches</td>
<td>Scientific method driven by opportunities: ongoing programs or one-of-a-kind projects</td>
</tr>
<tr>
<td>3</td>
<td>Learning from own experiences and past history</td>
<td>“Recognise the value of productive failure as contrast to unproductive failure.” Post-project appraisal.</td>
</tr>
<tr>
<td>4</td>
<td>Learning from the experiences and best practices of others</td>
<td>Benchmarking, conversation with customers, observation of customers</td>
</tr>
<tr>
<td>5</td>
<td>Transferring knowledge quickly and efficiently throughout the organisation</td>
<td>Written, oral, and visual reports, site visits and tours, personnel rotation programs, education and training programs, and standardisation programs</td>
</tr>
</tbody>
</table>

All of the abovementioned activities should be accompanied by an appropriate mind-set, tool-kit, and pattern of behaviour in order to help foster learning behaviour. The above proposed activities imply mastering the three interrelated strategies Kaizen (#1), innovation (#2), and experience feedback (#3-5). These three concepts are further discussed in sub-sections 3.1.2 and 3.2. The outcome of these processes of learning behaviour is knowledge (Choo et al., 2007a). Yeo (2005) defines the term “organisational learning” as the process of learning while the idea of “learning organisation” refers to a type of organisation rather than a process. On this basis, organisational learning is considered to depend on the collective cognitive processes of individuals. A learning organisation is concerned with the process of gaining, sharing and utilising the knowledge accumulated by individuals and transferring it through the organisation in order to meet its strategic goals (Ibid.). Both of these definitions indicate that CI and experience feedback are important elements that can help companies achieve their objectives, and hence warrant further attention.
Ackhof (1989) describes knowledge creation as an evolution of understanding, i.e. the process whereby contextualised data are transformed via interpretation into information, knowledge and eventually wisdom through the discernment of relations, patterns and principles. Thus, data, information, knowledge and wisdom can be regarded as forming a hierarchical model – the DIKW model (Ackoff, 1989; Fricke, 2009) – of enhanced understanding. Data represent objective facts (if removed from their context they lack meaning), information is data that has a meaning and thus is relevant to a question, while knowledge emerges when information is placed in a particular context, in addition it involves understanding and has a longer lifespan than information. These distinctions are supported by Nunaka and Takeuchi (1995), who state that information is a flow of messages and that knowledge is essentially related to human action. According to Ackhoff (1989), knowledge can be obtained by transmission from others or from experience, in either case it is argued that learning is involved, where learning is targeted to maintaining or increasing an efficiency level. Wisdom is argued to be of a permanent character. A simplistic linear model of the DIKW model is presented in Figure 9. The validity of the visualised linearity is not a concern, rather it stresses that understanding is interrelated to the process whereby data can be transformed to information, knowledge and ultimately wisdom.

![Figure 9. A simplistic view of the relation between data, information, knowledge, wisdom and understanding, developed from Bellinger et al. (2004).](image)

Interestingly, Ackhoff (1989) states that the difference between effectiveness and efficiency is that which differentiates wisdom from understanding, knowledge, and information. A pragmatic description of knowledge is provided by Davenport and Prusak (1998):
“Knowledge is a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experience and information. It originates and is applied in the minds of knowers. In organisations, it often becomes embedded not only in documents or repositories but also in organisational routines, processes, practices, and norms.”

The stated definition makes clear that knowledge is a complex matter. According to the cited author, the transformation of information into knowledge takes place during several interrelated actions:

**Comparison:** How does information about this situation compare to other situations we have known?

**Consequences:** What implications does the information have for decisions and actions?

**Connections:** How does this bit of knowledge relate to others?

**Conversation:** What do other people think about this information?

It should be noted that knowledge is commonly divided into two categories: tacit knowledge (e.g. intuition, unarticulated mental models, or embodied technical skills, i.e. know how) and explicit knowledge (i.e. a set of articulated information including numbers or diagrams) both of which interact (Nonaka and Takeuchi, 1995). These authors also state that during conversions from tacit to explicit knowledge and vice versa organisational knowledge is created, thus they could be considered as mutually complementary entities. The process of creating new knowledge in a business environment is described and visualised by Nonaka et al. (1996) in the SECI model, see Figure 10. Here, *socialisation* refers to transfer of tacit knowledge through conversation or observation at either individual or group level, *externalisation* occurs when tacit knowledge is transferred to explicit knowledge in the form of documents or databases, *combination* refers to transfer of combined, sorted or selected explicit knowledge, and finally *internalisation* is when explicit knowledge is transferred into tacit knowledge through documents or drawings.
The spiral in the centre of Figure 10 symbolises the conversion of tacit and explicit knowledge, which in turn creates new knowledge. Thus, any activity that stimulates conversion will contribute to knowledge creation in some form. This thesis considers ways to foster the evolution of knowledge and wisdom from data and information, thus it is interesting to investigate how knowledge could be managed.

### 3.1.1 Knowledge working models

To facilitate the continuous management of knowledge, and thus promote improvements, several working models have been developed. Blessing and Wallace (1998) propose a knowledge life-cycle representing the evolution of knowledge for an individual, a team and a company with the overall mission to support the design process. The knowledge life-cycle serves as a basis for the capture, analysis and use of experiences in a knowledge-generating manner, meaning that the quality of knowledge will increase as the cycle is used. Outside sources may contribute additional life-cycle knowledge as they interact. This model recognises the importance of capturing both knowledge and context in real time, making it available as soon as it is reported. This is difficult to apply in housing production since real-time capture in this manner implies use of a computer-based knowledge system. In Methodology and tools Oriented to Knowledge-based engineering Applications, the MOKA method (Stokes, 2001), a life-cycle for knowledge-based engineering applications is described according to the following steps: identify, justify, capture, formalise, package and
activate. The first step involves identifying opportunities for experience feedback. However, ways in which this identification should be conducted are not described in detail. A tripartite model for live data capture is presented by Kamara et al. (2003) and Tan et al. (2007) including use of: (1) ICT tools, (2) a working system and (3) an assigned knowledge manager.

There is also a wide spectrum of types of project knowledge, e.g. knowledge regarding processes, costing, legal requirements, best practices, and lessons learned (who knows what). In addition, each category could be sub-divided into more detailed kinds of knowledge, hence there is a need for demarcation. The conceptual framework presented by Kamara et al. (2003) and the technique presented by Tan et al. (2007) do not detail the kinds of knowledge that should be captured. Further, they do not address the hierarchal relations of understanding and the different levels of data-information-knowledge-and wisdom recognised by authors such as (Ackoff, 1989), or therefore the associated implications regarding the importance of facilitating interpretation of data etc. In contrast, Lin et al. (2006) present a map-based knowledge management concept for construction. This model is argued to help in identifying critical knowledge areas, since all knowledge is abstracted and summarised in maps created in the following phases: knowledge determination, extraction, attribution, linking, and validation. The proposed model pushes experiences into the company, and it requires a knowledge management team to function.

Foguem et al. (2008) describe experience as an intermediate step between information and explicit knowledge. Cross et al. (2001) stress the importance of knowledge created through networks and relationships as information technology solutions miss the opportunity to exploit embedded knowledge, and conclude:

“Despite advanced technical solutions employed to manage organizational knowledge, we continue to find that people are often more reliant on other people than they are on databases when seeking answers to unstructured questions.”

The process of learning with knowledge as an output incorporates all stages of managing knowledge, i.e. identification, creation, distribution and adoption of experiences. Knowledge models do not involve a
structured learning procedure and are here considered to represent a push of experiences. There is a need to identify models that include techniques for prioritising experience that should be fed back. There is also a need for models that help to identify destinations, i.e. people and places experience should be fed back to (in order to create a pull system).

3.1.2 Experience feedback

The term feedback is explained as the interaction between a system and its surroundings. If the effect of the system is fed back to the system it becomes an input that can contribute to shape future outputs of the system (Bertalanffy, 1968). Feedback is negative when it is used to correct deviations from a sought outcome regarding a process. If instead the process itself is altered, or even completely changed, the feedback is considered as positive (Stacey, 1996). A key feature of experiences is their practicality; you need to do something to actually gain an experience. Therefore, experiences, as well as knowledge, have both tacit and explicit components, and both are important (Kamara et al., 2002; Nergård and Larsson, 2009).

Nonaka et al. (1994) state that experience is the key to knowledge and that it needs to be shared in order to disseminate. Thus, the constituents of experience feedback are explained by principles of Knowledge Management (KM), since it is ultimately a learning issue (Henry, 1974). Experience feedback is not KM per se, but is described as a KM initiative by e.g. Carrillo et al. (2003), thus routines to gain improvements through experience have aspects of knowledge as a common denominator. Knowledge Management (KM) involves strategies and practices used to identify, create, represent, distribute, and enable adoption of experiences. Such experiences comprise knowledge, either embodied in individuals or embedded in processes or practice (McAdam and McCready, 2000; Thompson and Walsham, 2004). Kamsu Foguem et al. (2008) argue that experience feedback is:

“…another way to manage knowledge. It is a bottom-up approach, where knowledge is built gradually from useful cases. Generic knowledge can be extracted but above all, experience feedback is a way to ensure partial knowledge preservation.”

What can be fed back is not the whole experience since a person (or persons) needs to be in a similar situation to the person who had the experience to understand the more tacit parts. The more explicit parts
can be documented and explained more easily. If the person who had the experience participates in the feedback process some of the more tacit elements may be fed back. Experience without context is thus not knowledge. An ontology-based approach is presented by Kamsu Foguem et al. (2008), describing a model for capitalisation of tacit information into explicit knowledge, the authors classify experience feedback according to event, context, analysis and solution, which corresponds to the PDCA cycle, see Figure 11.

Figure 11. Experience model incorporating problem-solving developed from Kamsu Foguem et al. (2008).

The model described in Figure 8 could be characterised as a push approach where rich context feedback is dissected for explicit knowledge that can be stored for anticipated use. Some examples of experience feedback scenarios expressed in a construction context are presented in Table 7.

<table>
<thead>
<tr>
<th>Regarding products</th>
<th>Employees working downstream of the construction design process, or clients, feedback their experiences of how well the product could be produced, maintained, used and so forth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regarding processes</td>
<td>Employees feedback their experiences in terms of how well the organisation works in terms of all aspects, from management strategies to specific work methods</td>
</tr>
<tr>
<td>Regarding means</td>
<td>Employees feedback their experiences of how well equipment, machines, software, tools etc. work.</td>
</tr>
<tr>
<td>Regarding people</td>
<td>Employees feedback their experiences of how well certain people work.</td>
</tr>
</tbody>
</table>

Table 7. Some feedback scenarios.

There is a strong rationale for handling experience within a company to promote problem-solving and continuous improvement, but it should be noted that experience feedback requires an actual receiver in order to fulfil its intended use. As industrial systems grow in complexity, analysis becomes more difficult, thus automated methods are developed to meet the growing demand for complex analysis of information (Kamsu Foguem et al., 2008; Nergård and Larsson, 2009). However, the vision of supplying ready to use, available information in
complex manufacturing industries has not yet been realised (or at least demonstrated) and automated methods to store and subsequently efficiently access information have not yet been developed (Andersson and Isaksson, 2008).

Post-project evaluation, or debriefing, as described by Gameson et al. (2008), is a common approach for experience capture in construction projects according to Orange et al. (1999), but it is argued to be insufficient since inadequate time is allocated for this purpose. Further drawbacks associated with post-project evaluation include the common dispersal of workgroups after project completion, and the inevitable time lags between relevant experiences and data capture (Tan et al., 2007). In these respects, live capture of experience data may provide a better basis for the formulation of explicit knowledge and thus promote the efficiency of continuous improvement activities in organisations. Kamara et al. (2003), Ingirige et al. (2002), and Lee et al. (2005) all note six benefits of live knowledge capture, namely it: (1) avoids the need to reinvent old solutions, (2) facilitates innovation, (3) increases agility, (4) improves teamwork, (5) improves supply chain integration, and (6) improves project performance. The possibilities of knowledge capture are heavily promoted, but realising it depends on targeted feedback (i.e. functional feedback of collected knowledge).

Learning from experience and improving production is a strategy that is intended to enhance client satisfaction and efficiency. Elimination of defects is one driver for reusing experiences in construction, defects in this context are primarily regarded as the main proof that production processes are sub-optimal. The next section presents a review of defect studies that have been documented and discussed in construction literature.

### 3.1.3 Defects in construction

Early studies tended to blame the occurrence of defects on the craftsmen executing the construction, e.g. Schodec (1982), Kaplan (1994) and Beukel (Beukel, 1994). This is a view that was subsequently complemented with a broader approach for managing defects regarding their classification, roots, effects and correction. The International Council for Research and Innovation in Building and Construction (CIB) group W086 was essentially concerned with learning from past and current building pathologies and encouraging the systematic
application of that knowledge to the design, construction and management of buildings. Building pathology is defined in CIB (1993) as the systematic treatment of building defects, their causes, consequences and remedies. The same working group define defects as situations where one or more elements does not perform its intended function and an anomaly is referred to as an indication of a possible defect. This must not be confused with failure, as failure is the termination of the ability of a building (or building component) to perform a required function. Hence, a crack in the wall is a defect until the wall fails to perform its structural performance. Building pathology is concerned with defects that lead to extensive failure with not only economic implications, but also when there is a danger of structural failure because of defects. This thesis is more concerned with defects as indications of poorly managed processes.

Love and Josephson (2004) examined defects during one housing project, and complemented their observations with interviews in order to identify root causes of the documented defects. The observed defects were all conceived to have occurred during the construction phase; building inspection defects were not accounted for. However, their classification did not take into consideration the production method used to generate defects. The cited authors concluded that the most effective learning in relation to defects takes place in projects when an entire error-recovery process is performed, as defined by Sasou and Reason (1999) i.e. detection, indication and correction. It is emphasised that learning should be encouraged both at individual and organisational levels using quality management techniques, i.e. root cause analysis, benchmarking, failure effect analysis or Poka-yoke (Shingo, 1986; Wilson et al., 1993).

Josephson and Hammarlund (1999) emphasise the importance of gaining knowledge about defects (including both costs and causes) in order to prevent them arising. They suggest that organisational phenomena are the main causes of defects, a view supported by Sasou and Reason (1999), who propose that human errors in complex organisations originate in the working team. Pheng and Wee (2001) state that defects arise for two reasons: nature or human errors, their study is focused on human errors and they present a conceptual framework for defect reduction based on the ISO 9001 model of quality assurance. Porteus (1992) stated poor communication to be the
most common scapegoat for defects in scientific publications between 1973 and 1983. He also suggests a system for classifying defects according to their origin, i.e. type of natural cause or type of human error. This classification is argued to generate feedback information and data that promote long-term learning, the main benefit of this approach being to avoid involvement with issues of blame by using the term negligence rather than human error or mistakes. This is also promoted by CIB (1993), which points out the importance of such a methodology in order to not only cover liability aspects, but also aspects that can improve quality management systems. Davey et al. (2006) argue that Action Learning will bring contributions and significantly improve defect management and liability regarding defects. A more recent study of defects in residential homes built in Australia, by Ilosor et al. (2004), advocates analysis of historical data to identify patterns or sequences in defect occurrence. The study was based on documented defect inspections from a large number of houses, and found that mistakes regarding framing and roofing were the most prominent features requiring attention. In addition, a literature review conducted by Ilosor et al. (2004) suggests that defect studies can be divided according to their focus on: ways to systematically classify defects, causes of defects, and how defects are fixed or managed. Kim et al. (2007) suggest an Information Communication Technology (ICT) solution for managing defects in large construction projects. They identify three main reasons for inefficient actions regarding defect management:

1. Lack of on-site quality managers.
2. Excessive workloads for crews to meet deadlines.
3. Inefficient communication among project participants.

The cited authors suggested and carried out a real life test of a computerised Quality Inspection and Defect Management System (QIDMS) using hand-held computers, a Personal Digital Assistant (PDA) and wireless internet. This enabled real-time data collection and processing, and the study reported significant efficiency improvements based on a ten-project study of 700 apartments in multi-storey buildings.

The idea of improving efficiency and productivity by using intelligent wireless web services is also supported by Aziz et al. (2006). The quality
of construction critically affects building performance, both at delivery and after some years of initial occupancy. Hence, Chong and Low (2005) investigated the possibility of feeding information obtained in operation and maintenance stages back to design so that future errors could be reduced. The importance of feedback to design is also investigated and emphasised by Scott and Harris (Scott and Harris, 1998), who call for more structured learning at an organisational level.

Atkinson (2002) thoroughly examined theories regarding human error and its origin. The author draws interesting conclusions and states that communication has the greatest impact on defect occurrence. Furthermore, it is stated that management is the main factor for performance regarding quality, safety and business, hence the chosen management strategy, and the degree to which it promotes communication, will also affect the occurrence of defects. This conclusion relies on a statement by W. E. Deming that it is the system of work that determines how work is performed and only senior managers can create the system (Deming, 1986).

A contemporary defect study was conducted by Sigfrid (2007) and results are summarised in the report “Defects and deficiencies in new dwellings”. The study was financed by the Swedish National Board of Housing, Building and Planning, thus implying its use for generalisation. Defects and deficiencies of six building projects were investigated through interviews and examination of building inspection protocols. All building projects were traditional site constructions: three multi-storey projects and three single family houses. Calculations presented in the study (based on housing production figures for 2005) show that the costs for correcting defects after project delivery in Sweden could be as high as € 1.3 billion. Deficiencies in the design phase are suggested to contribute, together with insufficiencies in leadership, motivation and communication to these defects. The client is also to blame for a lack of life cycle approach to the constructed asset.

In addition, the report asserts that defects are indications of organisational shortcomings and insufficiencies in the construction industry. Josephson and Saukkoriipi (2007) summarise waste costs in Swedish construction projects, as follows:
3 Theoretical framework

- Defects (10 %), including costs of hidden and visible defects, and inspection costs.
- Resources (10 %), representing inefficiency at the construction site.
- Health and safety (12 %), the largest contributors being for rehabilitation and sick pensions.
- System and structure (5 %), there is a clear tendency that efficiency suggestions result in extended support systems.

It is pointed out that improvements should not result in new, costly enhanced administration. The authors also call for new vertical management processes, i.e. partnering.

A zero defect strategy is starting to gain attention among off-site constructors in Sweden. This strategy addresses the inspections at delivery and aims at lowering the amount of defect notations in the inspection protocols. This is far from the original thought of zero defects originating from the work of Philip B. Crosby in the 1960s (Juran and Gryna, 1988). Even if it is a misconception to use the zero defect concept in this context, it could be useful to recall the original purpose and maybe even apply it in the modern industrialised housing industry. Originally it was a strategy for setting a performance standard that could not be misunderstood, in which everyone involved should perform to the agreed requirements and do it right every time. The quest for standardised solutions could be seen as being in conflict with the tradition of seeking uniqueness in housing fabrication. However, lowering the level of defects is not a goal within itself (Deming, 1986), as the customer is looking for continuous improvements regarding performance and style of the product.

To conclude this section, defect studies are clearly focused on learning from mistakes, but not on addressing how learning could become sustainable, hence it is not clear how the reoccurrence of mistakes could be prevented. Both continuous improvement and experience feedback are crucial functions for any company aiming for efficiency and customer satisfaction to grasp. The importance of improvements through feedback is crucial for quality improvements, the next section introduces the concept of continuous improvement.
3.2 Continuous improvement

Continuous improvement, CI, is described as both a management strategy in itself, but also as a process within more comprehensive quality improvement strategies, e.g. TQM or Lean production (Bessant and Francis, 1999). Lindberg and Berger (1997) summarise this ambiguity as follows:

“It may obviously be debated whether CI is a part of TQM or vice versa, but what is essentially clear is that CI is one fundamental process of change that allows companies and organizations to gradually develop performance.”

Improvement is defined by Juran and Gryna (1988) as the attainment of a new level of performance that is superior to any previous level. According to Imai (Imai, 1986) improvements can be divided into Kaizen and innovation. Kaizen refers to maintaining and improving the work-standard through small, gradual improvements, while innovation means improvements as a result of large investments. It is vital to distinguish between innovation and Kaizen, since the former is more active as a separate process prior to design and the latter is more focused on production, see Figure 12 and Figure 13.

![Figure 12. Interrelation between innovation, design and feedback, developed from Imai (1986).](image)

The small step that continuously improves the working standard is often highlighted as the main difference between western and eastern quality management (Imai, 1997). Working standards within the Kaizen strategy are defined as a set of policies, rules, directives and procedures established by management for all major operations, which serve as guidelines that enable all employees to perform their jobs successfully (Imai, 1986). The key to Kaizen is to attain everybody’s involvement. Continuous improvement is often formalised by the PDCA (Plan, Do, Check, Act), learning cycle and improvement tools and methods, such as root cause analysis (RCA), and visualisations like
cause-and effect and tree diagrams (Wilson et al., 1993; Jones et al., 1999; Arnheiter and Maleyeff, 2005).

Figure 13. Kaizen (left) vs. innovation and continuous improvement (right) vs. standardisation, developed from Imai (1986).

The left part of Figure 13 illustrates how Kaizen aims to maintain and improve the working standard between innovation activities, while the right part show how improvements need to be stabilised in order to gain desired effects. This is an ongoing process, thus CI is not a static method, but rather an evolutionary process to become a learning organisation. Bessant et al. (2001) identify five evolutionary levels of continuous improvement work, which can be outlined as follows.

1. Unstructured continuous improvement work: There is no formal structure for improving performance of the company. Problems that occur are solved at random, depending on their nature. The personnel do not work with continuous improvements as a process, and use of measurements is limited or non-existent.

2. Structured continuous improvement work: A formal structure for continuously improving performance has been established throughout the entire company. Problem-solving is a structured process, depending of the nature of the problem. The personnel work with continuous improvement as a process, and the personnel are trained to use continuous improvement tools. Measurements are in place to facilitate progress monitoring.

3. Goal-oriented continuous improvement work: In addition to the previous level, goal and aims for the continuous improvement initiative have been implemented and progress towards them are carefully measured. Continuous improvement work is integrated in every-day work assignments.
4. Proactive continuous improvement work: In addition to the previous level, anatomy in continuous improvement work is targeted as the personnel are empowered to manage their own work.

5. The learning organisation: In addition to the previous level, work with continuous improvements is systematic and both identifying and solving problems are shared activities, in which experiences and knowledge are effectively shared by the entire organisation.

Thus, CI develops over time, from tentative first attempts and the conscious adoption of new ways of doing things, to the point where incremental improvement becomes an integral part of organisational life. Ten key behaviours are identified by Caffyn (1999) for promoting CI capability:

1. Employees demonstrate awareness and understanding of the organisation's aims and objectives
2. Individuals and groups use the organisation's strategic goals and objectives to focus and prioritise their improvement activities
3. The enabling mechanisms (e.g. training, teamwork, methodologies) used to encourage involvement in CI are monitored and developed
4. Ongoing assessments ensure that the organisation's structure, systems and procedures, and the approach and mechanisms used to develop CI, consistently reinforce and support each other
5. Managers at all levels display active commitment to, and leadership of, CI
6. Throughout the organisation people engage proactively in incremental improvement
7. There is effective working across internal and external boundaries at all levels
8. People learn from their own and others' experiences, both positive and negative
9. The learning of individuals and groups is captured and deployed
10. People are guided by a shared set of cultural values underpinning CI as they go about their everyday work
CI capability is defined by Caffyn (1999) as:

“The ability of an organisation to gain strategic advantage by extending involvement in innovation to a significant proportion of its members.”

From a construction perspective it should be noted that the list of key behaviours does not involve focus on production processes, it is rather seen as a prerequisite, as emphasised by Imai (1997).

Based on 129 Swedish cases and survey research Lindberg and Berger (1997) have investigated strategies for designing, organising and managing systems for CI. Based on the cases the authors conclude that firms more experienced in CI rely more heavily on decentralised team-based working than firms less experienced in CI. This is consistent with the Japanese application where permanent improvement groups work separately from production, i.e. in quality control circles or Kaizen event groups (Lillrank and Kano, 1989). For further information on Kaizen events and quality circles see, for instance, (Lawler and Mohrman, 1991; Farris et al., 2004; Doolen and Hacker, 2005; Farris, 2006).

According to Lindberg and Berger (1997) less experienced firms tend to apply more rigid approaches, seeking control in the CI process, CI content (following the PDCA format), and CI goals. The latter approach is focused on in this thesis, which primarily addresses the operative level of CI, i.e. how it is managed and organised in the construction phase of off-site construction (factory production and assembly on-site).

CI goals could be summarised in four parts (Wu and Chen, 2006) as: (1) a company-wide focus to improve process performance, (2) gradual improvement through stepwise problem-solving, (3) organisational activities with the involvement of all people in the company from top managers to workers, (4) creating a learning and growing environment. The rationale for implementing and executing a stepwise approach to problem-solving for reusing experience can be found within most quality management theories, including Lean production, TQM and Six Sigma theories (Dahlgaard and Dahlgaard-Park, 2006). Problem-solving cycles for this purpose are organised in TQM as PDCA and in Six Sigma procedures as DMAIC (Define, Measure, Analyse, Improve, Control) (Pyzdek, 2003).
3.2.1 Stepwise problem-solving

When moving from *ad hoc* problem-solving, as applied in construction in general, towards more structured improvements it incorporates implementation of a formal problem-solving process. The method of SWPS in manufacturing originates from the work of Shewhart (1986), who based his statements of process improvements on a scientific method of deduction and induction, namely a cycle of: hypothesis (plan)-experiment (do)-and evaluation (check) referring to the work of Bacon (2000), (originally 1620). This threefold improvement cycle was further developed by Deming (1986) and formalised as PDCA by the Japanese in the 1950s (Deming, 1986). Ohno (1988) describes a stepwise approach as complying with a scientific mindset, meaning it is a logical, knowledge-creating process, hence a systematic process of learning.

The four steps of the PDCA cycle are: Plan (study the current situation and develop solutions for improvement), Do (take measures on a trial basis), Check (investigate the effect of changes), Action (standardise on a permanent basis). A major characteristic of PDCA is the emphasis on the planning stage (in which analysis is a core activity), where several quality tools are important to master: (1) Ishikawa diagrams, (2) Pareto charts, (3) Check sheets, (4) Control charts, (5) Flowcharts, (6) Histograms, and (7) Scatter diagrams.

In order to develop effective improvement measures, underlying causes of problems must be identified, i.e. root cause analysis is required. Methods that can be used to identify root causes include: cause and effect analysis, five whys (a technique originally developed at Toyota industries) and fault tree analysis (Wilson *et al.*, 1993; Bergman and Klevsjö, 2003; Pyzdek, 2003). Thus, SWPS is a method for systematic problem-solving in which the individual steps of the PDCA improvement cycle are broken down to a sequence of steps. In Figure 14 a typical SWPS method is displayed, from Meiling *et al.* (2010a), and some published existing SWPS methods are summarised in Appendix 1.
Sobek II and Smalley (2008) outline a series of benefits using the A3 format together with SWPS methods to: promote the logical thinking process; maintain objectivity; present results in a consistent manner; promote synthesis, distillation and visualisation; achieve alignment; develop coherency and consistency across organisational units, and finally address ways to incorporate the results into the larger picture. SWPS is stressed by Wu and Chen (2006) to be a core activity when pursuing CI goals, while Spear and Bowen (1999) emphasise the importance for SWPS to be conducted as close to the event as possible.

The benefits of structured problem-solving are threefold: it promotes learning, provides a means to improve personal problem-solving skills, and helps stabilise production processes (Shiba and Walden, 2002; Sobek II and Smalley, 2008).

Standardisation is a vital part of stabilisation of processes. Standardised work could be regarded as a prerequisite for systematic improvements, but at the same time continuous improvement through SWPS could be described as a vehicle for achieving standardisation. Imai (1997) introduces the Standard-Do-Check-Act cycle (SDCA), a complement to the PDCA cycle, aimed at stabilising production processes after improvements. It has four distinct steps: 1) definition and documentation of operating procedures, process requirements, and other process specifications to ensure that the process is always executed in a standardised and repeatable manner, 2) conformance to the defined standards, 3) verification that conformance to the standards results in process stability, and 4) appropriate responses for the observed effects of the standards. In step 4, if the process has become stable, the standards are made permanent and deployed more widely (Imai, 1986).
Thus, ultimately created knowledge should cater for standardisation of operations formalised in a work chart, which could be defined as:

“... a document centred upon human motion that combines the elements of a job into the most effective sequence with minimal waste to achieve the most efficient level of production possible under current conditions (Smalley, 2004).”

The interaction between improvements and standardisation is stated by Henry Ford (Ford and Crowther, 2003):

“Today’s standardisation is the necessary foundation on which tomorrow’s improvements will be based.”

This relates to issues regarding the degree of standardisation required or is possible in construction vs. flexibility towards client demands.

SWPS methods involve alternation between induction and deduction, denoted by Neave and Deming (1990) as levels of thought and experience. Shiba and Walden (2002) describe systematic SWPS as proactive, reactive or in the form of control of standardised processes. Furthermore, they differentiate three different kinds of data to be captured: (1) control of standard methods requires mainly numeric data for monitoring, (2) reactive problem-solving requires both quantitative and qualitative data, and (3) proactive problem-solving, being a search for something new, requires knowledge mainly of qualitative nature, see Figure 15.

Figure 15. Levels of thought and experience regarding types of problem-solving and data required, developed from Shiba and Walden (2002).

The different kinds of data and information to collect are further emphasised by (Mann, 2005) and (Pascal, 2006), who suggest that problems should be classified in three levels, according to their severity:
3.3 Overall improvement strategies

This section describes two interrelated improvement strategies, TQM and Lean production, that are identified as central for understanding how improvements through experience feedback could become efficient and effective. It should be noted that Lean production is preferred by the case companies in this thesis, but much of the context in which these companies are active is regulated and influenced by ISO standards more related to TQM, which is thus considered first. The interest in quality management, organisational learning and knowledge
management within the construction sector has intensified through client demands and government legislation and attention (Thorpe and Sumner, 2004; Persson, 2006; Knauseder, 2007). Implementation of quality management strategies, e.g. TQM and Lean production, within the construction sector has been recommended by several researchers (Liu, 2003; Low and Teo, 2004; Lessing et al., 2005).

3.3.1 Total quality management

Klefsjö et al. (2008) state that quality management through TQM is a widespread concept for improved competitiveness, efficiency and profitability. Love et al. (2000) identify TQM as a means to achieve a state of continuous improvement in construction, which is considered to lead companies into learning from mistakes and become learning organisations. TQM is defined as both a philosophy and a set of guiding principles (Dale, 1999; Bergman and Klefsjö, 2003). The values of TQM are summarised in six cornerstones or core values: (1) focus on the customer, (2) base decisions on facts, (3) focus on processes, (4) improve continuously, (5) let everyone be committed, and (6) top management commitment (Dahlgaard et al., 1998; Bergman and Klefsjö, 2003). The cornerstones are supported by a set of techniques and tools (Bergman and Klefsjö, 2003), many of which are also used within the Lean production system (Arnheiter and Maleyeff, 2005).

Quality in production, i.e. the quality story (Dahlgaard and Dahlgaard-Park, 2006), developed over most of the twentieth century, mainly after World War II. During this time contributions to the “story” were made both by scientists (eastern and western) and various consultants. Thus, when describing the quality movement and quality management principles there is not a single truth, but rather diverse views and developments have been expressed regarding quality management and the implementation of quality practice. A fairly recent definition of TQM, preferred in this thesis, is presented by Hellsten and Klefsjö (2000):

“TQM is a continuously evolving management system consisting of core values, methodologies and tools, the aim of which is to increase external and internal customer satisfaction.”

This could be compared with the definition of Total Quality Control stated by Feigenbaum (1991), one of the inventors of TQM:
\textit{“Total quality control is to provide genuine effectiveness and control by identification of customer quality requirements and ends only when the product has reached the customer and he is satisfied.”}

An important difference is that Hellsten and Klefsjö emphasise that TQM is “continuously evolving”, indicating the long term commitment. According to Hellsten and Klefsjö (2000), the TQM system should be executed in three steps, the first of which is to establish the core values. Secondly, techniques should be identified that are suitable for the organisation to use and support its values. The third step is to find tools that can be used in an efficient way to support the chosen techniques, see Figure 16.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{tqm_flowchart.png}
\caption{Flow chart illustrating TQM, as developed from Hellsten and Klefsjö (2000). The stated techniques and tools are examples, not a complete list.}
\end{figure}

The introduction of TQM marked the start of an era subsequently called the second generation of quality management (Foster and Jonker, 2003). This era is characterised of a customer focus, whereas the ongoing evolution of a third generation quality management (not included in this thesis) introduces a stakeholder perspective (Bergquist \textit{et al.}, 2006). The first generation was characterised by a focus on inspections of the finished output. In the second generation, the level of quality consciousness in general is reflected upon, supported by the international organisation for standardisation, and formulated in the ISO 9000 series, a set of standards concerned with what a company’s quality system should include and how it should be implemented (Nee,
The ISO 9000 standards were written to provide guidelines to assist organisations in implementing and operating a Quality Management System (QMS), and are said to be key to implementing TQM (Poksinska, 2006). QMS is defined as a system for directing and controlling an organisation with respect to quality (ISO, 2000). The implementation of QMS is an extensive commitment for a company, and yet there is no certain outcome (Landin, 2000). The ISO 9000 logic for quality management is formulated in eight principles: (1) Focus on your customer, (2) Provide leadership, (3) Involve your people, (4) Use a process approach, (5) Take a systems approach, meaning linking processes, (6) Encourage continual improvement, (7) Get the facts before you decide, (8) Work with your suppliers.

Four stages have been proposed (Dahlgaard et al., 1998; Dale, 1999; Bergman and Klefsjö, 2003) and detected as leading the way towards a TQM approach: (1) inspection, (2) quality control, (3) quality assurance and (4) Total Quality Management, see Figure 17.

![Figure 17. The development of the quality movement, from Bergman and Klefsjö (2003).](image)

The first step is characterised by simple in-house, inspection-based, after-the-event actions, with no prevention content, aiming for quick-fix actions on the output. The second quality control step is an improvement because the requirements are more detailed, feedback is present and there is a focus on detection. Quality control can be defined, according to ISO standards (ISO, 2000), as follows:

“Part of quality management focused on fulfilling quality requirements.”

As a permanent working state this detection, or fire-fighting mode, is aimed at detecting non-conforming products, but it does not prevent
3 Theoretical Framework

their manufacture. The third step is quality assurance, characterised by finding the root cause of a problem rather than merely switching the blame. The ISO standard definition (ISO, 2000) is:

“Part of quality management focused on providing confidence that quality requirements will be fulfilled.”

The requirements of the ISO 9000 standards are seen as a minimum state for the third level. This level is the prevention-based level (Dale, 1999), which means that defects are identified as early as possible in processes. CI is applied in this level, often demonstrated by the PDCA (Plan, Do, Check, Act) learning cycle (Deming, 1986). The fourth and highest level, according to Dale (1999), is that of TQM, which involves the application of quality management principles in all aspects of the organisation, including customers and suppliers.

Yet another way to describe quality transformation is the Juran Trilogy (Juran and Gryna, 1988), a trilogy of managerial processes analogous to finance management: (1) Quality Planning (create a process that will be able to meet established goals and do so under operating conditions), (2) Quality Control (prevent the waste from getting worse, meet quality goals during operations), and (3) Quality Improvement (breaking through to unprecedented levels of performance), see Figure 18. The phases are interrelated and intended to find what the author calls fitness for use. It should be noted that Juran’s study has been criticised for not being scientifically conducted, a common flaw in quality management (Klefsjö et al., 2008). Nevertheless the trilogy is presented in this thesis as it serves as a useful model to illustrate three vital issues connected to the off-site construction sector, i.e. (1) inability to state the level of chronic waste within a firm, (2) a culture of fire-fighting of sporadic spikes that is confused with systematic improvement work, (3) inability to apply recognised sustained and effective quality improvement strategies.
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The Juran quality trilogy, from Juran and Gryna (Juran and Gryna, 1988).

The QMS approach should encourage the company organisation to analyse customer requirements, work with the processes that result in products that are accepted by customers and to continuously manage these processes towards improvement. QMS is supposed to constitute a foundation for CI in order to enhance interests of customers and other stakeholders. Where stakeholders can be defined as (Bergquist et al., 2008):

“...a subset of interested parties that are capable of causing the organisation to fail or inflicting unacceptable damage if their interests are not satisfied.”

The authors propose stakeholder concern to constitute a management field separated from TQM. However, quality work in accordance with the ISO standard could also be conducted as a routine exercise without any thoughts of implementing a system for continuous improvement (Nee, 1996). The result will then be management of documentation aspects of achieving or maintaining ISO certification rather than reaching desired performance goals (Gustafsson et al., 2001; Lam and Ng, 2005).

3.3.2 Lean production

The Lean production concept was introduced in 1990 by Womack et al. (2007) in the book The machine that changed the world, which resulted from a five-year benchmarking study conducted at Massachusetts Institute of Technology (MIT), regarding car production all over the
3 Theoretical framework

The machine that is referred to in the title of the book is Toyota’s product development, supplier management, customer support, and manufacturing processes collectively. Lean production is thus based on, and influenced by, the development of the Toyota Production System (TPS) created by Taiichi Ohno in the 1950s (Ohno, 1988). TPS and Lean production are actually different descriptions of the same concept, but TPS is related to the Japanese manufacturing culture and Lean production is related to the American view of what TPS consists of. The basic definition of Lean production seems to differ, but it is often essentially: “waste elimination and value creation” (Womack et al., 2007). The key characteristic is the use of less resources, as input to a less demanding manufacturing process, and demand for higher performance as output, resulting in enhanced customer satisfaction and (hence) a higher market share (Katayama and Bennett, 1996).

The Lean concept is considered by Green (1999) to be too extreme for the western world, only suitable for the Japanese industry were the work force is driven hard. The customer benefits of efficiency in production are also questioned as customer choices are often reduced (Piercy and Morgan, 1997). The book Lean thinking by Womack and Jones (2003) completed the Lean concept by presenting five guiding Lean principles of production: (1) value, (2) value stream, (3) flow, (4) pull, and (5) perfection, see Table 8.

Table 8. Lean principles of production, developed from Björnfot (2006).

<table>
<thead>
<tr>
<th>Principle</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specify value</td>
<td>Provide the value actually desired by the customer</td>
</tr>
<tr>
<td>Identify the value stream for each product</td>
<td>Identify, for each product, the sequence of actions needed to bring value to the customer</td>
</tr>
<tr>
<td>Make the product flow without interruptions</td>
<td>Line up the steps in the value stream in a continuous flow, everything disturbing the flow or not adding value is waste.</td>
</tr>
<tr>
<td>Let the customer pull value from the producer</td>
<td>Let the customer ask for the product or service and then work backwards to bring the product, i.e. pull value from the firm</td>
</tr>
<tr>
<td>Pursue perfection</td>
<td>An endless search for eliminating waste</td>
</tr>
</tbody>
</table>
These Lean principles are best mastered when the importance of people is recognised (Womack and Jones, 2003). Veech (2004) and Mann (2005) argue that Lean tools and practices should be mainly applied in order to improve the people involved; focusing merely on results will cause poor follow-up, lack of interest, no ownership of improvements and diminishing productivity.

Lean production is presented by its advocates (Womack and Jones, 2003) as the third significant production form after craft production (one-piece flow) and mass production (as pioneered by Henry Ford). The Lean epithet is chosen because lean production aims to continuously use less of everything. Further, it is said to result in fewer defects, as problems are visualised, while producing a growing product variety (Womack et al., 2007). To achieve this, work should focus on production, product development, supply and distribution. Liker (2004) published *The Toyota Way*, in which 14 management principles are presented that should aid companies in the transformation to become Lean (not to be confused with the 14 points presented by Deming, 1986).

According to Liker, TPS is a formalisation of “The Toyota Way” management philosophy used by the Toyota Corporation. “The Toyota way” comprises vital managerial principles regarding TPS, captured and organised by Liker (2004) in the 4P model, see Figure 19.

![Figure 19. The 4P model, developed from Liker (2004).](image)

The four P’s are often illustrated as a pyramid starting at the bottom with (1) Long term *Philosophy*, (2) The right *Process* will produce the right results, (3) Add value to the organisation by developing your *People* and partners, (4) Continuously solving root *Problems* drives organisational learning. This arrangement implies that the 4th P should
be implemented last, since it is on top of the pyramid, and fundamental when trying to understand how quality can be enhanced by minimising defects and mistakes.

The principles connected to the fourth element at the top of the pyramid, problem-solving, are (Liker, 2004):

− Go and see for yourself to thoroughly understand the situation.
− Make decisions slowly by consensus, thoroughly considering all opinions, implement decisions rapidly.
− Become a learning organisation through relentless reflection and continuous improvement.

At Toyota, seven major types of waste are identified as non-value adding in business and manufacturing processes, and Liker (2004) added an 8th:

1. Overproduction. Producing items for which there is no order creates storage.
2. Waiting. Unproductive workers, due to e.g. bottlenecks or stock outs.
3. Unnecessary transport or conveyance. Inefficient transport of goods or moving materials in or out of storage.
4. Over processing or incorrect processing. E.g. waste is generated when goods of higher quality than required are produced.
6. Unnecessary movement. Looking for, searching for, and reaching for tools or material. Walking is considered waste.
7. Defects. Production of defective parts or correction. Repair or reworking, scrapping, replacement production, and inspection mean wasteful handling, time, and effort.
8. Unused employee creativity. Losing time, ideas, skills, improvements, and learning opportunities by not engaging or listening to your employees represents a waste of human potential.

Ohno (1988) considered overproduction as the fundamental waste since it causes most of the other wastes (Liker, 2004). The list of wastes is again complemented with making-do (Koskela (2004). Making-do is
3 Theoretical Framework

defined as a situation where a task is started without all its standard inputs, or the execution of a task is continued although the availability of at least one standard input has ceased. Bicheno (2004) added a further waste; making the wrong product efficiently, which may arise when products that do not fulfil customer requirements are made.

Lean philosophy can be implemented in either a tool-based or flow-based manner. The tool-based approach is where a set of tools assist in the elimination of waste, enhancement of quality, and reductions in production time and cost. Lean implementation is criticised for having a tendency to concentrate on training people to use tools and techniques while focusing too little on understanding the human factor and building the right culture (Dahlgaard and Dahlgaard-Park, 2006).

The flow-based approach, applied by Toyota, represents implementation of flow in production, which exposes quality problems along with implementation, making the flaws expose themselves. The tool-based methodology focuses on getting things from the employees, when a truly lean company focuses on improving people and offers something to the employee (Veech, 2004). This leads to the notion that Lean philosophy is two-folded, focusing on both performance and people. Lean practice is implemented through management, but getting the people to work in a Lean manner requires leadership (Mann, 2005; Dahlgaard and Dahlgaard-Park, 2006). Based on a longitudinal field study, a model for developing an effort to become Lean is proposed by Karlsson and Ahlström (1996), the identified elements are ranked in the following:

1. Elimination of waste: This is related to the purpose of Lean philosophy, to lower costs.

2. Continuous improvement: If the elimination of waste is the most fundamental principle of Lean production, then continuous improvement can be said to come next. The production system is constantly improved, perfection is the only goal. There is even a specific word in Japanese for constantly striving for perfection, Kaizen.

3. Zero defects: Although quality is, in itself, an important performance variable in Lean production, it is also a prerequisite for the production system. To be able to attain high productivity, it is essential for all parts and products to be fault-free from the start. The goal is to work with products that are fault-free through
the continuous improvement of the manufacturing process. Thus, zero defects denote how a Lean company works in order to attain quality.

4. Just-in-time: Closely associated with zero defects is the principle of just-in-time, since the supply of fault-free parts is a prerequisite to achieve just-in-time deliveries.

5. Pull instead of push: Closely related to the principle of just-in-time is the way in which material flow is scheduled, through pull instead of push.

6. Multifunctional teams: A multifunctional team is a group of employees that can perform many different tasks.

7. Decentralised responsibilities: The multifunctional teams are charged with the duty of performing tasks that were previously carried out by employees in distinct departments.

8. Integrated functions: This means that tasks previously performed by indirect departments are integrated into the team, increasing the team’s work content.

9. Vertical information systems: Information is important in order for the multifunctional teams to be able to perform according to the goals of the company.

It should be noted that the 3rd step in the model does not mean that zero defects is a goal to become lean, it emphasises the importance of getting it right the first time. Fault-free means less expenses for waste, but a sole focus on producing a zero-defect product could in fact hide waste in production. Extensive efforts to correct defects commonly occur prior to construction project handover, this is a phenomenon the author has encountered in the off-site construction trade, due to sub-optimal customer focus, implying a need for a cultural change. Höök (2008) defines a Lean culture based on the notion that an overall goal of long-term profit is a means to prevent actors from favouring their own part of the process rather than the total process:

*Shared assumptions that the common goal is increased long-term profit, achieved by decreased costs and waste (performance), through a focus on customers and the people that create value.*

This is a distinct focus on cultural change in contrast to focusing solely on the customer, it also implies that production should aim towards a
simultaneous change in the mindset of management and employees. It should be noted that the same or similar components are presented in other management theories, e.g. the system of profound knowledge (Deming, 1993). Deming (1993) states that all organisations must be viewed as a system or network of processes. The goal is to optimise the entire system, rather than individual sub-systems or components. This statement forms the basis of Deming’s management theory “the system of profound knowledge” (Deming, 1993; Deming, 1998). There are three other parts of the system: variation, knowledge and psychology. Knowledge about aspects of variation is necessary when reducing variation in order to achieve a stable, predictable system. Theory of knowledge implies that information is not knowledge, and emphasises the importance of teaching people how to think on a continuous basis and not to assume any two problems are the same. The last part of this theory concerns knowledge of psychology, meaning leaders should understand human behaviour to motivate, coordinate and manage people to optimise a complete system.

3.4 Analytical model
As mentioned above, an analytical model was constructed to explain the connection between theory and the investigated problem of the relationship between continuous improvement and improvements in off-site construction. The theoretical framework underlying this model reflects a system thinking approach, which assumes the sum of the parts of a system to be less than the whole, where a system is a man-made network of processes that work together in attempts to accomplish the aim for the system. This reasoning is in line with the work of Contin (2006) and Deming (1998). It implies that off-site construction is challenged with handling a complex process when trying to learn from experiences. Following the reasoning by Garvin (1993) it could be stated that CI and experience feedback are closely interrelated, constituting vital components of a learning organisation. From the theoretical framework it is implied that the concept of experience feedback does not, in itself, constitute a framework for handling selection, sampling, refinement, and reuse of experiences. These are all aspects commonly read into the term, i.e. experience feedback is limited to identifying scenarios where experience is available (and hence it does not provide useful knowledge in itself). The actual infrastructure needed to handle and adopt knowledge gained from
experience is found in more extensive methods and techniques. Comprehensive methodologies, such as CI and Lean production are here seen as prerequisites for shaping learning behaviours and targeting useful experiences. The analytical model aims to visualise a system of how experience feedback could be incorporated in the improvement process, where balance between production efficiency and client effectiveness is sought, see Figure 20.

![Analytical model visualising the beneficial interaction between continuous improvements in the centre, experience feedback and overall improvement strategies.](image)

Learning from mistakes through experiences is here seen as a knowledge creating process, with structured learning behaviours as a process variable within the application of CI. Experience feedback is seen as input to the CI process, explained by aspects of learning and knowledge. CI constitutes a framework for handling the knowledge creating process. CI defines the learning behaviour, executed through systematic problem-solving i.e. the method of stepwise problem-solving, here seen as a vehicle for experiences. Lean production is included in the model as it is identified as a strategy offering a structure for modifying learning behaviours as well as constituting an infrastructure for knowledge dissemination.
4 FINDINGS FROM APPENDED PAPERS

This chapter presents selected empirical material and the main findings from each paper, a full description of empirical results can be found in the appended papers.

Main findings from appended Papers I to VI are presented here in order to recapitulate results from the conducted studies prior to meta-analysis in chapter 5.

4.1 Feedback in industrialised housing (Paper I)

In Paper I (Meiling and Johnsson, 2008) experience feedback practices in four off-site construction companies are investigated. From a Lean perspective defects represent waste. Follow-up regarding defects is a way of gaining perfection, but the study shows that within the investigated manufacturers defects are merely regarded as obstacles to closing projects. The companies strive to provide client value, together with a focus on streamlining production and minimising waste. However, the four companies investigated appeared (at the time of the study) to be still rooted in the construction culture without any implemented quality culture based on a belief of continuous improvement and follow ups.

The companies show similar patterns regarding feedback and learning behaviour. Information and knowledge are dependent on individuals and data are organised in a building-project basis. This is recognised as being effective while the project is current, but more problematic for reusing experiences after project closure. The companies producing timber modules, in contrast to a traditional builders, is often responsible for both design and production, thus providing the opportunity to seek and promote early design decisions that are compatible with production capability. However, alignment with the building system is often not achieved, even if cost-effective delivery of
projects is seen as imperative, thus there is a clear distinction between manufacturing and construction.

As the investigated companies take care of the whole construction process, i.e. the number of participating companies is less, there are greater possibilities for learning from experience, e.g. via feedback, and thus finding ways to improvement production within the companies. This could, in turn, provide a competitive edge towards other building systems and promote continuous improvement.

It was found that feedback initiatives have been taken by the companies, but not on a continuous basis, rather in an ad hoc fashion, dependent on individual initiatives. Examples of semi-discrete, recurrent feedback initiatives observed (Meiling and Johnsson, 2008) included:

- Meetings, with staff involved in design, prefabrication and assembly where discussions were documented with the intention of applying the records in further feedback analysis.
- Appointed groups, representing assembly staff, for contributing feedback and proposing new solutions back to production.
- Qualitative project debriefing documents filed with project material.
- Quality audits performed in the factory before transportation.

However, nobody deals with the incoming information from these initiatives in a consistent manner, or transforms it to engineering knowledge thereby changing the building system or even the production process. The various results from these initiatives are not analysed in a sustainable manner in order to promote continuous improvement, or implemented in production. Three quality audits of each product of the companies are executed, one in production (internal) before transport to the building site, one after finishing the building on-site and the third after the two-year warranty time (see Figure 21). These audits are documented and the resulting documents are stored in binders, in piles and in computer files.
The three audits are identified in the study as bearers of existing feedback information. The purpose of building inspections is to determine whether the contractor met the client’s procurement specifications. However, the building inspections are not evaluated and used as bearers of information by the companies. Two companies were chosen for analysing data from final and warranty audits. Within the audits only indoor building protocols were chosen, based on earlier studies from Sigfrid (2007), Persson (2006), and Josephson and Hammarlund (1999), see Table 9.

Table 9. Summary of inspection protocols.

<table>
<thead>
<tr>
<th>Company</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>Final audits</td>
<td>A 5 414 81 6.1 66 1/11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C 11 2415 877 3.1 63 1/7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warranty audits</td>
<td>A 5 66 81 1.1 81 0.4/2.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C 4 424 828 0.9 70 0.3/1.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The data in Table 9 show that there were large standard deviations in frequencies of defects, implying that quality is uneven in each project. Two difficulties were encountered when analysing the inspection audits, firstly in transforming the qualitative remarks to data, and secondly in translating each individually made defect remark. As the production phases of design, production and assembly are organised within the same company there are natural links for communication, but they are not utilised. Information is stuck in the system, accumulating at two bottlenecks, one regarding the transformation of
existing information and the other as a non-existent resource for product development.

The results of this study indicate that the companies lack a strategy for communicating feedback between design, factory and on-site assembly points. When focusing on defects in a Lean context the product development is as important as production, supply and distribution. Hence, the findings imply that product development is the missing link for functional feedback in the case study companies. Products are developed in a project-based fashion, and initiated by client demands related to each new project. Thus, the organisation at the companies offers great scope for experience feedback, but this is not currently functional.

4.2 Defects in off-site construction (Paper II)

Paper II (Johnsson and Meiling, 2009) reports an analysis of defects and problems recorded in inspection documents in two off-site companies. Examination of sorted defects from final and warranty audits clearly showed that dwellings had the most defects, which is not surprising since they constitute the major parts of the buildings. High proportions of defects were also recorded in common areas in the final audits (as can be seen in Figure 22), which is not surprising since common areas are constructed during on-site work, and thus their frequency will inevitably rise in the final audits.
4 FINDINGS FROM APPENDED PAPERS

Warranty audit

Figure 22. Where do defects occur? Examination of sorted defects from final and warranty audits.

The most frequent problems were clearly associated with walls and openings. Recorded defects included holes and mess on the walls caused by craftsmen, missing linings around doors and windows, and doors in need of adjustment because of movements in the structure. Of the grand total, 33% of all defects were related to walls, and 52% to walls or openings. Defects in interior installations emerged in the factory and final audits, and concerned objects that were missing or not properly installed. From the investigated final audits, almost half of the defects originated from factory production, followed by 35% from assembly activities. The type of defect is directly coupled to the cost to correct it, therefore it is interesting to grade the severity of the defect.

Figure 23 shows that many items were missing before delivery at the time of the factory audits (518 items in total, equivalent to 1.2 items missing/module, accounting for 42% of the defects recorded in these audits). Furthermore, many defects recorded in the factory audits concerned broken items (35%) that had to be corrected before the final audit. In the final audits, the lion’s share of defects concerned things that had not been delivered according to the contract (55%). On average, 79 items/project were listed as not to the client’s satisfaction in the final audits. According to the warranty audits, some 20 items/project did not meet contract stipulations. To qualitatively assess the costs of the defects for the contractor and establish another measure of the costs of correcting them, the measures taken to correct each defect were recorded. Most of the defects (51% of the total) were small, requiring only minor adjustments. Typical defects included stains, mess, small cracks and marks. The numbers of defects requiring
repair or exchange amounted to 9.6 % (260/2713) of the total. In the factory audits completion was the second most common measure to correct defects, which is unsurprising since many items were missing in that phase.

During factory production, most structural errors are directly connected to design errors, and long-term effects on the building system only become apparent after some time in service. Typical structural errors recorded in the warranty audits included cracks in corners and movements in the structure. Structural errors constituted nearly half of all the defects listed in the warranty audits, corresponding to 6 % of the grand total. For industrialised housing it is interesting to examine the number of defects associated with structural errors, since the structure is repeated, so structural errors affect every module produced. Such errors constituted 21 % (578/2713) of the defects.
During factory production, most structural errors are directly connected to design errors. Long-term effects on the building system only become apparent after some time in service.

Almost half of the defects recorded in the investigated final audits originated during the factory production processes, followed by 35% from assembly activities. Production in the factory is intense, and this is where attempts to optimise the work have primarily focused. Relatively little attention has been paid to the assembly phase, but this should be worthwhile, especially for company B, since many defects pertain to installations handled in the assembly phase.

Several reasons were identified in this study for the failure of the case companies to exploit the audit information. First, there are no explicit demands from clients or authorities. Secondly, there are cultural reasons (based on norms of traditional on-site and project-based construction), which influence the organisational culture of industrialised housing. According to Höök and Stehn (2008) this is related to lack of standardisation, lack of employee loyalty to strategies and a lack of top-management support and strategies. Efforts to identify defects and deviations are here demonstrated to have the potential to support improvements of process and product design, thus favouring both clients and companies in the long run, rather than merely getting one project approved and solely correcting finalised products in a firefighting mode. The conceptual benefits of industrialised housing cannot be achieved by focusing solely on external client value, while ignoring internal production efficiency and forgetting internal clients.

The struggle to improve quality in construction should be linked to an improvement strategy. Production in the case study companies is done in a closed factory environment, while assembly and some finishing are performed at the construction site. The importance of being in control of the entire defect recovery process is demonstrated in this study, and supported by findings of Love and Josephson (2004). From a learning perspective these companies could benefit more from applying organisational (company) learning than conventional construction companies (a conclusion supported by Kärrnä and Junnonen (2005), since the individuals, teams, clients and relationships involved in their projects are more constant and controlled. Altogether, several key ingredients required for advancing and exploiting experience feedback and to implement learning behaviours, i.e. CI, are present. This could
provide a competitive edge with respect to other building systems and promote long-term quality.

4.3 Feedback model (Paper III)

Paper III proposes a feedback model for off-site construction application. The initial studies (Meiling and Johnsson, 2008; Johnsson and Meiling, 2009) showed that constituents of a feedback model should be based on a KM framework of experience data capture, transfer and “evolution” into knowledge, implying it should provide learning behaviours. In addition, the model should link "contextual" information, such as where, why, what and when defects occur, as demonstrated in Johnsson and Meiling (2009). In addition the model should cater for analysis "activities" (such as statistical, root cause and risk analysis) and identified feedback "targets" among both internal and external customers. The core activities should be to identify targets for feedback followed by data capture, analysis and implementation stages, see Figure 24.

Figure 24. Proposed feedback model for capture and analysis of experience data.

Theoretical considerations combined with empirical data show how analysis of error-detection supported by the proposed model can enhance possibilities for prioritising improvement actions as well as identifying feedback targets. Thus, through live capture and incorporation of contextualised data the proposed model will promote interaction between tacit and explicit knowledge. In that way creating
new knowledge, as described by Nonaka et al. (2000). Theoretical considerations and empirical data show how analysis of error-detection can enhance the scope for prioritising improvement efforts. In addition, it could facilitate identification of the appropriate receivers of specific kinds of information.

4.4 Digitalisation of inspection data (Paper IV)

Paper IV (Lundkvist et al., 2010) presents a study in which management personnel in construction companies were surveyed to assess the extent to which their companies currently recognise inspections as not just a compulsory step towards project handover, but also as a good source of experience data for CI. Contractors need to make continuous improvements, and it is suggested that many improvements could be facilitated by knowledge about common defects. Contract (final and guarantee) inspections are already mandatory activities in the Swedish construction industry, and conducted on a regular basis, but the information they provide are generally used solely to correct defects before handover to the client. It is demonstrated in Johnsson and Meiling (2009) that existing defect notations are a neglected source of quality improvement information. Statistics can be drawn from the current paper-stored data, but the current practice is too resource-consuming and difficult for this to be really powerful and more widely applied.

The main findings from Paper IV, Lundkvist, Meiling et al. (2010), include the following. Twenty-five (out of 41) respondents stated that most of their companies’ production is conducted on-site. Nearly 60% (24 out of 41) stated that their companies were ISO 9000 certified, four were not certified, but applied ISO 9000 standards anyway, and 11 stated that their company had developed their own QMS. Results show that inspections were regarded as the least important source of new knowledge and project-related experience, see Figure 25.
Figure 25. Most important sources of knowledge and project-related experiences among the companies, according to survey respondents.

The findings can probably be explained by lack of practice to access relevant knowledge from inspection reports, and it is a strong indication that there is potential for future development in this area. Furthermore, 63% stated that their company did not have a system for compiling defect data from inspections, but nevertheless 80% agreed or fully agreed that their company had an expressed goal to reduce the number of defects in inspections. In addition, 46% agreed or fully agreed that their company actively analysed root causes of defects.

76% percent agreed or fully agreed that their company regarded inspection defects as valuable information, while as many as 88% personally agreed or fully agreed that defects reported from inspections provide valuable information. It seems that the respondents mostly agreed with the official company standpoint on inspection data, and the common opinion was that useful information is hidden in the reports.

However, 51% of the respondents disagreed or fully disagreed that their company made use of the defect data in their improvement work, although 62% stated that their company regarded the information as useful, and 71% that their company has an expressed goal to reduce the number of defects in inspections, see Figure 26.
These findings raise questions about the discrepancies. It is remarkable that half of the respondents felt that their company did not make any use of inspection data for improvement, although most of them regarded the information as useful, and up to 80% of the companies even have expressed goals to reduce defect rates. A possible explanation is that the companies do not know how to proceed according to their intentions.

Only 34% stated that their respective companies are compiling statistics about defects. As many as 90% agreed or fully agreed that the use of defects data in their company could be further developed. In responses to a question regarding whether or not they felt assured that defects from one project would not appear in future projects, 54% disagreed of fully disagreed. 56% agreed or fully agreed that their company needed a supporting IT system to better manage information from inspections, while 34% did not agree.
It is not surprising that so few contractors are mining statistics from inspection data. Obtaining relevant information from current manually compiled, paper-based data sources is highly resource-demanding. Hence, the results may reflect unease about the current situation, and awareness that something has to be done, combined with resistance to implementation of an appropriate IT system.

A total of 26% chose to answer the open-ended questions about inspections. The responses were categorised according to the stated accessibility of the inspection data, see Figure 27. The answers imply that many companies have started to store inspection reports, in formats such as project portals, a first step towards a more intelligent solution. Data stored in this way cannot be directly searched and the mining of statistics is still manual, but they are more accessible than in papers contained in a binder in some office.

![Figure 27. Codified results from open-ended questions on inspection data storage.](image)

The responses concerning the way in which companies use information about defects show that most companies try, in some way, to note the most common defects and to solve the root causes, but without formalised routines, see Figure 28. The empirical data gathered in this study suggest that there is a strong opinion among the contractors in general that inspection data provide valuable information. Some also try to use it for experience feedback and continuous improvement, but most companies lack a system or process to support the feedback of experience-based information provided by inspections. It is clearly in the interest of the contractor to develop and implement experience feedback systems that support the input of
inspection data for continuous improvement. This requires the inspectors to conform to the implemented systems, i.e. defect data must be delivered in an appropriate format.

![Bar Chart]

**Figure 28.** Codified results from open-ended questions on inspection data usage.

Strategic use of information-communication-technology (ICT) through hand-held computers is a possibility to promote efficient problem-solving, i.e. IT support for experience reporting and defect analysis, in which large amounts of data can be obtained and analysed.

### 4.5 CI through SWPS (Paper V)

Paper V (Meiling et al., 2010a) describes a study in which SWPS was applied in three off-site construction cases. Experience feedback conducted through SWPS in the three case examples brought the company units closer together. For example, the understanding of internal customer interconnection was improved. As a consequence, new routines were introduced. In accordance with the wide promotion of management personnel visiting the working place in lean literature, design personnel and management were requested to visit sites where problems occur. Through the problem-solving process actors realised the value of this procedure through experience.

Simple things make SWPS effective, i.e. a problem-solving stepwise procedure and the use of pictures and diagrams to visualise problems and acquire an overview of processes in which they arise. Other important aspects are involvement of the persons conducting the problem-solving and a systematic approach to the method. Another important aspect is avoiding personnel spending time addressing
problems that they are unable to solve, when it is better to let other kinds of personnel address root causes.

In order to develop a fully-fledged CI approach, off-site construction companies need to first establish an approach for standardised work, as it is a vital part of the SWPS method. Structured CI, as described by Bessant et al. (2001), also challenges a company to make extensive managerial changes. The most important function of SWPS is to establish a stabilised level in off-site production, from which the next level can be attained through CI efforts. In this sense it contributes to CI as an emerging and learned pattern of behaviour that evolves over time. The case companies have not reached the second stage of CI evolution described by Bessant et al. (2001), but have made an effort to leave the first stage, in which all CI activities are conducted ad hoc.

From a construction design perspective there is a lack of working processes for preventing the reoccurrence of poor solutions. From a production perspective there is a lack of tradition regarding routines for filing and compiling problem reports, documenting deviations, and defects (Meiling and Johnsson 2008). The current situation is a state where experience data are pushed out to the organisation instead of being pulled in by needs of the organisation. The gap between design and manufacturing must be understood and eventually minimised to optimise product effectiveness in module prefabrication, a problem also reported in other industries, e.g. the aviation and automobile industries (Blessing and Wallace, 1998; Andersson and Isaksson, 2008). SWPS can help close this gap.

The SWPS method was shown to identify root causes. The various problems generated pull for experience data, and acted as vehicles for experience feedback for both internal and external customers, in a feedback-generating loop. Communication was improved as it was demanded by the SWPS activity. In addition, SWPS was seen to facilitate identification of the appropriate receivers of specific kinds of information, because of tacit knowledge in the problem-solving group. SWPS in module prefabrication was shown to promote enhanced process knowledge about upstream and downstream effects of problems, and thus contributed to an overall goal of improving business results.

Maintaining a strategy of improvements will be challenging for many off-site construction firms. They need to learn about data collection
and analysis, and allocate time and resources in the organisation to conduct problem-solving and system redesign work. The management of SWPS in the case examples was supervised by one of the authors, but as yet no decision has been taken to appoint and educate problem-solving leaders, or even one person responsible for communication, in either of the two case companies. Moreover, many of the “problems” experienced are associated with relationships among internal customers, and often the optimal solutions lie in changing how work is performed in other departments. Perhaps the biggest challenge is to change the culture; the companies must move away from the prevailing firefighting, quick fix mentality and commit to the planning stage of SWPS. CI through SWPS has proven to be effective, therefore the right circumstances must be created to adopt it. However, more islands of success can contribute to change, as shown in the case studies.

4.6 Lean management and CI (Paper VI)

The aim of Paper VI (Meiling et al., 2010b) was to test a method measuring to what extent Lean management, via the 14 management principles is applied in off-site construction, see Table 10. Another aim has been to identify strengths and areas with scope for improvement. In this study, personnel at two Swedish off-site construction companies were surveyed. As representatives of off-site construction companies, two medium-sized, timber-framed module prefabrication firms in Sweden were studied. Two companies were considered sufficient to generalise the method. The case study results provide an overview of conditions within the studied companies. To be able to present more generalised and detailed results a more extensive survey involving several companies, as well as more in-depth case studies, and more questions related to each principle would be needed. The results highlight several aspects of interest that management should be aware of when implementing Lean manufacturing in off-site construction. They show that the companies have made good progress considering the short time that they have been implementing Lean production (one and two years, respectively, at the time of the study) and seem to building a good basis for further Lean implementation. The benefits of introducing the Lean concept with a holistic approach are also shown in this study.
Table 10. Four categories and 14 principles from Liker (2004).

<table>
<thead>
<tr>
<th>Four categories</th>
<th>#</th>
<th>14 principles</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1 Long-term philosophy</td>
<td>P1</td>
<td>Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals</td>
</tr>
<tr>
<td>C2 The right process will produce the right results</td>
<td>P2</td>
<td>Create a continuous process flow to bring problems to the surface</td>
</tr>
<tr>
<td></td>
<td>P3</td>
<td>Use pull systems to avoid overproduction</td>
</tr>
<tr>
<td></td>
<td>P4</td>
<td>Level out the workload</td>
</tr>
<tr>
<td></td>
<td>P5</td>
<td>Build a culture of stopping to fix problems, to get quality right the first time</td>
</tr>
<tr>
<td></td>
<td>P6</td>
<td>Standardized tasks and processes are the foundation for continuous improvement and employee empowerment</td>
</tr>
<tr>
<td></td>
<td>P7</td>
<td>Use visual control so no problems are hidden, i.e. 5S (sort, straighten, shine, standardise, sustain)</td>
</tr>
<tr>
<td></td>
<td>P8</td>
<td>Use only reliable, thoroughly tested technology that serves your people and processes</td>
</tr>
<tr>
<td>C3 Add value to the organization by developing your people and partners</td>
<td>P9</td>
<td>Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others</td>
</tr>
<tr>
<td></td>
<td>P10</td>
<td>Develop exceptional people and teams who follow your company's philosophy</td>
</tr>
<tr>
<td></td>
<td>P11</td>
<td>Respect your extended network of partners and suppliers by challenging them and helping them improve</td>
</tr>
<tr>
<td>C4 Continuously solving root problems drives organizational learning</td>
<td>P12</td>
<td>Go and see for yourself to thoroughly understand the situation</td>
</tr>
<tr>
<td></td>
<td>P13</td>
<td>Make decisions slowly by consensus, thoroughly considering all options, implement decisions rapidly</td>
</tr>
<tr>
<td></td>
<td>P14</td>
<td>Become a learning organization through relentless reflection and continuous improvement</td>
</tr>
</tbody>
</table>

The 4P model, see Figure 29, in itself shows the importance of a holistic view to become Lean. The scores awarded by production personnel indicate that the off-site construction personnel are dedicated to the company business. The focus on and deployment of a long-term philosophy is essential to obtain sustainable improvements. However, seven of the 14 management principles are focused on the process perspective, while the philosophy is only covered by one principle. This distribution of principles might be interpreted by management that the main focus should be on the process, which is not sufficient if the aim is to excel in CI.
Managing the 14 lean principles can be seen as a prerequisite for sustainable improvements, to reach C4, i.e. where the company continuously solves root problems and becomes a learning organization. From Figure 30, it seems that both companies have progressed towards becoming a learning organization (although management A might be more enthusiastic about the concept than in production practice).

The scores from the production personnel indicate how well management has succeeded with the implementation of Lean practice within the company. Even when management gave low scores for one principle, the production personnel at the same company could give the same principle higher scores, e.g. P1, P8 and P13, see Figure 31. Even if management commitment is an essential driving force to implement change, the study indicates that Lean philosophy should be implemented via both a top-down and bottom-up approaches.
This study shows that the top of the pyramid in the 4P-model must emerge and evolve simultaneously with its “prerequisites”, see Figure 29. This is an important insight as it could affect the way management chooses to implement Lean production. The questionnaire would gain considerable interest if it further clarified the strengths and weaknesses regarding context and method, as well as the top-down and bottom-up weaknesses within an organisation. This would inevitably require a larger number of questions, which in turn would complicate practical aspects of questionnaire completion and collection. The scores for responses by the production personnel indicate that they are dedicated to the company business, which is a major strength when implementing organizational change, i.e. an important prerequisite for implementing Lean practices. This should be considered by the management, especially since the construction business/culture is heavily based on craftsmanship and individual work tasks.
5 CROSS-PAPER ANALYSIS AND RESULTS

This chapter describes cross-paper analysis of the results presented in Papers I-VI, using the theoretical framework, and the analytical model presented in Chapter 3.

The theoretical framework in Chapter 3 was used to construct an analytical model, illustrated in Figure 32. The cross-paper analysis was conducted based on the theoretical understanding of CI as an evolving learning process that is semi-structured in the sense that it involves both structured methods, such as SWPS, and contextual elements, e.g. management efforts. The use (and value) of CI as a incremental improvement strategy have been well documented. However, it is not always successfully implemented, mainly due to shortcomings in managerial efforts according to Salah et al. (2010). This may be because the methodological elements can be formalised, but the behavioural execution of the methods requires training and evolving skills that need management. A comparison of the theoretical framework and empirical findings of this project revealed three misconceptions (see Figure 32), which can be regarded as hindrances for implementation of sustainable CI.

![Analytical model](image)

*Figure 32. Analytical model, showing points at which the three misconceptions arise, as discussed in sections 5.1 - 5.3.*
The conducted studies reveal a desire among the investigated companies to incorporate experience feedback in the working routines, but this desire is not realised (Meiling and Johnsson, 2008).

5.1 Experience feedback

Successful utilisation of experiences (as illustrated in Figure 32), is input to structured problem-solving. The conducted studies showed that experience feedback, as a method for learning from mistakes, commonly fails in the investigated companies. Documentation initiatives have been launched in the investigated firms, as shown by survey I (Meiling and Johnsson, 2008). However, when personnel seek the information they do not feel that it is readily available as it is “hidden” in binders, computer files or the minds of colleagues.

The investigated companies have the possibility to exploit defects reported in building inspection documents efficiently, as they control the entire construction process, but existing defect notations appear to be a neglected source of information for quality improvement (Johnsson and Meiling, 2009). The inspection audits are mandatory in the Swedish construction trade, therefore since they are not used they represent unutilised information, i.e. waste. Actions are not taken on the premise that defects are indications of organisational shortcomings, i.e. signs of poor processes (Juran and Gryna, 1988). Neither is it recognised that the motives for focusing on defect reduction should be to reduce poor quality costs and improve quality and client satisfaction. Instead, the investigated off-site construction firms focused on defects in a fire-fighting mode, seeking to reduce correction costs.

Initiatives taken to summarise experience from conducted projects, reported in Meiling and Johnsson (2008), showed that current practice reflects willingness to create knowledge through learning from mistakes, but it is characterised by push of information into the organisation (Figure 35). In addition, the various practises regarding experience utilisation were investigated (Lundkvist and Meiling, 2010). This study found indications of widespread discontent regarding the way experiences are used within the construction firms, which could be related to a need to distinguish between different kinds of experience. Experiences are commonly stored within documents (and minds of certain individuals) associated with specific projects, and thus withheld from any learning activity, making the stored information
difficult to access as it consists of an unstructured mixture of non-targeted, relevant and non-relevant information with low contextual content.

Furthermore, as noted above, this difficulty in accessing and exploiting information is exacerbated by three misconceptions, which can be summarised as follows.

**Misconception 1: Documentation of experiences is itself a means for improvements.**

This misconception will inevitably tempt management to put even more resources into documentation management. However, filed text represents information, not knowledge. Thus, this kind of information does not, in itself, have the capacity to solve problems. Instead, the non-targeted experience information should serve as indications for potential problem-solving.

It is shown in Paper II that codified defects from quality audits contain information regarding how well construction processes operate (Johnsson and Meiling, 2009). This kind of experience data could instead serve as input for structured problem-solving. All case study companies performed quality audits at the factory before transport, in which anomalies were reported. External quality audits are also performed on the finalised building both at delivery and after a warranty period of two years in Sweden. However, there is currently no link between these audits back to events in the manufacturing process. Analysis of the audits is lacking. If data were transformed and coded at the building site when defects occur, they could be evaluated more consistently, but there is no designated recipient of sampled data and information. Product development is currently seen as a costly activity that drains resources from production, and undertaken primarily within each ongoing project, rather than being a distinct process. The result is ad hoc solutions regarding new problems, since full-scale product development is not possible on a project basis.

The lack of management related to quality monitoring results in difficulties regarding improvements of the construction processes. The daily rate of module production is the main measure of process efficiency. Problems associated with documentation and distribution of experiences were readily apparent during observations of activities at the construction site, as reported in Meiling and Johnsson (2008).
There is no system to record any corrected deviations, as there is no pull for this kind of information. In Meiling et al. (2010a) it was shown how the problem-solving setting initiated pull for collecting experiences, which resulted in identification of technical solutions (for problems associated with doors and windows) as well as standardised work. This indicates that transmitting experiences, identifying and applying technical solutions, and standardising work, are mutually beneficial, interactive activities.

However, the current action process to correct defects is rapid, with no reflection about the characteristics of the notifications in the audits. This failure can be connected to a lack of systematic problem-solving embedded in a strategy of continuous improvement. There is no process support regarding feedback in the investigated off-site construction firms (Jansson, 2010). The current state of practice does not involve the learning processes required to generate sustained improvements, i.e. SWPS. Instead, existing practice is focused on storing information — which can be regarded as a push strategy towards experiences (see Figure 35) — i.e. managing information in contrast to activating learning or creating knowledge. To improve the situation, design and production processes need to be supported with follow-up activities.

5.2 Continuous improvement

Continuous improvement is placed in the centre of Figure 32, since it is the focus in this thesis. CI involves learning behaviours with increased knowledge as output and experience feedback as input. A model for experience feedback was proposed in Paper III (Meiling and Sandberg, 2009), based on empirical findings from the off-site construction firms reported in Papers I and II (Meiling and Johnsson, 2008; Johnsson and Meiling, 2009), which implied a need for experience feedback. In addition, stepwise problem-solving was conducted in three cases described in Paper V (Meiling et al., 2010a). Quality management methods for structured problem-solving are denoted PDCA cycles or SWPS methods, and the latter were shown, in Papers III and V, to promote the four managerial features attributes for a system to create “profound knowledge”, as stated by Deming (1993):
5 CROSS-PAPER ANALYSIS AND RESULTS

**Appreciation**

The model incorporated retrieval of information (feedback) from all relevant sub-processes. This will ensure that sub-optimisation is avoided.

**Knowledge of variation:**

The model promotes learning through retrieval of performance data aimed to reduce variation, which requires knowledge of when variation originates from a common or specific cause, recognising that a zero defect goal is unproductive.

**Theory of knowledge:**

The planning phase of the model promotes abilities to predict if a planned change will be beneficial. This involves continuously challenging current practice when it fails to meet the sought outcome, and recognising that information is not knowledge.

**Knowledge of psychology:**

The last part relies on the premise that people rise to challenges, given the possibility and trust to learn and act. The proposed model should involve the people closest to the problem.

There are several existing models for structured problem-solving (see Appendix A), which promote a scientific mindset according to Shiba and Walden (2002), implying the generation of sustained results. This indicates the importance of applying SWPS in general (the choice of specific method is subordinate). However, no models or methods for structured problem-solving are currently utilised in the investigated companies, although they believe they are conducting improvements continuously (Lundkvist and Meiling, 2010; Meiling et al., 2010b).

**Misconception 2:** To continuously improve construction activities *ad hoc* is itself a means to reduce the level of chronic waste within a firm.

The conducted studies support the work of Bessant *et al.* (2001) describing the capability of learning through CI as an evolutionary process. Thus, it is proposed that focus should be on evolving learning skills through training and use of standardised procedures for problem-solving, in contrast to the current focus on techniques for storing experiences. IT tools and archives should be considered as support rather than solutions. In terms of the PDCA cycle, current practice
among the studied companies appears to involve very little planning and much “do”. Execution of CI procedures requires training, formalisation and improvement to be effective. It is reported in Meiling et al. (2010a) that communication was improved when the SWPS method was applied in the three cases, and new standardised solutions were implemented. Incremental improvements imply single and double loop learning at individual and team levels (Snell and Chak, 1998). The planning phase (see Figure 33) in the SWPS method implies conversion of tacit knowledge into explicit knowledge, which is referred to as externalisation by Nonaka and Takeuchi (1995). This was achieved through dialogue and common reflection, aligned with the knowledge creating reasoning of Davenport and Prusak (1998) regarding comparison, consequence, connections and conversation. Thus, the planning phase should involve the acquisition of information, comparison of the information to other known situations, investigation of implications for decisions, connection of the gained knowledge to what is known, and communication of the knowledge to others (Davenport and Prusak, 1998).

Figure 33. Stepwise problem-solving model from Meiling et al. (2010a).

The implementation phase (see Figure 33) of the SWPS model implies knowledge conversion from explicit to tacit knowledge, referred to as internalisation by Nonaka and Takeuchi (1995). This relies on the premise that problem-solving should be a shared experience, not a top-down commitment where solutions are “forced” on the affected personnel. The benefits of shared problem-solving are supported by Beyer Donde and Janice (1997). When problem-solving is not a shared experience and is conducted by an appointed PDCA manager, it implies a top-down approach and the learning and knowledge outcomes are limited. Such an approach was observed in the investigated companies, as reported in Meiling et al (2010b).
Knowledge created from structured learning processes, i.e. SWPS, involves feedback of experience that is linked to the sought improvement. CI promotes a pull state for experience and enables the creation of knowledge with both tacit and explicit elements (see Figure 35). Some of the knowledge is formalised in standardised work and processes, but transmission of the tacit parts requires an infrastructure that promotes socialisation according to the SECI model (Nonaka et al., 2000), see Figure 33 in this thesis. The beneficial interaction between systematic problem-solving and experience feedback is supported by Garvin (1993), who holds them to be vital activities in efforts to become a learning organisation. Thus, SWPS clearly supports incremental improvements. However, it does not, in itself, guarantee alignment to company goals. Continuous improvement procedures, per se, do not encompass the infrastructure required to promote vital interactions between people, processes and goals, hence it must be augmented with appropriate, structured management support (Salah et al., 2010).

5.3 Lean production

Lean production is the overall improvement strategy applied in the studied companies. In Figure 32 it is visualised as a supporting process above continuous improvement, reflecting its overarching importance for sustained CI application. Lean production focuses on waste elimination and value-adding activities, i.e. efficiency. The managerial efforts of Lean production are focussed on long-term thinking, people and processes, all of which are important for CI application (Imai, 1997). Implementation of Lean production is partly methodological, i.e. tool-oriented, and partly contextual, i.e. reliant on managerial actions and the way people choose to embrace the concept. The methodological part involves aspects such as optimising production layouts to ensure flow, finding out how to achieve pull, visualising the workplace, evening out pace, standardising work, and implementation of problem-solving procedures. These actions are measurable. However, long-term benefits are achieved through managerial actions, e.g. aligning long-term company philosophy and goals with daily work, i.e. policy deployment (Akao, 1991). The combination of management and method supports learning, communication and collaboration between different actors (Witcher, 2003). In addition, it
implies a holistic approach to Lean production that focuses on improved knowledge transfer and common problem-solving.

Choo et al. (2007b) suggest that generic contextual efforts should focus on supporting leadership, resource availability, challenging work, and trust. Contextual efforts (i.e. management to foster Lean production) connected to the straightforward methodological part of Lean production are expressed and visualised in the 4P model by Liker (2004). This model is misleadingly shaped as a pyramid, indicating that emphases on long-term thinking, processes and people are prerequisites for creating a learning organisation focused on continuous improvement.

**Misconception 3: CI methodologies should be applied when all processes are controlled.**

The model, with its 14 managerial principles, was investigated in Meiling et al. (2010b), and the results indicated that continuous improvement capabilities and long-term thinking were equally important for supporting processes and people (see Figure 34). Stabilisation of processes requires long-term commitment, the outcome of which should be a level of standardisation that is suitable for the specific off-site construction company. CI is a key element of this process, since it is an inherently problem-solving activity that facilitates the identification of processes that should be adjusted.

![Figure 34. The problem-solving capacity is visualised as evolving simultaneously with people and processes, relying on long-term thinking. Developed from the 4P-model (Liker, 2004).](image)

The figure represents a top-down and bottom-up approach towards Lean management, in which the ability to extract experiences and solve problems evolves in alignment with managerial efforts and long-
term goals. An overall improvement strategy should not be simplified into a tool-based improvement strategy simply aiming to reduce costs and tidy up the working place (Veech, 2004; Mann, 2005). This is a misreading that will only provide short-term productivity gains. The importance of holistic managerial support regarding sustained CI efforts is supported by Salah et al. (2010). Different implementation strategies were chosen by the companies considered in Meiling et al. (2010b), one adopted a tool-based approach and the other a holistic approach. The holistic implementation was applied by a family-owned company in which management and production personnel were situated in the same location, while the tool-based approach was applied by a company that is part of a larger company group, hence management and production personnel were partly separated. Results presented in Paper VI (Meiling et al., 2010b) support the importance of embracing the contextual aspects of Lean production, i.e. a holistic approach.

Lean production provides an infrastructure for disseminating knowledge throughout the company. An overall improvement strategy such as Lean production supports continuous improvement by aligning learning activities towards long-term company philosophy and goals to avoid sub-optimisation.

5.4 Summary

Figure 35 visualises a summary of the cross-paper findings. Theoretical considerations and empirical results explain how problem-solving through SWPS constitutes a learning process for tacit and explicit knowledge creation, formalised in improvements.

Push for experience is characterised by storing information with low contextual content, representing “weak” explicit knowledge. This kind of information is difficult to access in a problem-solving situation. In Paper IV (Lundkvist et al., 2010) it is shown that stored quality audits are “pushed” into storage, even though management rank them as valuable, and they contain information that could identify potential problems (Johnsson and Meiling, 2009).

Pushed information has the potential to support CI, provided that only structured codified information is used for this purpose, but this is hindered by lack of a managerial strategy for handling and screening experiences.
Pull for experience represents the activation of retrieval of information from internal (construction processes) and external customers (clients) in a problem-solving situation. Pull is activated because experiences are demanded in the SWPS method, as visualised as the PDCA cycle in Figure 35. This implies a need to identify and prioritise the problems to solve prior to attaining experiences. These activities follow the construction process, i.e. it involves the people closest to the problems, as demonstrated in Paper V (Meiling et al., 2010a). Both management and production personnel are focused on the production process and its outcome, the methodological part of CI, i.e. SWPS, supports this since it is focused on the learning activities connected to production.

The implementation and maintenance of effective CI through SWPS require management support (visualised in Figure 35 as contextual elements). In Lean production these elements are promoted by the 14 managerial principles (Liker, 2004). Results obtained using the assessment method presented in Paper VI (Meiling et al., 2010b) demonstrate the beneficial interactions between appropriate methods and context. Lean principles, in this respect, can be regarded as
facilitators of streamlining production processes and (hence) learning behaviour. Thus, it is proposed that interplay between stored information, appropriate methodological elements and contextual elements will enable CI to evolve within the company. Focus on learning behaviours through CI promotes pull for experiences, where management of information (storage of information, Figure 35) is to be regarded as supporting sub-processes. The main CI process is connected to the way work is conducted and is based on methods and context. This understanding has been gained from investigating the production process from the perspective of experience feedback and continuous improvement. The cross-paper analysis confirms the theoretical understanding of CI as a series of learning events, but the focus of this thesis is the practical implications of applying CI, so the conclusions stated in the next chapter are focused on several distinctions and clarifications. These are stated as inspirational rather than universal truths, which should allow the investigated firms to form their own body of commitment towards CI and experience feedback, since the evolution of CI capacity within a firm needs to be shaped according to the context (Salah et al. 2010).
5 Cross-paper analysis and results
6 Discussion and Conclusions

This chapter discusses the implications of the cross-paper analysis, and presents the fulfilment of the aim and research questions.

Off-site construction is not, by itself, a source of sustainable advantage compared with on-site construction. Pan et al. (2007) have documented a number of perceived barriers for clients choosing off-site construction strategies, e.g. a lack of trust in the methods, while Levander et al. (2010) identify a lack of trust among clients towards off-site construction, in terms of high perceived life-cycle costs.

Experience feedback and CI are important for understanding and eliminating these barriers. The conditions for utilising experiences and learning from mistakes in off-site construction are favourable compared to those in on-site construction. In off-site construction personnel work in the same environment from one project to another, and there is more repetition, hence there is clearly scope to enhance interaction and apply process control as a basis for continuous improvement. Learning and CI thus offer potential competitive advantages in the off-site construction sector. However, these advantages are not fully utilised within the investigated companies.

The overall aims of this thesis, and the underlying studies, have been to describe and understand how CI, including experience feedback, can be applied in off-site construction. The discussion and conclusions are based on the author’s evolved understanding of CI as a learning framework. The scientific contribution of this thesis is to visualise how CI relates to off-site construction, applying an understanding of CI gained by studying aspects of learning and knowledge that have clarified how different formats of experience feedback interact to promote sustainable CI. The beneficial interaction of an overall improvement strategy has also been considered.
The industrial contribution is to state misconceptions and present conceptual models, as guidelines for the application of CI and problem-solving in off-site construction. The importance of shared conceptual models for learning are emphasised by various authors, e.g. Stata (1989). The conclusions confirm established aspects of learning and knowledge regarding experience feedback, problem-solving and continuous improvements. However, the way that experience is communicated is also important, i.e. a system view incorporating the whole process of incremental improvements is essential.

6.1 Experience feedback: A need for distinction

The large amount of experiences produced in each construction project implies difficulties to make them flow towards improvements. The current practice of experience feedback in the off-site construction industry is not efficient. This could be related to a misconception of the term, signalling a need to distinguish between what experience means from learning and knowledge perspectives. Based on the studies presented in this thesis, the following distinctions can be stated.

**Distinction 1:** Experience feedback can either identify potential problems or contribute to problem-solving. This is a useful distinction because it helps to define the requirements for transmitting the tacit and explicit content of the experience. Identification of potential problems involves procedures such as statistical representation of defects from quality audits. Feedback in a problem-solving situation is driven from the problem formulation and involves personal meetings where tacit knowledge, as well as statistical information, can be transferred.

**Distinction 2:** Experiences have both tacit and explicit components. If these are separated there is a risk that their meanings will be lost. Hence the way experience is collected must be compatible with the way it is to be communicated.

**Distinction 3:** Experiences are communicated through media of some form, i.e. verbally through meetings between humans or through some kind of documentation. Hence, the intended recipient(s) must be clearly identified.

**Distinction 4:** Feedback of experience relies on the premises that a person realises that he or she needs it, and it is available in an
appropriate format e.g. verbal or documented information. Hence, management must ensure that experience-based information is both compiled in an appropriate format, and made available to relevant recipients.

An example is presented for the 4th distinction. There is no connection between stored experiences, e.g. from post-project meetings, and individual working situations where problems need to be solved. Post-project evaluation cannot be regarded as a feedback initiative, unless it is processed or targeted to someone. However, this is not a common scenario. Once the experience is stored within a project file, much of the tacit components are lost. A strategic decision regarding experiences must relate to standardisation of processes, since unstable processes are the main sources of defects and mistakes. This enables a shift towards storing experiences related to identified processes that involves a team rather than individual needs anywhere in the organisation.

From the four stated distinctions a company can plan its actions regarding feedback of experiences. A conceptual model for this could be outlined as follows.

**Only needed experiences fuel the process of continuous improvement.**

This statement is a reflection of the initial research question, and encapsulates the four distinctions stated above. It implies a need to focus on separating experience feedback initiatives that identify potential problems to solve and experience that helps to solve problems. Thus, managers must ensure that information is stored in a manner that is need-oriented, thus turning storage into a supporting process, providing a source of information to help identify problems. Experiences that can be used to solve problems are initiated by the identified problem, can then be readily accessed, facilitating the establishment of structured problem-solving and a learning environment for the staff. This could serve as a useful insight for shaping the experience collection initiatives within a firm.

**Conclusion 1:** Experience feedback is an evolving skill that supports CI if it is related to identified or standardised processes based on identified technical solutions.
The beneficial interaction between identified or standardised processes and identified technical solutions is a strong driver for experience feedback (excluding extensive IT solutions aiming to incorporate individual needs in regard to anticipated problem-solving). This relates to the fact that as yet there is no support system for making relevant experiences available to for each individual in a firm. A strategic decision should therefore be taken to ensure that individual needs for knowledge are met through social networking and personal archives (initiated by each individual). The conclusion also states that processes may be either identified or standardised. This is related to the ongoing work in the studied companies, in which a process-focused strategy has been initiated but not standardised.

6.2 Problem-solving: A need for clarification

It is found that CI through structured problem-solving can provide a useful framework for further advancement, in the field of incremental improvements. Efforts to make improvements, through problem-solving, are being made within the studied companies on a regular basis, but more needs to be done since the level of chronic waste has not been shown to decrease, which could be related to a misconception of the term problem-solving. This signals a need for consensus regarding how improvements should be conducted, i.e. formalisation of the methods and tools that promote systematic problem-solving. The SWPS method has been shown to constitute a formalised learning behaviour procedure for solving problems related to processes or products. The execution of problem-solving, among personnel closest to the problems, creates pull for experience feedback. This implies handling experiences involving both tacit and explicit parts. However, during the studies the following questions were raised by personnel regarding the key, but time-consuming, activities of SWPS, which indicate a need for management clarification.

*Why should problem-solving be structured and formalised?* This question was raised as personnel within the studied companies have the ability to solve problems that confront them. Indeed, tackling problems is embedded in construction culture. The answer is that this ability needs to be redirected by management in order to encourage staff to base decisions on facts, to engage in cross-department communication, and
to predict the outcome of changes, i.e. their implications for internal and external customers.

*Why should it be a shared responsibility?* Often a particularly creative and confident person is appointed to solve problems. This results in the presentation of ready-to-use solutions to work teams, but does not involve the persons closest to the problem, which has serious drawbacks since they have both tacit and explicit knowledge regarding the pertinent problems. Furthermore, problem-solving is a rewarding activity, i.e. people feel good when they solve an intrinsic problem. Hence, there is a need to identify staff who are “close” to problems, since they are best placed to solve them, and doing so will help motivate them. A complication is that construction sites are often situated far from the factory, so personnel cannot easily attend problem-solving meetings, thus there is also a need to appoint a person responsible for communicating information about problems and their (actual or potential) solutions, i.e. a process leader.

*Must all problem-solving be structured?* Usually, numerous problems are reported in a firm every day, thus problems need to be filtered and clustered in regard to severity. Many minor problems can be solved with simple tools like asking 5 whys. Further, in Meiling et al. (2010a) it is shown that a handful of severe problems can be successfully managed simultaneously. However, the study shows that appointing a process leader facilitates communication.

The answers to the questions raised constitute a clarification of why SWPS is an efficient method for promoting learning and knowledge. The answers indirectly correspond to the research question and can be summarised in the following conceptual model.

**The SWPS method is the engine of CI, it is fuelled by experience feedback and should focus on standardised processes.**

This statement recognises the SWPS method as a knowledge-creating process that promotes learning behaviours and initiates pull for experience feedback. It should be noted that the investigated off-site construction firms still lack standardised processes, i.e. the degree of standardisation is still not optimal, and successful CI application relies on standardised processes. However, the role for SWPS in the studied
companies could be regarded as a means to support standardisation rather than merely awaiting its implementation.

**Conclusion 2:** SWPS is an evolving skill that supports CI capability if it is related to a company-wide process focus and aligns with company vision and goals.

This conclusion still leaves several relevant questions unanswered, including how can a process focus be maintained, and how is it possible to know if improvements align with company vision and goals?

### 6.3 Lean production: Closing the loop

Both Lean production and TQM have been investigated in the studies this thesis is based upon. Both are identified as improvement strategies comprising guiding principles for company-wide focus on processes, personnel involvement and customers. Both of the companies considered in Papers V and VI have chosen Lean production as their overall improvement strategy, but their implementation strategies differ. This could be related to a misconception (in one company) of how an overall improvement strategy relates to incremental improvements, reflecting a focus on results prior to focusing on supporting people conducting standardised work (rather than on long-term philosophy, processes, humans and learning, as in true Lean practice).

**Lean practice provides a structure for disseminating embodied and embedded knowledge.**

This statement differentiates knowledge creation and learning from dissemination. The author has gained this view from following how Lean philosophy has been implemented in the case companies, as described in section 2.6. The infrastructure that is created by applying Lean production ensures dissemination of implemented solutions. Broadly, this provides the context for the development of profound knowledge and (hence) avoidance of sub-optimisation. CI implies the generation of a culture of sustained incremental improvements targeting elimination of waste in all processes of an organisation. The improvement activities applied in the investigated companies so far are based on a general willingness to improve, but without any certainty regarding the sought effects. Thus, the full potential impact of CI will
not be felt until incremental change takes place consistently and is focused on a specific goal.

**Conclusion 3:** An overall improvement strategy such as Lean production provides a structure for aligning CI efforts to company vision and goals.

This conclusion is based on the premise that Lean production is implemented holistically, recognising all parts of the 4P-model. The managerial efforts are confirmed to be of vital importance for sustainable CI.

Continuous assessment regarding the current state of Lean production and CI is proposed to provide vital support for management. This assessment should also involve reflection on the contextual enablers (Figure 35) as these are prerequisites for sustainable CI. The success of CI is ultimately reliant on management persistence to foster a company-wide learning commitment, and it is the learning activities within CI that create pull for experiences. Experiences are identified as containing knowledge that is unexploited unless it is targeted to problem-solving. Hence, information contained in some experiences (e.g. records in quality audits) should be restructured in appropriate formats in order to support CI. Enhancing experience feedback in such a manner is likely to be highly valuable for off-site construction companies, providing a substantial competitive advantage for future market expansion.

### 6.4 Validity of conclusions and possibility for generalisation

The case study approach limits the possibility for generalisations, and the limited number of companies involved in each case study reduces the confidence in stated conclusions. However, most module prefabrication companies (i.e. companies specialising in the prefabrication of commercial, multi-family, and multi-storey buildings) in Sweden were examined in the studies this thesis is based upon. Furthermore, by using several different data collection methods, both qualitative and quantitative, and thus triangulation, the similarities of the companies were validated. Hence, generalisation within the specific module prefabrication building system is established. In addition, the concepts expressed in this thesis have evolved as industry-wide and
specific needs have been pointed out by the module prefabrication companies themselves, further validating the results.

Timber module prefabrication is not the only strategy for moving construction indoors to simplify the processes. Other building systems in which construction process have been moved into factories include alternative module systems, closed and open panel systems, and technical platforms. The latter refers to an initiative in which design work, technical solutions and building methods are standardised (to improve the ability to adjust technical solutions in response to feedback regarding mistakes). As standardisation is identified as a crucial element for CI also in other off-site methods (Meiling et al., 2010a; Meiling et al., 2010b), it should be possible to generalise the conclusions to a broader range of off-site construction initiatives.

Conclusions regarding Lean production implementation are based on only two companies, which have adopted different approaches for implementation, limiting the possibility to generalise in this respect.

6.5 Future research

Several statements have been made within this thesis regarding experience feedback and continuous improvement. These statements are based on research on a limited number of companies utilising the same off-site construction strategy. A wider generalisation of these statements and recommendations would require a wider investigation, encompassing other building systems. As mentioned above, a contractor in Sweden has developed “technical platforms”, a concept aiming to integrate accumulated experience into flexible standardised technical solutions. The platforms are intended to foster the accumulation and sharing of knowledge, via efficient experience feedback practices. However, according to Styhre and Gluch (2010), there are bottlenecks in the feedback process, so it would be interesting to assess the applicability of the conclusions regarding experience feedback to technical platforms.

Overall improvement strategies, which represent a quality management approach towards production, have been addressed in this thesis. The field of quality management has developed for more than 50 years in manufacturing industry, but the construction industry has only paid serious attention to it quite recently. It will be necessary to address
concerning the adoption of quality management procedures in off-site construction. The investigated companies have chosen to apply Lean production as their overall improvement strategy. However, this requires long-term dedication. Continuous assessment of the outcome should provide vital information about how Lean production relates to the evolution of CI capabilities. Such assessment should focus on managerial, i.e. contextual, evaluation in a broader group of construction companies than investigated in this thesis.

Standardised work and even pace are described in the literature as prerequisites for effective CI, and this is an area that warrants further investigation. It is vital to identify the appropriate level of standardisation in off-site construction, related to the level of customisation in the product. This requires consideration of how phase and flow relates to client demand and customisation.

Performance measurement procedures applied in manufacturing are not usually applied in construction, where producers and clients emphasise the uniqueness in each project. Hence, efficient housing production methods need to be tuned to customer requirements regarding effective and flexible buildings. In order to develop analogous procedures to those applied in manufacturing, housebuilders need to gather, evaluate and finally distribute information from design, manufacturing and assembly points, subcontractors and customers. Control should be sought with process-compatible metrics, rather than project-specific performance estimates, related to the production process in regard to continuous improvements, standardisation, production pace and flow (takt). Eventually this will involve investigating the application of statistical methods (e.g. statistical process control, capability analysis) in order to improve process and product quality.

The technical report (Lundkvist and Meiling, 2010) presents an overview of practices regarding information storage, knowledge retrieval, and practices of experience feedback. These results should serve as a good basis for follow-up, including in-depth interviews, that should lead to a more generalised view of experience feedback in the construction trade. Eventually this will lead to a need for further insight regarding specific knowledge and learning-related studies. These studies should involve social network analysis in order to
explore the processes specifically related to knowledge retrieval and learning activities.

A wider application of quality management in construction would involve a stakeholder perspective, reflecting the third generation of quality management. This thesis has emphasised how even small incremental improvements must be related to long term thinking. However, the question arises how the company strategies, formalised in goals, should relate to all involved stakeholder. Where stakeholders can be defined as (Bergquist et al., 2008):

“..a sub set of interested parties that are capable of causing the organisation to fail or inflicting unacceptable damage if their interests are not satisfied.”

Thus further research involves to link stakeholder satisfaction to continuous learning and quality improvements. This will inevitably effect how experience feedback related to clients is managed. Client satisfaction is a neglected area that off-site construction firms need to address, especially since client demands regarding building performance over time (service life planning) are becoming increasingly stringent (SIS, 2005). Customer-centred development of construction processes has been investigated by Kärnä et al. (2009), who conclude that the most significant improvement targets are related to communication and construction project handover methods. Thus, customer satisfaction is related to both management and method, and thus connected to the phenomena addressed in this thesis.
REFERENCES


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FEEDBACK IN INDUSTRIALISED HOUSING –
WHY DOES IT NOT HAPPEN?

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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: Industrialised housing, Quality management, Feedback

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). Vrijhoef (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 Company</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 housing and feedback

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.

Figure 1 Construction process timeline with experience feedback from audits, case study is performed from building- and guarantee inspections.

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.

Figure 2 Time frame for the typical building project with activities during design, manufacturing and commissioning.
Meiling and Johansson

**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 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>
<thead>
<tr>
<th>Company</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></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>inspections</td>
<td>A</td>
<td>5</td>
<td>414</td>
<td>81</td>
<td>6.1</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>11</td>
<td>2415</td>
<td>877</td>
<td>3.1</td>
<td>63</td>
</tr>
<tr>
<td>Guarantee</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>inspections</td>
<td>A</td>
<td>5</td>
<td>66</td>
<td>81</td>
<td>1.1</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>4</td>
<td>424</td>
<td>828</td>
<td>0.9</td>
<td>70</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.
Meiling and Johnsson

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


Industrialised housing and feedback


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DEFECTS IN OFFSITE CONSTRUCTION:
TIMBER MODULE PREFABRICATION.

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Defects in offsite construction: timber module prefabrication

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The construction industry is based on craftsmanship. Quality control and assurance procedures applied in manufacturing cannot usually be readily applied in construction, where there are higher degrees of uniqueness in each project. One category of companies, industrialized housebuilders, is attempting to bridge some of the gaps between construction and manufacturing. These companies prefabricate building modules for later assembly at the building site. Since they are wholly responsible for large parts of the building process, these companies have greater opportunities to control and improve quality in a more consistent way than ordinary construction companies. Thus, it could be hypothesized that the frequency and severity of defects should be lower in industrialized housing than in ordinary construction. The aim of the study presented here is to examine this hypothesis by measuring and characterizing defects in industrialized housing. The design and manufacturing processes at two Swedish timber module prefabrication firms has been analysed through interviews, site visits and document reviews. Quality audits from three phases of the building process were compiled, analysed and categorized to provide statistical measures of defects in industrialized housing. The results show that the case study companies are better in terms of product quality than conventional housing.

Keywords: Building defects, offsite production, quality management, industrialized housing, modular construction.

Introduction

Both governmental and customer demands for enhanced product quality and lower product and production cost in construction make it interesting to investigate how reduction of defects can contribute to enhanced product quality. From a lean production perspective, defects and rework are waste (Liker, 2004). The cost of poor quality is proven to be greater than the investment for managing quality (Juran and Gryna, 1988; Sörqvist, 1998) and should be eliminated by e.g. learning from experience (Wilson et al., 1993). When focusing on quality and product effectiveness an adequate definition regarding construction is ‘fitness for use’ (Juran and Gryna, 1988), i.e. quality is determined by the customer. Bisgaard (2007) suggested two subsidiary definitions: (1) quality of design; and (2) quality of conformance. This paper concerns the latter, i.e. identifying the mixture of random and chronic problems related to both internal and external customers (Bergman and Klenfjö, 2003). Reducing deviations and removing their causes is the essence of continuous improvements. According to Juran (1986) any production is charged with a current level of chronic waste, to be regarded as the level of opportunity for improvement. The Juran trilogy of planning, control and improvements constitutes a threefold strategy for enhanced quality (Figure 1).

Offsite construction is thought to have the potential to increase efficiency and control, reduce costs and increase quality in construction (SOU, 2000; Roy et al., 2003; Apleberger et al., 2007). Industrialization in construction is not a new phenomenon (CIB, 1965), and the emerging industrialization follows an international trend; e.g. Egan (1998) argues that construction must develop into a manufacturing process. The choice of manufacturing offsite does not in itself lead to effectiveness and efficiency (Gibb, 2001). Lessing et al. (2005) raise systematic performance measurement and use of knowledge acquired through experience as a key ingredient for industrialized housing. Offsite manufacturing of timber-framed modules is one application of offsite modern methods of construction (Buildoffsite, 2006; Pan et al., 2007). The use of modules shifts 90%
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of the work from the site into factories, Figure 2. Höök (2006) states that this kind of industrialized housing changes the company culture from organizational learning and learning between projects, to building process knowledge.

Early defect studies, e.g. Schodec (1982), Kaplin (1994), often focused on poor craftsmanship and negligence (Pheng and Wee, 2001). While Ramly et al. (2006) focus on design implications for defect occurrence, engineering-based defects are supported by quality management systems such as ISO 9000 (Low and Teo, 2004). Several studies (Josephson and Hammarlund, 1999; Porteous, 1992) have also linked the occurrence of defects to the organization and, more specifically, poor communication. Thus, organizational learning (e.g. Senge, 2006) may be a key ingredient for successful application of quality management procedures as described by Scott and Harris (1998).

Ilozor et al. (2004) argue that historical analysis can be a powerful tool, which can be combined with categorization and systemization of defects (Josephson and Saukkoriipi, 2007). Estimates suggest that costs for correcting defects may account for up to 6% of the production costs (Josephson and Hammarlund, 1999). Industrialized housing production shares scheduling problems with regular construction, though it has the advantage of a dry working environment and above all traceable defects in production and design. Offsite manufacturing could be assumed to be of generally higher quality than construction by conventional methods (Pan et al., 2008), but the level of chronic waste has not been established. This study focuses on defects and anomalies recorded in quality audits of work done by two offsite manufacturing housebuilders that produce timber-framed modules for the Swedish market. The aim of this study is to characterize defects and present the production process at two companies (Table 1) in order to establish knowledge on the current quality level.

Each of the two companies has 50 years’ production experience and together they account for 50% of the market for modular housing in Sweden, which in turn has a 15% share of the total market for multi-family dwellings and commercial buildings. Clients in this segment are mostly real estate trustees and municipalities, i.e. professional clients who conduct repeated procurement under more severe functional requirements (regarding fire, sound and capacity) than those of single family dwellings. However, the building code is the same regardless of material and production in Sweden.

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<table>
<thead>
<tr>
<th>Case company</th>
<th>No. of employees</th>
<th>Main products</th>
<th>Turnover (€m)</th>
<th>No. of storeys</th>
<th>Annual production (modules)</th>
<th>Contract type</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>150</td>
<td>Multi-family and student dwellings</td>
<td>34</td>
<td>Mainly 4–5</td>
<td>1400</td>
<td>Design build</td>
</tr>
<tr>
<td>B</td>
<td>253</td>
<td>Nursing homes, schools, office buildings</td>
<td>43</td>
<td>Mainly 1–2</td>
<td>1500</td>
<td>General</td>
</tr>
</tbody>
</table>
Timber module prefabrication

The two investigated companies are 1100 km apart and work with different clients. Still there are substantial similarities in the production process. The organization is not process-oriented in any formal way but projects follow predefined paths involving multiple activities (Figure 3). Most activities remain in-house, although some are performed by external consultants, i.e. drafting of heating, ventilation and air conditioning (HVAC), and electricity as well as structural design. Company A works solely for clients who sublet dwellings to private customers, while company B works with institutions procuring public buildings, e.g. schools, jails, day-care centres etc. Company A has chosen to work with its clients very early in the building process, sometimes even before building permits are granted. Company B does not have this option since public buildings are subject to European procurement rules and thus have to be announced and open to competition. Early design decisions favouring industrialized housing are almost impossible to make in open bidding. Both companies preferably apply a make-to-order (Winch, 2003) production strategy, where company solutions can be readily applied and configured according to the client’s wish. Company B is often pushed to accept design-to-order projects, where more extensive engineering is required, as they enter procurement later. Winch (2003) argues that traditional housing projects are based on the concept-to-order strategy, which does not favour module prefabrication where repetition is sought.

Briefing

Briefing, handled by the sales department (two persons at each company), includes four weeks of early client contacts, twelve weeks to acquire the building permit (only company B), eight weeks to prepare a tender and twelve weeks for tender negotiations and acceptance. The architectural work is conducted by either in-house or external architects who are experienced with the module prefabrication system. After briefing, a start-up meeting is held in which object-specific demands are considered. Early design work at company A is prioritized and assigned to a skilled senior design employee allocated to the sales department.

Figure 3

Timeframe for a typical building project and activities during design, manufacturing and commissioning stages

<table>
<thead>
<tr>
<th>Outsource structural design</th>
<th>Construction logic</th>
<th>Manufacturing logic</th>
<th>On-site production</th>
<th>Post production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase materials</td>
<td>Outsourcing</td>
<td>Factory production</td>
<td>Quality audit</td>
<td>Final audit</td>
</tr>
<tr>
<td>Interior design and materials</td>
<td>In-house drafting</td>
<td>Volume assembly</td>
<td>Assembly on-site</td>
<td>Warranty audit</td>
</tr>
</tbody>
</table>

Briefing process 24–36 weeks, Design process 12–20 weeks, 4 weeks, 4 weeks, Commissioning 2 years, Operation and maintenance.
workers use printed drawings to keep track of work tasks for a particular module. Before covering and storing the module, deviations are reported and all missing equipment or incomplete work is noted. Notations are used for ordering material or assigning labour to correct defects. No one is assigned responsibility for improving activities or product development, and there are as yet no formal procedures for fostering such improvements.

**Onsite assembly**

Modules are transported by truck and managed on site by small groups, five people in each, of in-house teams (company A) or external carpenters (company B). The teams have inherent knowledge about practical aspects of the building system. At the building site information about work activities, equipment and construction material is channelled through ad hoc meetings and brief instructions on an irregular basis. Common problems are e.g. keeping track of material that has been sent inside the modules from the factory, and the lack of detailed work standards for specific tasks. Thus all teams have their own solutions concerning matters such as edging, joints and doors.

**Research method**

The results and conclusions reported here are drawn from two companies, representing a niche in offsite manufacturing; 17 housing projects were investigated. These housing projects are considered as ‘one-of-a-kind’ on a system level, but the companies aim to handle unique projects in repetitive processes. Defects are detected at several control points in the building process (Figure 3). In Sweden there is one mandatory audit (final audit) when a building is complete and a second mandatory audit (warranty audit) after the building has been in service for two years, both conducted by certified professionals (Figure 4). Certification (given by SP SITAC, an approval and certification body) is given to individuals after a minimum of five years’ skilled experience in the construction field and 300 hours’ experience in auditing. Building and warranty audits are formalized and sustained through an association of clients, consultants and contractors in the Swedish construction trade. The sets of rules are presented in general regulations for construction, AB (2004) and design-build contracts, ABT (1994). In addition, the studied companies make an internal quality audit (factory audit) before the modules leave the factory (Figure 4).

The analysis was restricted to eight projects run by companies A and B for which complete data were available (factory, final and warranty audits, Table 2).

In addition a set of 11 projects (regarding final audits from company A, Table 3) was used to validate the results.

In total, 1320 (443 + 877) modules were included in the analysis of quality audits. Across the eight projects

![Figure 4](image)

**Figure 4** The three audits in relation to the building process

<table>
<thead>
<tr>
<th>Table 2</th>
<th>The eight selected projects where factory audit, final audit and warranty audit were investigated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case company</td>
<td>Selected projects (no. of modules)</td>
</tr>
<tr>
<td>A</td>
<td>Condominiums (40 mod.)</td>
</tr>
<tr>
<td></td>
<td>Student dwellings (92 mod.)</td>
</tr>
<tr>
<td></td>
<td>Student dwellings (230 mod.)</td>
</tr>
<tr>
<td>B</td>
<td>School (11 mod.)</td>
</tr>
<tr>
<td></td>
<td>Hospice (19 mod.)</td>
</tr>
<tr>
<td></td>
<td>Preschool (16 mod.)</td>
</tr>
<tr>
<td></td>
<td>Preschool (28 mod.)</td>
</tr>
<tr>
<td></td>
<td>Preschool (7 mod.)</td>
</tr>
</tbody>
</table>
Offsite construction

in Table 2, 1234 defects were detailed in the factory audits, 1147 in the final audits and 332 in the warranty audits; the final audit from the 11 projects in Table 3 constitutes 2415 defects giving a grand total of 5128. Defects are recorded (by inspectors) as text documents and at the best stored in the companies’ archives. The summoned documents were reviewed and all defects coded using six different categories: where, what, type, measure, why and when. Each category was associated with a nominal scale according to Table 4, corresponding partly to Love and Josephson (2004), who categorized defects according to classification, correction, roots and cost effects.

The first two categories (where and when) were each divided into more detailed sub-categories (Tables 5 and 6). Every defect was coded and entered in SPSS statistical software for analysis and presentation of data in a consistent manner.

Table 7 exemplifies a handful of coded defects from the final audits. Tables 4 to 6 provide the code key; the first pair of digits (2–7) is ‘Where’ in Table 4 with the sub-category from Table 5, the second pair (3–2) is ‘What’ in Table 4 with the sub-category from Table 6.

A series of three focus group meetings was held in order to attain feedback from the investigated companies on the defect analysis. Three onsite visits have

<table>
<thead>
<tr>
<th>Case company</th>
<th>Selected projects (no. of modules)</th>
<th>No. of storeys</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Condominiums (48 mod.)</td>
<td>2</td>
<td>2004</td>
</tr>
<tr>
<td></td>
<td>Condominiums (172 mod.)</td>
<td>4</td>
<td>2003</td>
</tr>
<tr>
<td></td>
<td>Condominiums (82 mod.)</td>
<td>4</td>
<td>2003</td>
</tr>
<tr>
<td></td>
<td>Condominiums (174 mod.)</td>
<td>4</td>
<td>2006</td>
</tr>
<tr>
<td></td>
<td>Student dwellings (54 mod.)</td>
<td>4</td>
<td>2005</td>
</tr>
<tr>
<td></td>
<td>Student dwellings (92 mod.)</td>
<td>4</td>
<td>2003</td>
</tr>
<tr>
<td></td>
<td>Condominiums (64 mod.)</td>
<td>2</td>
<td>2005</td>
</tr>
<tr>
<td></td>
<td>Condominiums (36 mod.)</td>
<td>4</td>
<td>2007</td>
</tr>
<tr>
<td></td>
<td>Condominiums (67 mod.)</td>
<td>4</td>
<td>2007</td>
</tr>
<tr>
<td></td>
<td>Student dwellings (60 mod.)</td>
<td>4</td>
<td>2006</td>
</tr>
<tr>
<td></td>
<td>Rental apartment (28 mod.)</td>
<td>2</td>
<td>2007</td>
</tr>
</tbody>
</table>

Table 4 Nominal scales for characterizing defects

<table>
<thead>
<tr>
<th>Where did the defect occur?</th>
<th>What was defective?</th>
<th>What type of defect was it?</th>
<th>What measures were taken to correct the defect?</th>
<th>Why did the defect occur (root cause)?</th>
<th>When did the defect occur?</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Unrelated</td>
<td>0 Unrelated</td>
<td>0 Unrelated</td>
<td>0 Unrelated</td>
<td>0 Unrelated</td>
<td>0 Unrelated</td>
</tr>
<tr>
<td>1 Dwelling</td>
<td>1 Int. installations</td>
<td>1 Missing</td>
<td>1 None</td>
<td>1 Transport</td>
<td>1 Structural design</td>
</tr>
<tr>
<td>2 Common areas</td>
<td>2 HVAC</td>
<td>2 Unfinished</td>
<td>2 Cleaning</td>
<td>2 Damaged</td>
<td>2 Factory</td>
</tr>
<tr>
<td>3 Separate buildings</td>
<td>3 Opening</td>
<td>3 Broken</td>
<td>3 Adjustment</td>
<td>3 Bad craftsmanship</td>
<td>3 Transport</td>
</tr>
<tr>
<td>4 Outdoors</td>
<td>4 Lining</td>
<td>4 Erroneous</td>
<td>4 Completion</td>
<td>4 Structural error</td>
<td>4 Assembly</td>
</tr>
<tr>
<td></td>
<td>5 Wall</td>
<td></td>
<td>5 Repair</td>
<td></td>
<td>5 Warranty time</td>
</tr>
<tr>
<td></td>
<td>6 Ceiling</td>
<td></td>
<td>6 Exchange</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7 Floor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8 Completions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9 Information</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5 Sub-categories for the ‘Where’ category in Table 4

<table>
<thead>
<tr>
<th>Where</th>
<th>Where</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Common areas</td>
<td>3 Separate buildings</td>
</tr>
<tr>
<td>1 Waste disposal</td>
<td>1 Waste disposal</td>
</tr>
<tr>
<td>2 Laundry</td>
<td>2 Laundry</td>
</tr>
<tr>
<td>3 Storage room</td>
<td>3 Storage room</td>
</tr>
<tr>
<td>4 Ventilation</td>
<td></td>
</tr>
<tr>
<td>5 Electricity</td>
<td></td>
</tr>
<tr>
<td>6 Cleaning</td>
<td></td>
</tr>
<tr>
<td>7 Entrance</td>
<td></td>
</tr>
<tr>
<td>8 Stairwell</td>
<td></td>
</tr>
<tr>
<td>9 Corridor</td>
<td></td>
</tr>
</tbody>
</table>

‘What’ in Table 4 with the sub-category from Table 6. The following four single digits are ‘Type’, ‘Measures’, ‘Why’ and ‘When’ in Table 4.

A series of three focus group meetings was held in order to attain feedback from the investigated companies on the defect analysis. Three onsite visits have
been conducted in order to participate during audit performance and to trace root causes.

Results and analysis

On average from the eight projects in Table 1, each module had 6.1 (2713/443) defects (accumulated from all three audits). Defects were distributed in the three control points accordingly: (1) factory audit had 2.7 (1234/443) defects per volume; (2) final audit had 2.5 (1147/443) defects per module; and (3) warranty audit had 0.7 (332/443) defects per module. Modules made by companies A and B had, on average, 5.0 and 9.3 defects per module, respectively. Company A produces dwellings, which are not official buildings and are not subject to the European Procurement Agreement, which is the case for company B that has more site work (generating more defects) because of more extensive technical installations in HVAC and electricity.

When analysing final audits from the 11 projects in Table 3 the amount of defects per module is 2.7 (2415/877) and defects per habitat is 5.3 (2415/453). Sigfrid (2007) investigated building inspections (final audits) from six traditionally built projects and found 9.3 defects per habitat in three projects containing 91 multi-storey habitats, and 16.2 defects per habitat in three projects containing 73 terraced houses. The grand average being 12.7 defects per habitat, the case study companies produce 42% of this amount of defects. It can be hypothesized that the difference lies in the part of the process that is industrialized, thus if the investment ratio is 2:1 regarding prefabrication and onsite production, prefabrication should compare only 2/3 of its defects to onsite production. This leads to a speculation that offsite production in the case study companies instead generate 32% (10.9/3.5) defects in the final audits compared to onsite projects.

Where did the defects occur?

This question is linked to how far the building process has progressed at the time of the audit. Total numbers of defects in separate buildings, outdoors, common areas and dwellings recorded in each class of audit are presented in Figure 5.

Where did defects occur?

(a) Factory audit
(b) Final audit
(c) Warranty audit

Dwellings harness the most defects, which is not surprising since they constitute the major parts of the buildings. The higher proportion of defects in common areas recorded in the final audits (which can be seen in Figure 5) is also no surprise since common areas are constructed during onsite work, and thus their frequency will inevitably rise in the final audits.

What was defective?

The generic parts of the building structure were used to map the defects (Figure 6). Recorded defects include holes and mess on the walls caused by craftsmen, missing linings around doors and windows, and doors in need for adjustment owing to movements in the structure. Of the grand total, 33% of all defects were related to walls, and 52% to walls or openings. The contractor is held responsible for defects in interior installations concerning objects that are missing or not properly installed. In the warranty audits malfunctions were noted. Sub-categories from the most prominent groups (60% of defects) from the factory audits (Figure 6(b), wall, opening and interior installations) are presented in a Pareto chart, Figure 6(d).

What was defective?

The Pareto chart in Figure 6(d) reveals what could be regarded as ‘the vital few’ (Juran and Gryna, 1988) identified here as windows and doors, which are the main causes of defects at both companies. Discussions in focus group meetings revealed that both windows and doors are expensive to purchase, as well as time critical for delivery (early order). The purchase
department chose to buy non-adjustable doors and to mount windows without adjustment screws. This is a questionable decision as the modules move during transport and assembly, resulting in costly adjustments on site. A lean production implementation is under-way in company A, implying a willingness to decrease the defect rate through improved communication and management support as supported by Josephson and Hammarlund (1999) and Porteous (1992). A lean strategy could eventually lead to a decrease of small defects, missing objects and faulty installations through standardization, continuous improvements and supply chain management. Company B is a ‘fire fighter’, relying on hard work as well as maintaining an ISO 9000 certificate, neither of which has proven to bear fruit regarding enhanced quality and lowered defect rate (Gustafsson et al., 2001; Lam and Ng, 2005).

What type of defect was it?
The cost for correcting a defect is clearly coupled to the type of defect involved, therefore it is of obvious interest to grade the severities of the defects (as illustrated in Figure 7).

Figure 7 shows that many items went missing before module delivery (518 items in total, equivalent to 1.2 items missing per module, accounting for 42% of the defects recorded in the factory audits). Furthermore, many defects recorded in the factory audits concerned broken items (35%) that had to be corrected before the final audit. In the final audits, the lion’s share of defects concerned things that were not delivered according to the contract (55%). On average, 79 items per project were listed as unsatisfactory in the final audit. According to the warranty audit, some 20 items per project did not meet contract stipulations. The final and warranty audits demonstrate that many defects are related to failure to fulfil customer demands regarding installations in the building (alarm systems, professional kitchen appliances, etc.). Thus, there is great potential for improvements in the companies’ procedures for addressing these issues, which are not directly linked to the framing system, but are still part of the overall offer. Figure 7(d) shows defects recorded by Sigfrid (2007) on final audits from six traditionally built projects. Figure 7(d) indicates that the level of items not installed or delivered according to contract is far lower than in the case study companies, Figure 7(b). Here is a potential for the case study companies to synchronize the flow of information, material and construction workers (activities), as well as required resources in the factory and on site. From a lean supply chain management view all efforts should be made in order to avoid reoccurrence of defects or unsatisfactory matters (Stratton and Warburton, 2003) which coincides with Juran’s (1986) view of chronic waste. The supply chain is handled through contracts and agreements but relations are not fully developed to handle the kind of line-balanced,
Johnsson and Meiling

time-critical production that module production constitutes.

What measures were taken to correct the defects?
To qualitatively assess the costs for the defects and establish another measure of the costs for correcting them, the measures taken to correct each defect were recorded (Figure 8).

Most of the defects (51% of the total) were small, requiring only minor adjustments. Typical defects, getting much attention in audits, included stains, mess, small cracks and marks. It is shown by Höök and Stehn (2008) that the production culture in Swedish timber frame module production still relies on a traditional onsite culture resulting in low worker motivation, lack of continuous improvement, problems that appear being solved but not analysed, ad hoc solutions and a low responsibility for maintenance of equipment. Thus the level of defects could be expected to decrease if when implementing tools such as 5S and standardized work as it improves the repetitive process, making mistakes easier to discover and improvements possible to measure. The numbers of defects requiring repair or exchange amounted to 9.6% (260/2713) of the total. In the factory audits completion was the second most common measure to correct defects, which is unsurprising since many items were missing in that phase.

Why did the defect occur?
In accordance with expectations, a work-intensive activity such as construction results in many defects originating from human errors, both from factory production and assembly on site (Figure 9). One of the major criticisms that has been raised against timber module prefabrication (Höök, 2006) concerns the choice of building system (lightweight timber frame walls and floors assembled into modules). One would therefore expect a substantial frequency of defects to be associated with the building system or structural design and, accordingly, 21% (578/2713), here implied to constitute the vital few (Juran, 1986), of the grand total of recorded defects can be directly linked to the

Figure 6 What was defective?

Figure 7 What was defective?

Figure 8 Measures taken to correct defects (a) Factory audit (b) Final audit (c) Warranty audit

Figure 9 Pareto chart of sub-categories (table 6) for wall, opening and interior installations (from chart 6b), solely from final audits in table 3.
Offsite construction

Structural design phase and/or building system. Structural errors constituted nearly half of all the defects listed in the warranty audits, corresponding to 6% of the grand total including cracks in corners and movements in the structure. Defects are of several types: as chronic waste visible in audits as cracks in weak sections and as design errors such as misplacement of doors or poor choices of material. The standard procedure to correct these cracks is to use putty and paint. Yet another crack type was encountered at company A and could be defined as lack of standardized work in the factory resulting in prominent cracks (Figure 10). The cracks propagated during the two lifts during production, one with a fork truck in the factory and one with a crane at the construction site.

Walls were dismounted revealing that studs and plywood were not mounted according to instructions. The root cause is lack of standardized work, and it is to be considered as a sporadic production spike (Figure 1) and should not be confused with quality improvement measures. In general the building system requires some modification to improve long-term performance and responses to settlement. The overall performance is satisfactory, but not excellent.

**When did the defect occur?**

Transport and lifts cause some 10% of the defects detected in the final audits (Figure 11) manifested in cracks in weak sections, and windows and doors in need of adjustment. Half of the defects detected in the warranty audits arose during the two years that had passed since the final audits. However, even after two years, defects either remained or had arisen that can be directly linked to errors during the factory production (20%) or building assembly (23%). Almost half of the
Figure 8  Measures taken to correct defects

Figure 9  Root causes of defects
Figure 10  Cracks propagating from door openings, after lift

Figure 11  Building process stage when defects occurred
Defects recorded in the investigated final audits originated from factory production, followed by 35% from assembly activities. Production in the factory is intense, and this is where attempts to optimize the work have primarily been focused. But factory production of housing projects is saddled with high process variability as the projects so far tend to be one-of-a-kind on a system level. As factory production is managed through specialized craftsmen in both companies, it could be described as moving onsite construction indoors and not adjusting to factory physics. A line-based production would level the flow and even out variations in tact time (Hopp and Spearman, 2001). Relatively little attention has been paid to the assembly phase, but this should be worthwhile, especially for company B, since many defects pertain to installations handled in the assembly phase.

Principal component analysis

Datasets in the factory, final and warranty audits were each subjected to principal component analysis (PCA). There was insufficient scatter in the factory audit data to summarize into aggregated variables, which is not surprising since several of the scales applied only allow one or two categories at the factory audit stage, e.g. ‘where’ can only elicit the responses ‘0, Unrelated’ or ‘1, Dwelling’ since the other alternatives in the scale are non-existent at the time of the factory audit. Rotated component matrices for the PCAs of the final and warranty audits are presented in Table 8.

The PCAs show some relationships that remained consistent throughout the timeframe of the quality audits. The first principal component (PC) obtained from the PCA of the final audits is designated ‘Matter_3D’, and describes what was defective in combination with the positions of the defects. Accordingly, the final audits show that it is not uncommon for certain types of defects to repeatedly occur—for instance cracked corners may repeatedly occur at the same position for the same reasons. The first PC obtained from the PCA of the warranty audits, ‘Position_4D’, also has positional contributors, but in this case it is also related to time, which is consistent with expectations since time can only be related to defects at specific positions after some time has elapsed. Defects typically detected in the warranty audits include cracks around openings as a result of settlement. This type of defect can only be detected during the warranty period, since it is invisible before it.

One component that arose in both analyses illustrated in Table 8 is ‘Problem_fix’, which combines the defect type with the measure to correct it. This component shows that the type of defect detected and the corrective measure are closely related and could be described using just one variable, which should facilitate future analysis. The connection is also unsurprising since small defects also need small measures for correction. Defects ultimately should be coded at source during inspection or as self-inspection in order to facilitate later analysis leading to enhanced possibility working and gaining from both historical analysis as well as categorization of defects (Ilozor et al., 2004; Josephson and Saukkoriipi, 2007). To assess possible differences between companies A and B in terms of defect-related variables, scatterplots were produced, but none of them indicated any significant differences between the companies (Figure 12). No statistically significant differences between them in these respects were detected by a t-test either.

From Figure 12 it is evident that the scatter around zero is evenly distributed for both companies and there is no significant clustering of data or interesting outliers that requires attention.

Discussion and conclusions

The defect information presented in this paper is extracted from existing quality documents, representing...
Offsite construction is a neglected source of information. As these data are currently readily available in mandatory audits it represents a low-hanging fruit. Why is it that the companies currently use audits only as checklists for correcting defects and make little use of information captured in the audits for further analysis? We believe this is due to several reasons. First there are no explicit demands from clients or authorities. Secondly there are cultural reasons (based on norms of traditional onsite and project-based construction), which influence the organizational culture of industrialized housing resulting in lack of standardization, lack of employee loyalty to strategies and a lack of top management support and strategies (Höök and Stehn, 2008). Working with identification of defects and deviations is here demonstrated to have potential to support improvements of process and product design, thus favouring both clients and company in the long run, rather than just getting one project approved and solely correcting finalized products in fire-fighting mode. The perceived benefits of industrialized housing cannot be achieved by focusing solely on external customer value, while suppressing internal production efficiency and forgetting internal customers. The struggle for quality in construction is a small step revolution where control of defects should be linked to an improvement strategy. It is shown that the case study companies achieve a lower defect rate in the final audits than the six compared onsite projects. Production in the case study companies is done in a closed factory environment, with assembly and some finishing performed at the construction site. The importance of being in control of the entire defect recovery process is demonstrated in this study and supported also by the findings of Love and Josephson (2004). From a learning perspective these companies could benefit more from applying organizational (company) learning (Kärnä and Junnonen, 2005) than conventional construction companies, since the individuals, teams, customers and relationships involved in their projects are more constant and controlled. Altogether, several key ingredients required for advancing and exploiting experience feedback and learning are present, which could provide a competitive edge with respect to other building systems and promote long-term quality.

However, methods need to be introduced to standardize experience capture and, more importantly, implement knowledge gained through experience in earlier process stages. This problem has been addressed in several studies, e.g. Shelbourn et al. (2006) and Sandberg et al. (2008), but no simple, robust way of tackling it has been implemented as of yet. If the development of product quality in the housing industry is to be conducted through the people working in a company, the defects signal a need for learning in the organization rather than a technical, economical problem. The main reasons for investigating defects are to lower poor quality costs and improve production efficiency, product quality and customer satisfaction. The case study companies have the potential to take full advantage of quality management, but they need to shift focus from project-based to process-based production (Winch, 2006).

This investigation focused on two industrialized housing companies and projects procured by repeat clients. If generalization towards offsite modern methods of construction, or industrialized housing or even modular building systems is sought, extended investigations would preferably include also European companies outside Sweden. Further research will focus on how deviations can be continuously gathered and cumulated, analysed, traced and corrected to support continuous improvements and process development. As one of the two investigated companies has just recently decided to apply a lean manufacturing approach further investigations should measure improvements regarding the occurrence and severity of defects. Further comparison regarding onsite and offsite production would take into consideration defects per square meter living or gross area and e.g. form of tenure. The comparison of onsite construction was made in respect of only six traditionally built projects; statistically this would benefit from a broader investigation and should be treated accordingly.

![Figure 12 Example of scatterplot from the PCA of the final audits](image_url)
Acknowledgements

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References


PAPER III

TOWARDS A FEEDBACK MODEL FOR OFF-SITE CONSTRUCTION

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TOWARDS A FEEDBACK MODEL FOR OFF-SITE CONSTRUCTION

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There is a need for efficient experience feedback in the construction industry, which encompasses companies that use a wide spectrum of on- and off-site production methods to produce (inter alia) roads, bridges and railways, as well as low- and high-rise buildings. The rationale for developing and implementing methods for experience feedback is well documented, and regardless of the choice of production strategy common denominators are needs to recognise defects and to apply a continuous quality improvement program that incorporates learning from mistakes. The purpose of this paper is to present ongoing work regarding experience feedback, with the ultimate aim to close the feedback loops in off-site housing sales, design and production. An indoor production process at a Swedish housing company is probed. The investigated company utilises off-site module manufacturing, a production form with a 15 % market share among professional clients in Sweden (recurrent clients purchasing commercial and multi-storey buildings). This production form appears to be well-suited for implementing experience feedback, since control is already required in the production process. Based on a literature review and case examples a model for experience feedback is proposed. The feedback model is executed in a logical control structure with four levels: (1) plan and learn, (2) capture and assign to targets, (3) analyse and prioritise, solve and assess, (4) implement and use feedback. Theoretical considerations and empirical data show how analysis of error-detection can enhance possibilities for prioritising improvement actions as well as identifying feedback targets.

Keywords: Experience feedback, off-site manufacturing, knowledge management

INTRODUCTION

Housing production companies currently face intense competition and a failing market. Modern, off-site construction methods could possibly ease some of the pressure on them since they are thought to have the potential to increase efficiency, control and quality, while reducing costs. The benefits and possibilities of using off-site methods – notably low costs and high quality levels compared to in-situ construction – have been reported by several authors, including Pan and Gibb (2008), Pan et al. (2008) and Johnsson and Meiling (2009). The opportunities off-site manufacture provides in this respect have been heavily promoted, but it should be recognised that manufacturing off-site is not a panacea and does not inevitably lead to effectiveness and efficiency (Gibb 2001). Furthermore, a number of perceived barriers

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for choosing off-site manufacturing strategies among British house builders have been documented by Pan et al. (2007), including a lack of trust in the methods. Lack of trust among clients, in terms of life cycle costing, have also been noted and investigated by (Levander and Stehn 2007). Hence, a number of problems associated with off-site construction need to be addressed before it can fulfil its apparent potential. In Meiling and Johnsson (2008) it is suggested that off-site module manufacturing would benefit more from experience feedback than traditional construction, since there are higher levels of repetition and control is already required in production. The importance of the latter in regard to the defect recovery process and learning is also emphasised by Love and Josephson (2004). Love et al. (2000) argue for continuous improvements as a vehicle to lead construction companies into learning from their mistakes and become learning organisations. Effective and efficient communication of experience data can nurture improvements, and simultaneously support learning in organisations (Kärnä and Junnonen 2005). Hence, there is a strong rational for constructing a working model for systematically developing and implementing experience feedback procedures that can promote continuous improvements in terms of both off-site efficiency and effectiveness.

It has been reported from the Swedish construction sector that information does not reach the people that need it, and/or in an appropriate format, resulting in lack of quality, low profitability and weak co-operation in the companies (Industrifakta 2007, Josephson and Hammarlund 1999). Information is captured in various formats, e.g. documents, databases and people, but is seldom readily available, as feedback, since people are not aware of its existence (Blessing and Wallace 2000). Presumably another problem is that even when people are aware of the existence of relevant data, the information they specifically require is buried in large amounts of data that they do not have the time or skill to filter. Thus, there is need for better “Knowledge Management” (KM), i.e. more coherent strategies for creating a learning organisation by managing the creation, handling and use of knowledge. According to Kamara et al. (2003), there is a lack of proactive KM strategies within the construction industry and companies often rely on people as experience carriers between projects and departments. There are also more specific models concerned with the capture and reuse of experience data, for instance those presented by (Lin et al. 2006, Stokes 2001, Kamara et al. 2003), but these studies do not specifically address the analysis of experience data to be captured. Thus, there is a need for further research about how to prioritise capture of experience data, and to develop a better understanding of where the experience is needed, who needs access to it, and the form in which it should be delivered.

Theoretical considerations and empirical data are presented here showing the need for an analysis (and compilation in a suitable format) of experience data. Based on these findings a model that focuses on prioritising experience data capture in regard to continuous improvements is proposed.

EXPERIENCE FEEDBACK APPROACHES

The rationale for implementing and executing a system for reusing experience can be found within quality management theories, including Lean Production, Total Quality Management (TQM) and Six Sigma theories (Dahlgard and Dahlgard-Park 2006). Tools for this purpose are organised in TQM and Six Sigma procedures within the PDCA (Plan, Do, Check, Act) learning cycle and the DMAIC (Define, Measure, Analyse, Improve, Control) problem-solving cycle, respectively (Pyzdek 2003).
However, the constituents of experience feedback are explained by principles of Knowledge Management (KM), since it is ultimately a learning issue (Henry 1974). Experience feedback is not KM per se, but is described as a KM initiative by various authors, e.g. Carrillo et al. (2003). Kamara et al. (2003), Ingirige et al. (2002), and Lee et al. (2005) all note six benefits of live knowledge capture, namely it: (1) avoids the need to reinvent old solutions, (2) facilitates innovation, (3) increases agility, (4) improves teamwork, (5) improves supply chain integration, and (6) improves project performance. Thus, several managerial theories can facilitate attempts to distil principles of experience feedback, all of which have aspects of knowledge as a common denominator. It should be noted that knowledge can be divided into tacit and explicit forms, both of which (and the interactions between them) are important (Kamara et al. 2002b). A key process is the “evolution” of knowledge, i.e. the process whereby contextualised data are transformed via interpretation into information, knowledge and eventually wisdom through the discernment of relations, patterns and principles (Ackoff 1989). Thus, data, information and knowledge can be regarded as forming a hierarchical model – the DIKW model (Fricke 2009, Ackoff 1989) – of enhanced understanding in which wisdom is the ultimate kind. This paper considers ways to foster the evolution of knowledge and wisdom from data and information in the off-site construction industry that may provide a sound, rational basis for a task-performing system, as described by Kamara et al. (2002a). Post-project evaluation, or debriefing described by Gameson et al. (2008), is a common approach for experience capture in construction projects according to Orange at al. (1999), but it is argued to be insufficient since inadequate time is allocated for this purpose. Further drawbacks associated with post-project evaluation include the common dispersal of workgroups after project completion, and the inevitable time lags between relevant experiences and data capture (Tan et al. 2007). In these respects, live capture of experience data may provide a better basis for the formulation of explicit knowledge and thus promote the efficiency of continuous improvement activities in organisations. To facilitate the continuous management of knowledge and thus promote improvements, several working models have been developed.

**Knowledge lifecycles and models**

Several knowledge life-cycle models have been proposed to assist management of the life (and evolution) of knowledge, three of which will be mentioned here. Blessing and Wallace (2000) propose a knowledge life-cycle representing the evolution of knowledge for an individual, a team and a company with the overall mission to support the design process. The knowledge life-cycle serves as a basis for the capture, analysis and use of experiences in a knowledge-generating manner, meaning that the quality of knowledge will increase as the cycle is used. Outside sources may contribute additional life-cycle knowledge as they interact. This model recognises the importance of capturing both knowledge and context in real time, making it available as soon as it is reported. This is difficult to apply in housing production since real-time capture in this manner implies use of a computer-based knowledge system. In Methodology and tools Oriented to Knowledge-based engineering Applications, the MOKA method (Stokes 2001), a life-cycle for knowledge-based engineering applications is described according to the following steps: identify, justify, capture, formalize, package and activate. The first step, justify, involves identifying opportunities for experience feedback. However, ways in which this identification should be conducted are not described in detail. A tripartite model for live data...
capture is presented by Kamara et al. (2003) and Tan et al. (2007) including use of: (1) ICT tools, (2) a working system and (3) an assigned knowledge manager.

There is also a wide spectrum of types of project knowledge, e.g. knowledge regarding processes, costing, legal requirements, best practices, lessons learned (who knows what) etc. In addition, each category could be sub-divided into more detailed kinds of knowledge, hence there is a need for demarcation. The conceptual framework presented by Kamara et al. (2003) and the technique presented by Tan et al. (2007) do not detail the kinds of knowledge that should be captured. Further, they do not address the hierarchal relations of understanding and the different levels of data-information-knowledge-and wisdom recognised by authors such as (Ackoff 1989), or therefore the associated implications regarding the importance of facilitating interpretation of data etc. In contrast, Lin et al. (2006) present a map-based knowledge management concept for construction that is network-based and is argued to help in identifying critical knowledge areas, since all knowledge is abstracted and summarised in maps created in the following phases: knowledge determination, extraction, attribution, linking, and validation.

There is a need to develop robust models that include techniques for prioritising experience that should be fed back. There is also a need for models that help to identify destinations, i.e. people and places experience should be fed back to.

**OFF-SITE TIMBER MODULE MANUFACTURING**

Off-site timber module manufacture refers to the prefabrication (≥80% off-site) of closed three-dimensional timber “modules”, each with a floor, roof and wall elements. The off-site manufacturing phase for a single module is divided into three main stages: (1) wall, roof and floor element production, (2) module assembly and (3) module completion. The completed volumes are covered with moisture-proof tarpaulins before transport by truck to the construction site (Meiling and Johnsson 2008). Defects are reported at three control points: (1) a factory audit before tarpaulin cover, (2) a final audit before tenants move into the building, and (3) a warranty audit after two years occupancy. Characteristics of defects detected at these three control points are reported in Johnsson and Meiling (2009). Deviations are interactively reported in a visual manner, and colour-coded to track their status. The main purpose is to make sure that deviations have been corrected before units reach the customer.

**Case examples**

A case example, in this context, refers to a set of identified defects and the procedures use to address them (and similar defects in the future) that illustrate needs for enhanced analysis of experience data and indicate how enhanced systematic capture and analysis of experience data could help to improve quality. Two such sets are considered here.

**Example 1**

The first case example set consists of 2713 defects in 443 modules (used in eight housing projects) noted at three control points (factory, final and warranty audits), compiled and analysed by Johnsson and Meiling (2009). Structural errors accounted for 21% of these defects (578/2713), including cracks in corners and movements in the structure. Defects were of several types, for instance, cracks in weak sections and design errors such as misplacement of doors or poor choices of material. The standard procedure to deal with cracks was to apply putty and paint without reporting their extent other than as text in quality audits.
Example 2
The second example set, also from Johnsson and Meiling (2009), consists of 2415 defects noted in final audits of 877 modules used in 11 projects. The defects in these audits were classified according to the generic parts of the modules they affected, and their relative frequencies were graphically visualised. The analysis revealed that most defects were associated with walls, openings and interior installations. A further investigation is called for regarding prioritisation of quality improvement efforts.

PROPOSED MODEL
The proposed feedback model is inspired by lean theories and quality concepts, based on a belief in continuous improvements, minimising waste and satisfying internal and external customers. However, the model constituents are based on a KM framework of experience data capture, transfer and “evolution”. In addition, the model links "contextual" information, such as where, why, what and when defects occur (Johnsson and Meiling 2009) to analysis "activities" (such as statistical, root cause and risk analysis) and feedback "targets" for both internal and external customers, in a feedback-generating loop. The core activities are to prioritise and identify targets for feedback through data capture, analysis and implementation stages, as illustrated in figure 1.

Figure 1: Proposed feedback model for capture and analysis of experience data.

1. Plan and learn
Experience feedback initiatives must be planned and coordinated in order to support the design, manufacturing and assembling processes. This is an iterative control phase preceding the live capture (2) and analysis (3) stage, in which each activity is evaluated in order (mainly) to balance context information and context data. This is where conformity between available knowledge and actually used knowledge is sought (Blessing and Wallace 2000). The planning stage should formalise the kind of experience data that is sought, i.e. clearly identify each class of defect, and associated details, in the construction process that should be recorded.

Structure
The structure of context data is dependent on the end user, who needs to be identified.

2. Capture
This is an ongoing activity in which context data regarding defects, anomalies and problems in selected processes are gathered. People, machinery and product output are all potential sources for capturing experience data.
Assign
All defects should be codified as they are discovered, and if possible assigned to a primary cause and target instance. Codification in a generic mode is demonstrated in Johnsson and Meiling (2009).

3. Analyse
Analysis is scheduled in the planning stage and the context data as well as the targets for feedback should be considered when selecting methods to be applied. Such analysis has three main purposes: (i) to facilitate choice of action decisions, i.e. to prioritise actions, (ii) to identify root causes of, and solve, chosen problems and (iii) to assess risks regarding chosen actions. This is not a static operation, providing a schedule that cannot be subsequently changed, but an activity that is open to allow continuous improvements and better integration with the capture of experience data so as to facilitate decisions and execution of fact-based actions. The methods that can be used include the statistical analysis, root cause and risk analysis procedures (for prioritisation, problem-solving and risk assessment, respectively) outlined below.

Prioritise: (A) The seven quality tools

Solve: (B) Root cause analysis, RCA
RCA encompasses various problem-solving methods aimed at identifying the ultimate, underlying causes of problems or events (Wilson et al. 1993). Some of the methods that can be used include:

- Cause and effect analysis (based, for instance, on Ishikawa diagrams). It is assumed that there is a causal chain of relationships linking an initial cause and its final effect. Thus, hypothetically, removal of the primal cause in the chain will make the problem disappear (Pyzdek 2003).
- Five whys. This technique was originally developed at Toyota industries and later adopted by lean production theorists as an approach to solve problems (Liker 2004).
- Failure modes and effect analysis, FMEA (IEC 1985b), is an inductive, mostly qualitative analysis method used to identify possible failures and predict effects of these failures on the system.
- Fault tree analysis, FTA (IEC 2006), is based on use of deductive logical diagrams that show relationships between system failures.

Assess: (C) Risk analysis and assessment
Risk assessment refers to the objective evaluation of risk, with clear consideration and presentation of assumptions and uncertainties. The process involves risk analysis (IEC 1985a), which is defined as a systematic use of available information to identify hazards. This is a wide, intensively researched subject area that is not further considered in this paper.

4. Implement
Implementation is the phase in which the feedback action should be executed in order to improve the process or product. Feedback of experience is the ultimate goal for the data capture and analysis efforts, thus this is where the data acquired are applied, and the overall exercise proves its value (if appropriately done).
Construction feedback model

Use
Captured experiences could have uses both in directing “fire-fighting measures” to correct defects in houses and modules that have already been produced, to satisfy customers, and in new process/products, after which further iterative cycles of experience feedback can be applied (Meiling and Johnsson 2008).

ANALYSIS
Two types of real quality problems that have been observed and documented, cracks (1) and poor fitting of windows/doors (2), are used here to illustrate how the proposed model could have been used to feedback experience data. A summary of how the proposed feedback model could have been applied to correct these two classes of faults is shown in table 1.

Table 1: Two case examples follow through the proposed feedback model

<table>
<thead>
<tr>
<th>Model Stages:</th>
<th>Example 1: (Cracks)</th>
<th>Example 2: (Windows/doors)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Plan/learn</td>
<td>A decision is taken to investigate cracks, including their overall frequency and</td>
<td>Windows and doors are chosen for investigation because they are expensive and need to be</td>
</tr>
<tr>
<td>(structure)</td>
<td>how they arise in production.’</td>
<td>ordered and installed at correct times.</td>
</tr>
<tr>
<td>2. Capture</td>
<td>1. Quality audits are gathered from earlier projects</td>
<td>1. Quality audits are gathered revealing high frequencies of defects related to windows</td>
</tr>
<tr>
<td>(assign)</td>
<td>2. Live capture of crack frequency at on-site assembly.</td>
<td>and doors.</td>
</tr>
<tr>
<td></td>
<td>Information is targeted to design.</td>
<td>2. Live data capture at on-site assembly reveals high frequencies of adjustments for</td>
</tr>
<tr>
<td></td>
<td></td>
<td>windows and doors.</td>
</tr>
<tr>
<td>3. Analyse</td>
<td>A. Quality analysis</td>
<td></td>
</tr>
<tr>
<td>(prioritise)</td>
<td>Histograms from quality audits reveal high frequency of cracks from post-</td>
<td>A Pareto chart reveals “the vital few” (Juran and Gryna 1988) identified here as windows</td>
</tr>
<tr>
<td></td>
<td>production phase, implying importance.</td>
<td>and doors</td>
</tr>
<tr>
<td></td>
<td>B. Root Cause Analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cracks are traced back in production; cracks propagate during two lifts, one</td>
<td>The purchase department chose to buy non-adjustable doors and production chose to mount</td>
</tr>
<tr>
<td></td>
<td>with a fork-lift truck in the factory and one with a crane at the construction</td>
<td>windows without adjustment screws. These are questionable decisions since the modules</td>
</tr>
<tr>
<td></td>
<td>site. Finally walls are dismounted in the factory, revealing the root cause of</td>
<td>move during transport and assembly, resulting in costly adjustments on-site.</td>
</tr>
<tr>
<td></td>
<td>cracks to be a lack of standardised work because some craftsmen did not follow</td>
<td></td>
</tr>
<tr>
<td></td>
<td>specifications for performing sheathing in weak sections, failing to mount</td>
<td></td>
</tr>
<tr>
<td></td>
<td>strengthening plates in corners.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C. Risk Assessment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High probability of reoccurrence if standardisation is not implemented.</td>
<td>High probability of reoccurrence if door hinges and window mountings are not changed.</td>
</tr>
<tr>
<td>4. Implement</td>
<td>The off-site manufacturing process is targeted, and wall workstations are</td>
<td>Purchasing department is targeted, resulting in changes of subcontractors and new</td>
</tr>
<tr>
<td>(use)</td>
<td>standardised.</td>
<td>routines regarding material acceptance.</td>
</tr>
</tbody>
</table>

The Pareto chart mentioned in section 3 "Analyze" above is related to example 2 and displays the relative frequencies of defects originating from the indicated generic parts of wall, openings and interior installations accounting for 60% percent of all recorded defects in 11 housing projects (60% of 2415).
DISCUSSION AND CONCLUSIONS

Experience data is embedded in knowledge that is stored as information and data in handbooks, drawings, documents, electronic files and (especially), in the heads of individuals. From a design perspective there is a lack of working processes for preventing the reoccurrence of poor solutions, and from a production perspective a lack of tradition regarding routines for filing and compiling problem reports, and documenting deviations and defects (Meiling and Johnsson 2008). The gap between design and manufacture must be understood and eventually minimised in order to optimise product effectiveness in the construction trade, a problem also reported in other industries, e.g. the aviation and automobile industries (Blessing and Wallace 2000, Andersson and Isaksson 2008). For this purpose, relevant data must be acquired and analysed (i.e. a rational experience feedback process is required) since information and knowledge generated from experience only becomes useful in the improvement process when it has been contextualised. From a lean production perspective waste includes all activities and resources used that do not contribute to value for the end user, so compilation of experience data without a target and purpose should be avoided, to avoid creating an information overflow (Fricke 2009).

Based on theoretical studies and case examples from off-site manufacturing a novel feedback model is proposed. The model focuses on prioritising experience data capture and analysis, and incorporates techniques for prioritising the kinds of experience that should be fed back, determining the form in which experience data should be fed back and identifying the destination to which experience-based information should be fed. The proposed approach has similarities to the MOKA method (Stokes 2001) in this respect, since both incorporate refinement of data steps. Other models do not include support for identifying experience feedback, but focus on the importance of live capture of knowledge (Lin et al. 2006, Tan et al. 2007, Kamara et al. 2003). Through live capture and incorporation of contextualized data the proposed model will promote interaction between tacit and explicit knowledge, thus creating new knowledge, as described by Nonaka et al. (2000). Theoretical considerations and empirical data show how analysis of error-detection can enhance the scope for prioritising improvement efforts. In addition, it could facilitate identification of the appropriate receivers of specific kinds of information.

Future work

In future work the proposed model will be formalised and validated. In the next step the working feedback model will have to be synchronised to company production systems as well as to enterprise resource planning systems. Factory production is well suited for information gathering and anomaly reports, often using manual systems such as Kanban cards and note boards for live capture in Oriental countries, while ICT tools are typically used in the West (Nonaka et al. 1996). An interesting extension would be to expand live capture to on-site production with hand-held computers. A further logical step would be to extend experience data collection into the post-production phase, which would ultimately allow the development and implementation of a performance-based, lifecycle approach to the assessment and improvement of constructed assets.

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Meiling and Sandberg


DIGITALISATION OF INSPECTION DATA: A MEANS FOR ENHANCING LEARNING AND CONTINUOUS IMPROVEMENTS?

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DIGITALISATION OF INSPECTION DATA: A MEANS FOR ENHANCING LEARNING AND CONTINUOUS IMPROVEMENTS?

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According to Total Quality Management (TQM), Lean Production and Six Sigma literature, companies should develop organisational arrangements that foster learning from experience and base decisions on facts, since continuous improvements require continuous experience feedback in some form. In Sweden every construction project is checked in several inspections, and data about defects are collected in paper-based “punch lists”, but what happens to these data after the defects have been corrected and the building is delivered to the client? This study describes the current inspection regime in terms of the scope it provides for collecting experience feedback in the Swedish construction industry, and evaluates the extent to which Swedish construction companies recognise this scope. Empirically, it is based on a survey of the views of field superintendents in medium-sized to large building/construction contractors regarding the use of inspection data as a source of experience feedback in their respective companies. The results show that contractors are generally aware that inspection data can provide valuable information for experience feedback and constant improvements, but currently they do not have systems or processes for feeding back experience from inspections. The possibility of replacing paper-based punch lists with a digital system to process and access inspection data is discussed, which it is proposed could provide a means for improving organisational experience feedback-based learning among construction contractors.

Keywords: Automation, Information technology, Inspection, Knowledge-based system, Quality.

INTRODUCTION

The construction sector is generally considered to perform poorly in terms of learning and improvement. For example, according to Latham (1994) construction industry practitioners believe that approaches promoting the management of the corporate memory of their organisation would help to overcome many of the constraints inherent to their sector. However, it has been found that feedback and learning loops are often broken in project-based organisations (Gann and Salter 2000) and that project-based companies lack organisational mechanisms for transferring and applying knowledge acquired from one project to other projects (Prencipe and Tell 2001, Dubois and Gadde

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2002). Staff generally tend to ignore feedback processes, or have too little time to organise or facilitate feedback (Sterman 2000), and as project-based organisations become increasingly decentralised (Lindkvist 2004) and loosely coupled, effectively sharing knowledge becomes increasingly challenging (Orton and Weick 1990). The focus is generally on projects rather than processes, which is a key difference between construction and manufacturing industry cultures (Riley and Clare-Brown 2001).

The Swedish construction industry is regulated by two sets of General Conditions of Contract: AB 04 for (traditional) performance contracts and ABT 06 for design and construct contracts (BKK 2005, BKK 2007). These General Conditions have been drafted by representatives of both contractors and clients, hence they should be well balanced and provide a contractual framework that can be used to facilitate agreements that are acceptable for all parties involved in specific projects. Among other contractual matters, AB 04 and ABT 06 regulate the use and purpose of inspection.

A Final Inspection is compulsory, as well as a 2-year Guarantee Inspection. The client appoints a person he or she feels "is competent" for the job (BKK 2005), usually a consultant construction engineer specialising in inspection. Many of the inspectors are educated by the Swedish National Federation of Construction Engineers (SBR) and certified by SP SITAC (a subsidiary of the SP Technical Research Institute of Sweden) in cooperation with SBR, although there is no requirement for certification. After the inspection the inspector writes an inspection report including a defects list (punch list), which is sent to both the contractor and client. The contractor can then start to correct the defects. In AB 04 and ABT 06, the final inspection is seen merely as a compulsory point at which the project is accepted by the client and legally handed over from the contractor. The 2-year Guarantee Inspection checks for any new defects that may have surfaced since the final inspection (BKK 2005, BKK 2007).

Although regulations concerning quality inspection of construction projects differ between countries, similar problems are associated with current practice across countries, e.g. duplicated work, lack of standardisation and poor communication between on-site contractors and tradesmen. In addition: data are generally manually collected on paper; there are difficulties in monitoring the correction of defects; systems for analysing and verifying causes of defects, and compiling statistics on defect rates etc., are poor or non-existent; and there is usually no feedback system. Cox et al. (2002) and Kim et al. (2008) focused on possible technical approaches to develop and implement an efficient feedback-incorporating inspection system. Such a system could be categorised as part of a Project Knowledge Management (PKM) system.

Information technology (IT)-based support has proven to be a necessary, but not sufficient factor for high-quality PKM. Without good IT-tools PKM is difficult, but the tools themselves are not sufficient to ensure effective PKM if the corporate culture does not encourage their use (Hanisch et al. 2009).

The purpose of this paper is to investigate the extent to which construction companies today recognise that inspections can serve as valuable sources of experience data for continuous improvements, rather than simply as a compulsory step towards project handover, and whether they feel a need for an IT tool to support such use.

The following sections present the theoretical framework of the study. Then, the methodology and results of a survey of Swedish contractors’ representatives’ views of inspections and experience feedback are presented and discussed. Finally, conclusions regarding the implications of the results are drawn and issues that warrant further research are noted.
QUALITY IN CONSTRUCTION

Prompted by customer demands, government legislation and less formal governmental concern, quality management within the Swedish construction sector has intensified in recent years. Laws and regulations have been sharpened to emphasise the importance of quality control, for instance a “Quality Plan” concept was introduced in the Swedish General Conditions of Contract, 1994 (AB 94), and a Plan for Inspections was introduced in the regulations that came into force in 2004 (BKK 2005). Authorities in Sweden require construction companies to have certain knowledge of ISO 9001 (BFS 1996). However, the increasing demands from clients for quality assurance have led to companies implementing a top-down quality approach because their motivation for adopting quality management principles and routines springs solely from a desire not to lose customers (Dale 1999; Gustafsson et al. 2001; Poksinska 2006).

Total Quality Management (TQM) approaches can be summarised in five principles or core values; (1) focus on the customer, (2) base decisions on facts, (3) focus on processes, (4) improve continuously, and (5) foster commitment at all levels in all participants (Dale 1999). The cornerstones are supported by a set of techniques (including Six Sigma, QFD, QC circles, Benchmarking, Supplier partnership, Process management and Self-assessment) and tools (including Design matrices, Pareto diagrams, Quality house applications, Tree diagrams, Ishikawa diagrams, Process maps and Control charts (Bergman and Klefsjö 2003), many of which are also used in the Lean production system (Arnhelter and Maleyeff 2005). Low and Peh (1996) suggest a framework for implementing a Total Quality Management (TQM) quality system in construction. However, it has substantial impediments, summarised by Low and Teo (2004), who state that the success of TQM is yet to be proven in construction. Numerous barriers hinder efforts to improve quality, e.g. failure to: correctly understand customer requirements, both internal and external; understand the capability of the production system; track defects; improve sub-optimised processes; and track quality costs (Sower et al. 1999). A common feature of all of these obstacles is that they originate, ultimately, from poor management and deficient communication (Deming 1986; Svensk Byggtjänst 2007, Josephson and Hammarlund 1999).

The core objectives in Lean theory are waste elimination and value creation (Womack et al. 2007). Liker (2004) presented 14 management principles to help companies adopt Lean working methods, which could be categorised in four groups, the fourth being "Continuously solving root problems". This is to be implemented last and is a fundamental element of attempts to improve quality by minimising defects and mistakes. Essential aspects of this category are to: "go and see for yourself to better understand the situation", "make decisions slowly by consensus by thoroughly considering all options, then implementing them rapidly, and "become a learning organisation through relentless reflection and continuous improvement" (Liker 2004). Continuous improvement is also important in Lean construction theory, e.g. one of Koskela's (1992) 11 Lean principles for the construction industry is that companies should incorporate continuous improvement into their processes.

Experience feedback

The nature of experience lies in its practicality, i.e. something needs to be done to actually gain an experience. Therefore experiences, as well as knowledge, have both tacit and explicit components. The more explicit parts can be relatively easily
documented and explained, but if the person who had the experience participates in the feedback process some of the more tacit elements may also be fed back.

Examples of experience feedback for continuous improvement include improvement of:

- Processes; when employees feed back their experiences in terms of how well the organisation works regarding any aspects, from management strategies to specific work methods;
- Means; when employees feed back their experiences of how well equipment, machines, software, tools etc. work;
- People; when employees feed back their experiences of how well certain people work;
- Products; when employees working downstream of the construction design process, or customers, feed back their experiences of how well products are produced, maintained, used and so forth.

According to Juran (1986), any production is charged with a current level of chronic waste, which can be regarded as the level of opportunity for improvement. From a quality management perspective, defects are signs of sub-optimal product quality and must be detected in order not to reach the customer (Feigenbaum 1991). From a Lean perspective, defects are seen as one of seven types of waste in production, resulting in reductions in long-term profit (Liker 2004).

A recent defect study was conducted by Sigfrid (2007). The study was financed by the Swedish National Board of Housing, Building and Planning (implying that its recommendations may be generally applied). Calculations (based on housing production in 2005) presented in the study indicate that the costs of correcting defects after project delivery in Sweden could amount to 1 300 €M per year calculations based on the 2005 years housing production. The report states that defects are indications of organisational shortcomings and inadequacies in the construction industry.

Josephson and Saukkoriipi (2007) state that Defects, one of their Four Biggest Wastes, account, in various ways, for up to 10% of the total project costs in construction; e.g. costs of hidden and visible defects and inspection costs. Other estimates suggest that costs of correcting defects may account for up to 6% of production costs, highlighting the importance of acquiring knowledge about both costs and causes of defects in order to prevent them arising (Josephson and Hammarlund 1999).

Johnsson and Meiling (2009) examine the severity of defects in industrialised house construction, and suggest that existing defect notations are a neglected source of quality improvement information, which can be used to help realise the benefits of off-site construction. In the cited study, information about defects is extracted and codified from quality documents, compiled during the construction and inspection processes, regarding 11 projects covering 2415 defects, representing ongoing types of waste as long as the companies concerned neglect to access and analyse the causes, and ways to address, the recorded defects (Figure 1). The main reasons for investigating defects are to reduce costs associated with poor quality and to improve production efficiency, product quality and customer satisfaction.
**METHOD**

**Survey design**

The survey was set up through a common web survey service, using individual participant links to the survey. This facilitated the possibility to send out reminders to those who had not yet responded, and provided a certain level of confidence that company representatives selected for inclusion in the sample were the actual respondents. There was also a possibility for respondents to voluntarily enter contact data at the end of the survey, giving further proof that selected representatives were the actual respondents. Answers were anonymised before data analysis.

The survey consisted of several groups of questions concerning matters ranging from general quality strategies to more specific questions about inspections. The inspection-specific part of the questionnaire consisted of nine Lickert-scaled statements and two open-ended questions. The answers from the open-ended questions were analysed and categorised/codified to enable conclusions to be drawn from the data.

**Populations and sampling**

In a first round, the survey was sent to 66 site/production managers and project/factory managers in both medium and large-sized construction contractor companies in Sweden, all of which were members of the Swedish Construction Federation. The companies were both traditional, mostly on-site producing contractors, and members of the industrialised segment, mostly off-site multi-storey housing producers; the authors identified these as two separate populations. This first round was complemented with a second larger dispatch.

The two population groups were sampled in the same way, by selecting one or more site manager(s) and one or more project manager(s) from every company (more than two participants were selected for the bigger companies for reasons explained below). We wanted to maximise randomisation of the sample, as much as possible, but overall the elements were sampled with a convenience approach. For some companies it was possible to obtain a random selection from a company-supplied list of all their available personnel in the population. However, for larger companies with subsidiaries operating in local markets in several regions, pairs of participants were selected for every region. One reason for this was to capture possible differences in ways of working between different parts of the country in the same companies, another was to obtain a better balance in the sample between the large and medium-sized companies. It was assumed
that regionally organised divisions are of approximately the same size in every such company, but no attempt was made to check the validity of this assumption.

RESULTS AND DISCUSSION

Results show there was a response rate of 65 % (43 respondents), of whom 62 % (41) completed the survey.

Forty-one (out of 43) respondents answered the questions about inspections. Out of these one respondent was female, 51 % (21) had a college education or higher, with 21 years experience of the industry, on average. Thirty-one of the respondents were employed in a company working on a national market, five on a regional and five by smaller local companies. The respondents were employed in company types listed in Table 1.

Table 1. No. of respondents and the size of their company.

<table>
<thead>
<tr>
<th>No. of respondents</th>
<th>Size</th>
<th>No. of employees</th>
<th>Annual turnover</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Small</td>
<td>10-49</td>
<td>&lt;10 €M</td>
</tr>
<tr>
<td>19</td>
<td>Medium</td>
<td>50-249</td>
<td>10-50 €M</td>
</tr>
<tr>
<td>16</td>
<td>Large</td>
<td>250-</td>
<td>&gt;50 €M</td>
</tr>
</tbody>
</table>

Twenty-five (out of 41) respondents stated that most of their companies’ production is conducted on-site. Nearly 60 % (24 out of 41) stated that their companies were ISO 9000 certified, four were not certified, but were following ISO 9000 standards anyway, and 11 stated that their company had developed their own Quality System.

Responses to a question intended to rank the three most important sources of new knowledge and project-related experiences indicated that inspections were regarded as the least important source (Table 2). This is probably because there is no good way in today’s practice to get knowledge out of inspection reports, and it is a strong indication that there is potential for future development in this area.

Table 2. Most important sources of knowledge and project-related experiences among the companies.

<table>
<thead>
<tr>
<th>Percent</th>
<th>Clients</th>
<th>Employees</th>
<th>Post-market</th>
<th>Sub-contractors</th>
<th>External sources*</th>
<th>Design consultants</th>
<th>Inspections</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>81</td>
<td>78</td>
<td>44</td>
<td>32</td>
<td>27</td>
<td>22</td>
<td>17</td>
</tr>
<tr>
<td>No. of responses</td>
<td>33</td>
<td>32</td>
<td>18</td>
<td>13</td>
<td>11</td>
<td>9</td>
<td>7</td>
</tr>
</tbody>
</table>

* Such as: University co-operation, monitoring of trends in the industry, trade fairs, external and internal training, in-company experts, experience meetings and cross-industry benchmarking.

Sixty-three percent (of 41 respondents) stated that their company did not have a system for compiling defect data from inspections, but nevertheless 80 % agreed or fully agreed that their company had an expressed goal to reduce the number of defects in inspections (Figure 1). Forty-six percent agreed or fully agreed that their company actively analysed root causes of defects.

Seventy-six percent agreed or fully agreed that their company regarded inspection defects as valuable information, while as many as 88 % personally agreed or fully
agreed that reported defects from inspections provide valuable information. It seems that the respondents mostly agreed with the official company standpoint on inspection data and the common opinion was that useful information is hidden in the reports.

However, 51% of the respondents (21 out of 41) disagreed or fully disagreed that their company made use of these defect data in their improvement work - still 62% of these 21 stated that their company regarded the information as useful and 71% that their company has an expressed goal to reduce the number of defects in inspections.

These findings raise questions about the discrepancies. It is remarkable that half of the respondents felt that their company did not make any use of inspection data for improvement, although most of them regarded the information as useful, and up to 80% of the companies did even have expressed goals to reduce defect rates. A possible explanation is that the companies had not yet started, but were planning, to address these issues in the near future. These questions need further research, and are not further considered in this paper.

Thirty-four percent (14 of 41) stated that their company are compiling statistics about defects. As many as 90% agreed or fully agreed that the use of defects data in their company could be further developed. In responses to a question regarding whether or not they felt assured that defects from one project would not appear in future projects, 54% disagreed of fully disagreed. Fifty-six percent (23 of 41) agreed or fully agreed that their company needed a supporting IT system to better manage information from inspections, while 34% did not agree.

It is not surprising that so few contractors are mining statistics from inspection data, since obtaining relevant information from current manually compiled, paper-based data sources is highly resource-demanding. Hence the results may reflect unease about the
current situation, and awareness that something has to be done, combined with resistance to implementation of an appropriate IT system, due to the complications involved in incorporating such a system into an already broad, diverse and decentralised IT fauna.

Twenty-six (of 41) respondents chose to answer the open-ended questions about inspections, and the responses were categorised according to the stated accessibility of the inspection data (Table 3). The answers imply that many companies have started to store inspection reports, in formats such as project portals, a first step towards a more intelligent solution. Data stored in this way cannot be directly searched and the mining of statistics is still manual, but they are more accessible than on papers contained in a binder in some office.

Table 3. Codified results from open-ended questions on inspection data handling practices.

<table>
<thead>
<tr>
<th>In what way are defect data from different projects saved within the company?</th>
<th>Paper-based archive (e.g. binders)</th>
<th>Digitally within projects (e.g. in digital reports on project portals)</th>
<th>Digitally between the projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of comments</td>
<td>12</td>
<td>12</td>
<td>2</td>
</tr>
</tbody>
</table>

The responses to the second inspection question, concerning the way in which companies use information about defects, show that most companies try, in some way, to note the most common defects and to solve the root causes, but without formalised routines.

On defects

Since defects data are already available in mandatory inspection reports these sources represent a low-hanging fruit, raising questions about why the companies currently use inspection reports only as checklists for correcting defects and make little use of information captured in the audits for further analysis. We believe this is due to several reasons. Firstly, there are no explicit demands to do so from clients or authorities. Secondly, there are cultural reasons (based on norms of traditional on-site and project-based construction); if the development of product quality in the housing industry is to be conducted through the organisations concerned, the poor use of defect data indicate a need for learning rather than a technical, economic problem. The most alarming effect of defects is not the cost of correcting them, but the associated reduction in product quality. The two main reasons for investigating defects are to reduce poor quality costs and to improve product quality and customer satisfaction.
On sampling

In the survey design process it was initially decided on a probability sampling approach in that the authors should randomly select the participants for the samples from company provided lists of their total record of site/production and project managers, a sort of stratified sampling. That approach proved to be very difficult follow. Many of the smaller companies had only a few persons on the requested positions, i.e. not much to randomise. Other companies were not eager to hand out lists of their employees, claiming privacy reasons, and the choice would then be between not asking the company at all to accept those few names provided. Thus it presented a non-probability convenience sampling approach.

Among the two population groups in the survey, the traditional mostly on-site contractors and the industrialised, mostly off-site housing producers, the latter is the smaller number in the matter of share of the building market.

CONCLUSIONS

This paper investigates to what extent construction companies currently recognise inspections as more than a compulsory step towards project handover, but also as a good source of experience data for continuous improvements. Contractors need to make continuous improvements, and it is suggested that many improvements could be facilitated by knowledge about common defects. Contract (final and guarantee) inspections are already mandatory activities in the Swedish construction industry, and conducted on a regular basis, but the information they provide are generally used solely to correct defects before handover to the client. As Johnsson and Meiling (2009) showed, statistics can already be drawn from the current paper-stored data, but the current practice is too resource-consuming and difficult for this to be really powerful and more widely applied.

The empirical data gathered in this study suggest that there is a strong feeling among the contractors in general that inspection data provide valuable information, and some also try to use it for experience feedback and constant improvements, but most companies lack a system or process that supports the feedback of experience-based information provided by inspections.

Future research

It is clearly in the interest of the contractor to develop and implement experience feedback systems that support the input of inspection data for continuous improvements, but this requires the inspectors to conform with the implemented systems, i.e. defect data must be delivered in an appropriate format. This possible obstacle and other uncertainties have to be investigated in future studies.

This study is the first part of a new PhD research project being conducted at the Luleå University of Technology. Next, an interview study with the different role types of construction projects will be conducted, aiming to answer what type of information they would like to pull out from a suggested digital inspection solution.

ACKNOWLEDGEMENT

The authors would like to thank the Swedish Construction Federation for the list of companies, as well as the companies and individuals that participated in the survey.
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CONTINUOUS IMPROVEMENTS THROUGH STEPWISE PROBLEM SOLVING;
A STUDY WITHIN OFF-SITE CONSTRUCTION.

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CONTINUOUS IMPROVEMENTS THROUGH STEPWISE PROBLEM SOLVING – A STUDY WITHIN OFF-SITE CONSTRUCTION

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There is a need for efficient and continuous improvements in the construction industry. The rationale for developing and implementing methods for continuous improvement is well documented. Regardless of the choice of production strategy common denominators are needs to recognize problems and a continuous quality improvement program that incorporates learning from mistakes and success. The purpose of this paper is to explore how targeted systematic problem-solving methodology can support continuous improvements in off-site construction. A Stepwise Problem Solving (SWPS) method is probed within three problem settings in two medium-sized Swedish construction companies. Both companies utilize off-site module manufacturing, a production form with a 15 % market share among professional clients in Sweden (recurrent clients purchasing commercial and multi-storey buildings). This production form appears to be well-suited for implementing methods for continuous improvements, since control is already required in the production process. Results from the three case examples show that the SWPS method targets accuracy in problem-solving, fosters experience-feedback among employees and promotes enhanced communication and learning, ultimately enabling continuous improvements.

Keywords: Continuous improvements, off-site manufacturing, knowledge management, stepwise problem solving

INTRODUCTION

Some construction companies have chosen to face competition by adopting an off-site manufacturing strategy, e.g. module and panel-based building construction. This way of working is thought to increase efficiency and quality, while reducing costs and time compared to on-site construction (Roy et al., 2003; Apleberger et al., 2007). The benefits and possibilities of using off-site methods have been reported by several authors, including Pan and Gibb (2008), Pan et al. (2008) and Johnsson and Meiling (2009). Benefits include, inter alia, enhanced scope for process control, better quality, cost and time reductions. These benefits are obtained via continuous improvements (CI) strongly promoted by quality management advocates of strategies based, for instance, on Total Quality Management, Six Sigma and lean production theories (Arnhiteier and Maleyeff, 2005; Dahlgaard and Dahlgaard-Park, 2006; Haikonen et al., 2004). Bessant et al. (1994) defines CI as “a
company-wide process of focused and continuous incremental innovations”. Hence given an overall strategy of customer focus, i.e. effectiveness, the core principle of CI is the self reflection of business processes. The purpose of CI is the identification, reduction, and elimination of suboptimal processes, i.e. efficiency. The emphasis of CI is on incremental continuous steps, rather than major innovative leaps.

According to Henry (1974), CI and its constituent elements can be analyzed by applying Knowledge Management (KM) theory, since fundamentally it is a learning process. KM is an extensive discipline, embracing a wide range of strategies and practices for handling the intangible assets of organizations. CI is not KM per se, but is described as a KM initiative by (inter alia) Carrillo et al. (2003), Choo et al. (2007), Hsu and Shen (2005). Thus, there is a need for more coherent strategies to manage the creation, handling and use of knowledge through improvement to become a learning organization (Nonaka, 1991; Schein, 2004; Senge, 2006).

A major characteristic of CI is that improvements in processes and procedures are handled according to Deming’s PDCA (Plan-Do-Check-Act) cycle, which could be regarded as a basis for stepwise problem-solving (SWPS). Stepwise, in this context, means that the four stages of PDCA are broken down into more specific routines following a predefined problem-solving process. Structured problem-solving has three main benefits: it promotes learning, provides a means to improve personal problem-solving skills, and helps stabilize production processes (Sobek and Smalley, 2008; Shiba and Walden, 2002). SWPS methods are often applied within small improvement teams, e.g. QC (quality control) circles (Ishikawa, 1985; Deming, 1986). In this context the method is referred to as the QC story (Kume, 1985), typically implemented via “Kaizen” processes by small, short-term, low-cost problem-solving groups (Letens et al., 2006; Farris et al., 2008; Doolen et al., 2008). Kaizen is the Japanese term for improvements conducted in small incremental steps.

According to Kamara et al. (2003), there is a lack of proactive KM strategies within the construction industry, and companies often rely on people as knowledge and experience carriers between projects and departments, as also reported by Meiling and Johnsson (2008). Love et al. (2000) recommend that CI should be used as a vehicle to encourage construction companies to learn from their mistakes and make their building production more efficient and effective. The evolution of CI is described by Bessant et al. (2001) as proceeding through five stages: (1) Unstructured, (2) Structured, (3) Goal-oriented, (4) Proactive and (5) Full capability. According to Bessant et al. (2001), at level two staff use structured problem-solving, there is high participation in CI activities, and staff have been trained in basic CI tools, while at level three the company monitors and measures CI against strategic goals. This paper focuses on a phase in progress towards the second stage, in which a structured strategy for CI activities is sought in the prefabrication of modules for commercial and multi-storey buildings. Off-site timber module manufacturing in Sweden is a building system that was initially developed ca. 50 years ago, but has only recently begun to realize its potential, consequently programs to improve design and factory processes (and thus industry standards) have been launched (Meiling and Johnsson, 2008; Höök, 2008; Söderholm, 2010).

There are powerful motivations for investigating a method that can deliver systematic, continuous improvements in terms of both off-site efficiency and effectiveness, but the implementation of these improvement tools has received little attention in construction-related research to date. Thus, it is interesting to investigate some of the reactive problems that occur downstream, on the construction-site, as they reflect the work methods upstream in the factory and design phases. The aim of this paper is to explore how SWPS methodology can support continuous improvements via targeted, systematic problem-solving, as opposed to the symptom fire-fighting methods commonly applied in construction companies (Meiling and
The application of the first six steps of a nine-step problem solving method, based on the PDCA cycle, in the prefabrication of timber-framed modules is probed. Analysis of the SWPS method is based on a literature study and comparison of existing SWPS methods.

MANAGEMENT FOR CONTINUOUS IMPROVEMENTS

Analysis regarding the efficiency and effectiveness of improvement strategies is in off-site construction mainly based on lean theories (Höök, 2008). Lean production is a manufacturing concept based on the Toyota Production System (TPS) developed by Ohno (1988). It is often equated to waste elimination and value creation (Womack and Jones, 2003), accomplished by reducing unnecessary operations (waste), with simple methods to promote increased flow targeted at creating customer value (Womack et al., 2007). The overall goal is to enhance customer satisfaction, and hence increase market share and profit (Katayama and Bennett, 1996; Karlsson and Åhlström, 1996). Lean theories emphasize the importance of CI and learning (e.g. Liker, 2004), as illustrated by the 4P model, see Figure 1. The 4P model stresses the fundamental requirements for supporting CI activities: long term learning, waste elimination, and leadership that fosters challenge and trust among people and partners. In analogy, TQM values are 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 (Bergman and Klefsjö, 2003; Dale, 1999). Thus, learning per se is not emphasized in TQM, but it will inevitably be an important element of any improvement strategy. The cornerstones of TQM are supported by a set of tools, values and methodologies (Bergman and Klefsjö, 2003), many of which are also used in lean production methodology.

In attempts to promote learning and knowledge-based quality improvement, an integrated approach in which a prescribed methodology is applied, but the context is also considered, can be highly beneficial, as described by Choo et al. (2007), who identified three key method elements: (1) analysis with a set of tools, (2) a SWPS method and (3) common metrics. In order to gain long term quality improvements, the three methodological elements should interact with four contextual elements, namely: (1) support through leadership, (2) resource availability, (3) challenging work and (4) trust, see Figure 1. Similar findings are reported by Bessant et al. (1994), who identify the following drivers for successful implementation of CI: a clear strategic framework, strategic management, supportive culture, enabling infrastructure, process management and supporting toolkit.

Insert figure 1 here

Stepwise problem-solving methodologies

Stepwise problem-solving cycles are organized in TQM and lean production as PDCA and in Six Sigma procedures as DMAIC (Define, Measure, Analyze, Improve, Control; Pyzdek, 2003). The use of SWPS methods in manufacturing originates from the work of Shewhart (1939), and further developed by Deming (1986) and formalized to PDCA by the Japanese in the 1950s (Deming, 1986). Ohno (1988) describes a stepwise approach as complying with a scientific mindset, meaning it is a logical thinking process.

The four steps of the PDCA cycle are: Plan (study the current situation and develop solutions for improvement); Do (take measures on a trial basis); Check (investigate the effect of changes), and Action (standardize on a permanent basis). A major characteristic of PDCA is emphasis on the planning stage (where analysis is a core activity), in which it is important to apply several quality tools, e.g. Ishikawa diagrams, Pareto charts, and Scatter diagrams. In order to develop effective improvement measures, underlying causes of problems must be identified, i.e. root cause analysis is required. Methods that can be used to identify root causes
include: cause and effect analysis, five whys and fault tree analysis (Wilson et al., 1993; Pyzdek, 2003; Bergman and Klefsjö, 2003). Sobek and Smalley (2008) outline a series of benefits of using the A3 format together with SWPS methods, e.g. to promote a logical thinking process, present results in a consistent manner, visualization, and consistency across organizational units. In addition, Imai (1997) emphasize the use of the Standard-Do-Check-Act cycle (SDCA), prior to the PDCA cycle, aimed at stabilization of production processes. A summary of some published existing methods is outlined in Figure 2.

Insert figure 2 here

The constituents of the problem-solving methods are based on a KM framework of experience data capture, transfer and evolution into knowledge. In addition, the methods link contextual information, such as where, why, what and when problems occur (Johnsson and Meiling, 2009) to analytical activities (such as statistical, root cause and risk analysis) and feedback to both internal and external customers. Deming (1993) introduced the use of “Study” instead of “Check”, thus converting the PDCA cycle to a PDSA cycle. In contrast, Sobek and Smalley (2008) emphasize the eastern approach of visualizing results in the planning stage sufficiently to require at most very small corrections after executing measures. In PDCA "Do" is more of a test, while in DMAIC there is an immediate progression to "implementation" after measurement and analysis. Aims of PDCA and SDCA are improvement and endorsement to sustain the change (by incorporating it in routine work management), respectively. According to this conceptual framework, the Control step in DMAIC methodology is associated with the SDCA cycle. Thus, the difference in focus between PDCA and SDCA/DMAIC is in improving a process (PDCA) and sustaining a change (SDCA and DMAIC). Thus, there are clear similarities among the methods presented in Figure 2, and the choice of method is subordinated to the overarching principle of applying a stepwise method that promotes a scientific mindset. Hence, the importance of SWPS as a core activity when pursuing CI goals is stressed by Wu and Chen (2006). Spear and Bowen (1999) also emphasize the importance of conducting SWPS as close to considered events as possible.

OFF-SITE TIMBER MODULE MANUFACTURING

In Sweden, off-site timber module manufacture refers to the prefabrication (>80% off-site) of closed three-dimensional timber modules, each with floor, roof and wall elements. The entire production process (for a 20-apartment building), involves 24 weeks of early client contacts, design for offer, offer negotiations and acceptance, followed by a 20-week design phase, and a 4-week manufacturing phase. Assembly of a building on-site takes one week, but the on-site finishing (installations, etc) requires another four weeks. The completed modules are covered with moisture-proof tarpaulins before transport by truck to the construction-site (Meiling and Johnsson, 2008).

Defects are reported at three control points during production: (1) a factory audit before tarpaulin cover, (2) a final audit before tenants move into the building, and (3) a warranty audit after two years occupancy. Characteristics of defects detected at these three control points are reported in Johnsson and Meiling (2009). Deviations are reported on a daily basis within the company in a visual manner, and color-coded to track their status. The main purpose of the audits is to ensure that deviations have been corrected before units reach the customer. Problems and issues related to safety, quality, lead time, and cost are reported and visualized on whiteboards in short, daily work-group meetings: firstly meetings of the factory production teams, followed by production middle management meetings, then purchase, design, and factory production management meetings, and finally top management meetings. These routines are intended to improve production processes and, ultimately, improve safety, quality, lead times and costs.
RESEARCH APPROACH

The three case studies were based on three different applications of a SWPS method, in each of which one of the authors acted as a SWPS process leader and was in charge of communicating activities and documentation. Empirical results are based on data gathered through interviews and observations from September 2009 to February 2010. Fourteen semi-structured interviews were conducted with seven on-site managers and seven group managers at two module prefabrication companies (one with 99 and the other with 150 employees, with turnovers of €18 M and €34 M, respectively). Both studied companies had adopted a lean overall production improvement strategy with the overall goal to eliminate wasteful practices and promote customer value.

Assembly on-site was identified as the main point at which the quality of upstream processes could be empirically recognized. In order to probe existing problems the on-site assembly of modules was studied during nine field trips to the building sites. Twelve focus group meetings were conducted with varying participants in the three different case examples. A list of problems was compiled from the interviews with on-site managers, reflecting the quality of upstream processes, i.e. how well the design and factory production processes fulfilled customer requirements. The list consisted of approximately 50 problems that were considered to reoccur. The following seven groups were compiled by the authors: (1) Module size variations, (2) Holes and fire proofing, (3) Material logistics, (4) Window adjustments, (5) Door adjustments, (6) Module connections, (7) unclassified quality problems. Photographs illustrating all of the problems were taken and presented at focus group meetings, where the problems were prioritized, and as a result the three case examples were drawn.

The probed stepwise method

An SWPS problem-solving method, synthesized from the published methods listed in Figure 2, was applied, consisting of nine steps representing approximate averages of the corresponding steps in the plan-do-check-act cycles. The nine-step method is outlined in Table 1.

Insert Table 1 here

Steps 1 to 5 represent the plan stage, in which a problem is prioritized and put into context, goals are formulated and root causes are discovered, leading to proposed measures. Step 6 represents the do stage, in which a plan for suggested measures should be presented and executed. Step 7 covers the check stage, in which the effects of actions should be verified. Stages 8 and 9 both represent the act stage, in which knowledge should be accumulated and processes standardized. A3 sheets were used to communicate results in the focus group meetings, and to track activities, under the following headings:

- Problem description, and goals
- Reasons for focusing on the chosen problem – assessing the current status
- Activities
- Concerns
- Results – measures

The A3 display headings relate to the nine-step SWPS method as described in Figure 3.

Insert figure 3 here

Case examples

A case example, in this context, refers to an identified problem, and the procedures used to address it. Three such problems, chosen from the compiled list of reoccurring problems, are considered for each of which problem-solving activity involved three different focus groups.
The case examples were originally presented on A3 sheets. The information presented in Table 2-4 is reduced, to keep the paper’s content on a appropriate level.

Case example 1
Adjustment of windows when finishing a building on-site is a common problem that is conducted just before the last audit, and often consumes substantial time, drawing resources away from fine-tuning the project before the client takes over. This problem may originate from errors or mismatches in several construction stages, such as sales, design, factory production and on-site assembly. There is limited information on the frequency of this problem, but all on-site managers raised it is a matter that requires urgent attention.

Case example 2
The second problem addressed was failure of openings to coincide when connecting modules during completion on-site. This problem was chosen because solutions in factory production are sub-optimal, so addressing it requires duplication of work, on-site. Design and factory staff struggle to maintain consistency with respect to assembly, with the result that several different solutions are applied in the factory, leading to several different solutions on-site. Hence, standard solutions are urgently needed.

Case example 3
Problems associated with adjusting leaky and warped doors are costly, and badly affect client perceptions of the building system. Complaints regarding doors account for 25% of all restoration at one of the case companies.

Case example 1 – Window adjustments
Insert table 2 here

Case example 2 – Failure of openings to coincide when connecting modules
Insert Table 3 here

Case example 3 – Adjustments of warped and leaky doors
Insert Table 4 here

ANALYSIS AND DISCUSSION
The experience feedback through SWPS in the three case examples brought the company units closer together, improving the understanding of internal customer interconnection. As a consequence, new routines were introduced. In addition, in accordance with the wide promotion of relevant personnel visiting the working place in lean literature, design personnel and management were requested to visit sites where problems occur. Through the problem-solving process actors realized the value of this procedure through experience.

Case examples
Case example 1, window adjustments: This problem was raised by on-site crews, i.e. tight working groups of five persons, who were skilled and experienced with the building system, but did not know the cause of the problem. They assumed that windows were mistreated during factory production. Introduction to the planning phase of the SWPS method was a learning experience for the construction workers. They were simply not accustomed to sampling information and pondering root causes. An Ishikawa chart was presented at a group meeting where 15 persons were gathered in one visit to the factory plant together with design representatives. A comment from one of the workers was, “So you mean no single action in particular will solve the problem, but a series of small actions will minimize it?”
Case example 2, openings between modules: Identification and assessment of this problem revealed communication problems between the design, factory production and on-site assembly units. As result a series of actions will be taken to enhance communication prior to production. Both on-site managers and factory group leaders will be able to comment on project details before executing a new project. Information on drawings will be simplified to meet factory production explicit needs. In addition, the design crew will visit the factory during production and on-site assembly, on a regular basis to remain informed about reactions to drawing information. One design engineer participating in the solving process commented, “It seems to me we need to investigate how to find new ways to communicate design in a more production-friendly manner, and to verify exactly how assembly staff solves problems on-site.”

Case example 3, leaky and warped doors: The problem with adjustments of warped and leaky door was revealed through final audits executed by a third party, which are mandatory under Swedish construction project contracts. Firm action could be taken since new routines were adopted in parallel to choosing SWPS as a production improvement method. The new routines involve factory plant managers participating in all final audits on-site, together with a person responsible for handling all deviations and restorations. It was noted by the authors that the person responsible for restorations handled his assignment in a non-structured manner, i.e. without documentation. In two similar projects, 50 alterations were made to satisfy new customers. The SWPS method, which is intended to address larger scope problems, was perceived as less effective, ceremonial and time consuming. The persons involved preferred to solve numerous minor problems rather than spend larger amounts of time tackling root causes in the planning stage, as also reported by Neave and Deming (1990), who found that participants in their study tended to revert to fire fighting, i.e. little “plan” and much “do” rather than to endure the planning and analysis stages.

DISCUSSION AND CONCLUSIONS

Simple things make SWPS effective, i.e. a problem-solving stepwise procedure and the use of pictures and diagrams to visualize problems and acquire an overview of processes in which they arise. Other important aspects are involvement of the persons conducting the problem-solving (a systematic approach to the method). Another important aspect is avoiding personnel spending time addressing problems that they are unable to solve, when it is better to let other kinds of personnel address root causes.

In order to develop a fully-fledged CI approach, off-site manufacturing needs to first establish an approach for standardized work, as it is a vital part of the SWPS method. Structured CI, as described by Bessant et al. (2001), also challenges a company to make extensive managerial changes. The most important function of SWPS is to establish a stabilized level in off-site production, from which the next level can be attained through CI efforts. In this sense it contributes to CI as an emerging and learned pattern of behavior that evolves over time. The case companies have not reached the second stage of CI evolution described by Bessant et al. (2001), but have made an effort to leave the first stage, in which all CI activities are conducted ad hoc.

From a construction design perspective there is a lack of working processes for preventing the reoccurrence of poor solutions, and from a production perspective a lack of tradition regarding routines for filing and compiling problem reports, documenting deviations, and defects (Meiling and Johnsson 2008). The current situation is a state where experience data are pushed out to the organization instead of being pulled in by needs of the organization. The gap between design and manufacturing must be understood and eventually minimized to optimize product effectiveness in module prefabrication, a problem also reported in other
industries, e.g. the aviation and automobile industries (Blessing and Wallace, 2000, Andersson and Isaksson, 2008). SWPS can help close this gap.

A nine-step method for stepwise problem-solving (SWPS), representing all stages of the plan-do-check-act improvement cycle, has been utilized in three case examples. Theoretical considerations and empirical data show that SWPS can reduce defects and enhance learning in module prefabrication. The SWPS method was shown to target accuracy in problem-solving. The various problems generated pull for experience data, and acted as vehicles for experience feedback for both internal and external customers, in a feedback-generating loop. Communication was improved as it was demanded by the SWPS activity. In addition, SWPS was seen to facilitate identification of the appropriate receivers of specific kinds of information, due to tacit knowledge in the problem-solving group. SWPS in module prefabrication was shown to promote enhanced process knowledge about upstream and downstream effects of problems, and thus contributed to an overall goal of improving business results.

Maintaining a strategy of improvements will be challenging for many off-site construction firms. They need to learn about data collection and analysis, and allocate time and resources in the organization to conduct problem-solving and system redesign work. The management of SWPS in the case examples was supervised by one of the authors, but as yet no decision has been taken to appoint and educate problem-solving leaders, or even one person responsible for communication, in either of the two case companies. Moreover, many of the “problems” experienced are associated with relationships among internal customers, and often the optimal solutions lie in changing how work is done in other departments. Perhaps the biggest challenge is to change the culture. The companies must move away from the prevailing fire-fighting, quick fix mentality and commit to the planning stage of SWPS. CI through SWPS has proven effectiveness; therefore the right circumstances must be created to adopt it. However, more islands of success can contribute to change, as shown in the case studies.

Future work

Further work is needed to understand how CI and SWPS methodology could be successfully implemented and integrated in a working process in the off-site construction context, i.e. in regard to supporting leadership, resource availability, trust among employees and challenging work. Thus how sustainable leadership, resource availability, trust among employees and challenging work. Thus how sustainable quality advantages could be achieved in contrast to short term benefits. Inevitably off-site construction needs to apply a level of standardization in order to gain the benefits of systematic problem solving; this is an area for further investigation. Strategic use of information-communication-technology (ICT) through handheld computers is a possibility to promote efficient problem solving, i.e. IT support for experience reporting and defect analysis, in which large amounts of data can be obtained and analyzed.

ACKNOWLEDGEMENT

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TABLES AND FIGURES:

Tables 1-4:

Table 1 Description of the nine steps in the SWPS method probed in the case studies

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Select problem</td>
<td>The problem should be described as precisely as possible, answering the questions: what, which and where?</td>
</tr>
<tr>
<td>2. Clarify reasons</td>
<td>The reasons for choosing the problem should be clearly stated answering the questions: why was the problem chosen, is the problem essential, and is it relevant? The seven quality tools and pictures could be used.</td>
</tr>
<tr>
<td>3. Assess the present status</td>
<td>Describe the present situation with facts from visits at the work place, addressing the question: under what circumstances did the problem occur?</td>
</tr>
<tr>
<td>4. Establish goals</td>
<td>Quantified and realistic goals based on facts and instructions from subordinates, addressing the questions: what will be achieved, at what level, and by when?</td>
</tr>
<tr>
<td>5. Analyze</td>
<td>Probable factors causing the problem should be probed, finding root causes. Ideas for correcting the causes should be discovered. Again the seven QC tools should be used.</td>
</tr>
<tr>
<td>6. Take steps</td>
<td>Present a plan for chosen measures and implement them. Measures must be connected to the analysis results, ad hoc implementation is prohibited.</td>
</tr>
<tr>
<td>7. Verify effect</td>
<td>Did the measures have the sought effect?</td>
</tr>
<tr>
<td>8. Standardize</td>
<td>The problem is not to reoccur before closure of the problem.</td>
</tr>
<tr>
<td>9. Follow up</td>
<td>Debriefing stage, evaluation before starting the next cycle.</td>
</tr>
</tbody>
</table>
Table 2 Representation of A3 display for case example 1

Problem description
Adjustment of windows frequently occurs; adjustments are hindered as window frames are fixed to the framework. Large number of quality control remarks in final audit. Some adjustments are made twice, once in the factory and at assembly on-site. Time-consuming and ceremonional adjustments on-site. The goal is to minimize and allow efficient window adjustments on-site from the next project onwards.

Reasons for choosing the problem – assessing the present

<table>
<thead>
<tr>
<th>Ishikawa diagram:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine</td>
</tr>
<tr>
<td>Lifting</td>
</tr>
<tr>
<td>Crane</td>
</tr>
<tr>
<td>Screw</td>
</tr>
<tr>
<td>Diff. lifts</td>
</tr>
<tr>
<td>Moisture</td>
</tr>
<tr>
<td>Vibrations</td>
</tr>
<tr>
<td>Transport</td>
</tr>
<tr>
<td>Wear</td>
</tr>
<tr>
<td>Lack of feedback</td>
</tr>
<tr>
<td>Adjust to a maximum</td>
</tr>
<tr>
<td>Stress</td>
</tr>
<tr>
<td>Method</td>
</tr>
<tr>
<td>Product quality</td>
</tr>
<tr>
<td>Different suppliers</td>
</tr>
<tr>
<td>Quality problem:</td>
</tr>
<tr>
<td>Jamming</td>
</tr>
<tr>
<td>Windows</td>
</tr>
<tr>
<td>in need of adjustment</td>
</tr>
</tbody>
</table>

Comments from supplier:
Elit windows are P-marked, meaning it has to pass a type test. The window manufacturer’s in-house inspection is reviewed by external auditors. Elit recommends frame screw Adefix™, there is no functional warranty when using regular screws. It is possible to use an eccentric socket, thus avoiding opening the window when installing the socket.

Comments:
Elit windows are preferable due to better quality and pivot mechanism. Wide windows get bent at the lower frame part. At present windows are mounted in cassettes before installation in wall elements, this operation is not standardized and not yet equipped to handle frame screws.

Concerns
Adjustments are conducted in the factory with different methods. Side suspended windows are adjusted in the hinges, after dismounting the windows, with the danger of being bottom adjusted. Pivot mounted windows are adjusted by mounting an extra screw at the lower part of the frame. All windows should be adjusted at-site after assembly of modules.

Results – measures

<table>
<thead>
<tr>
<th>Results from diagonal measurements, project Balder from 22/10:</th>
</tr>
</thead>
<tbody>
<tr>
<td>32 big windows</td>
</tr>
<tr>
<td>16 small w.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project Cederterrasen, Elit windows:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjustments</td>
</tr>
<tr>
<td>No. of w. in total</td>
</tr>
<tr>
<td>Percent</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Complete modules</th>
</tr>
</thead>
<tbody>
<tr>
<td>34 windows OK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stored modules</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 windows OK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Results from factory control 30/10 and 2/11:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Ädelstenen, Elit windows:</td>
</tr>
<tr>
<td>Adjustments</td>
</tr>
<tr>
<td>No. of w. in total</td>
</tr>
<tr>
<td>Percent</td>
</tr>
</tbody>
</table>

Final comments:
The cost of window adjustments is strongly affected by choosing pivot windows. Recommended frame screws will be used in the next project, this will affect how work is performed at the window mounting station, mounting procedure will be standardized. Alternative frame seals will be used to make room for adjustments. New and improved installation methods will be implemented in factory assembly of frames and windows, to facilitate mounting of frame screws.
Table 3 Representation of A3 display for case example 2

**Problem description**
Problems arise during completion on-site, concerning openings between modules for floors and walls. The problem is chosen as duplication of work is performed on-site and solutions are sub-optimal in factory production. Several different solutions are produced in the factory. This leads to several different solutions on-site. The goal is to standardize the module openings.

**Reasons for choosing the problem – assessing the present**
Three different joint categories are considered: 1. Wall joints, 2. Openings without a door, 3. Openings with a door.

**Concerns**
How should details be communicated to the factory to optimize completion on-site? Are current routines good enough? Spread in module distances should be measured. Identify type solutions from interviews. Important to open communication between design and on-site assembly staff.

**Results – measures**

<table>
<thead>
<tr>
<th>Storey</th>
<th>Mean left</th>
<th>Max</th>
<th>Min</th>
<th>Mean right</th>
<th>Max</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24</td>
<td>32</td>
<td>11</td>
<td>23</td>
<td>30</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
<td>30</td>
<td>10</td>
<td>23</td>
<td>33</td>
<td>12</td>
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<tr>
<td>3</td>
<td>22</td>
<td>26</td>
<td>8</td>
<td>22</td>
<td>34</td>
<td>7</td>
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<tr>
<td>4</td>
<td>22</td>
<td>32</td>
<td>10</td>
<td>23</td>
<td>31</td>
<td>14</td>
</tr>
<tr>
<td>Mean</td>
<td>23</td>
<td>30</td>
<td>10</td>
<td>23</td>
<td>32</td>
<td>11</td>
</tr>
</tbody>
</table>

Summary of results from distance measurements:

- Storey 1: Mean left = 24, Max = 32, Min = 11
- Storey 2: Mean left = 22, Max = 30, Min = 10
- Storey 3: Mean left = 22, Max = 26, Min = 8
- Storey 4: Mean left = 22, Max = 32, Min = 10

Comments on measurements: In total 94 openings were measured. Mean values are according to drawings but there are too large spreads in max and mean values to optimize standardization of module interaction in opening. A set of type solutions should be identified to solve the greater deal of opening.

Identified type solutions:
- With floor moulding
- Seamless opening

Final comments:
Type solution with T-cornice, and type solution for sheeting covering without cornice are identified, further openings will be defined. Enhanced communication will be executed prior to production in next project, where all openings will be probed for detail improvements.
Table 4 Representation of A3 display for case example 3

**Problem description**
Problem with adjusting leaky and warped doors. Complaints regarding doors account for 25% of all restorations. Large numbers of quality control remarks in final audit. Time consuming and prolix adjustments on-site. The goal is to minimize and allow efficient adjustments on-site.

**Reasons for choosing the problem – assessing the present status**
Leaky doors lead to cooled air leakage into apartment:

Comments: Door cases are straight in the factory but not on-site. Movements in modules are not known but are assumed to contribute to problem, as well as crossbar movements due to moisture and lifting of modules. Doors with connecting vertical side windows are noted to be inclined to warp.

**Concerns**
There is no single specific cause for door problems, thus it is difficult to prevent occurrence. Minimizing problems through various measures are more realistic. To decrease service costs doors should be easy to adjust. This is not the case. Tenants have requested faster responses regarding corrective measures, this could be accommodated through readily standardized adjustments. The door manufacturers should supply and guarantee non-leaking doors.

**Results – measures**
Rubber-sealed door cases will be tested in the Tegeludden project (January 2010). This should make adjustments easier and less time consuming to carry out, and make factory production more effective. A control function is being introduced in the factory – warped and non straight door cases will be reported prior to installation.

Figures 1-3:

![Image](image_url)

**Figure 1** The 4P model developed from Liker (2004) related to key elements stated by Choo et al. (2007).
Figure 2 Summary of some published methods for SWPS, the extent of each step of P-D-C-A is outlined.

Figure 3 The nine steps in the problem-solving method corresponding to headings in the A3 display.
MANAGING FOR CONTINUOUS IMPROVEMENT IN OFF SITE CONSTRUCTION

Lean management principles

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MANAGING FOR CONTINUOUS IMPROVEMENT IN OFF-SITE CONSTRUCTION

An assessment of Lean management principles

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Abstract

Off-site construction requires higher levels of repetition and process control than on-site construction, making it suitable for application of Lean management principles, methods and tools, which are intended to improve value creation by continuous elimination of waste and improvement of process flows. A state of continuous improvement is a key goal of Lean management. The aim of this study is to test a method to measure the degree to which the 14 lean management principles have been adopted by off-site construction companies, as a prerequisite for a sustainable approach to continuous improvement. Results are based on responses to a questionnaire distributed to management and factory production personnel in two off-site construction firms in Sweden. The study provides information about aspects of the companies that may promote and hinder their full implementation of Lean management. The Likert scores regarding the degree to which Lean principles have been applied in the two studied companies showed similar patterns (and similar differences between the management and production personnel’s responses), indicating that the results can be generalised within an off-site construction context. The study shows that continuous improvements must emerge and evolve simultaneously with a focus on processes, people and long-term thinking.

Keywords: Lean production, off-site construction, continuous improvement

Introduction

Some construction companies have chosen to face competition by adopting an off-site manufacturing strategy, e.g. module and panel-based construction. In addition, several off-site construction companies in Sweden have attempted to apply Lean management approaches to improve process efficiency, a key element of which is continuous improvement (CI) (Jansson, 2010; Meiling et al., 2010; Söderholm, 2010). Off-site construction is more amenable for implementation of lean production concepts than on-site construction since it requires higher levels of repetition and process control (Lessing et al., 2005; Björnfot, 2006; Meiling and Johnsson, 2008), and hence has greater scope for enhancing productivity, customer satisfaction and profits (Roy et al., 2005; Apleberger et al., 2007).

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Lean production incorporates principles, methods and tools that focus on value creation by continuously eliminating waste and improving process flows (Womack and Jones, 2003; Liker, 2004). The “Lean concept” was established by Womack et al. (1990) based on their studies of the Toyota Production System (TPS), a formalisation of the management philosophy applied by the Toyota Corporation. “The Toyota way” or TPS incorporates several key principles captured and organised by Liker (2004) in the 4P model (Figure 1). In this model continuous improvement and learning is at the top of a pyramid, the base of which consists of long-term thinking, process orientation and the development of people and partners. Practical realisation of this model requires stable processes in an environment where standardised work is conducted in a value-generating flow with a focus on people, partners and customers that provides the foundations for improvements (Womack and Jones, 2003).

Figure 1 The 4P model, adapted from Liker (2004)

The 4P model comprises 14 management principles (see Appendix A), which provide the foundations of the TPS practices at Toyota manufacturing plants around the world (Liker, 2004). The 4P model and the management principles can be regarded as fundamental prerequisites for CI activities (Liker, 2004).

CI implies an incremental, ongoing effort to improve products, services or processes (Imai, 1986) that can be regarded as a simple concept with a low entry barrier for even small-scale enterprises (Bessant et al. 1994). The core principle is self-reflection on business processes, i.e. continuous feedback in order to identify, reduce and eliminate sub-optimal processes. Thus, CI should be viewed as a “process intended to achieve improvement” rather than a series of isolated improvement activities (Jha et al. 1996). Further, the cumulative effect of small incremental improvements needs to be directed towards a clear customer focus through company vision and goals (Imai 1997). Bessant and Caffyn (1997) identified several organisational factors that are essential for successful CI implementation, including extensive training in problem-solving and tools, the allocation of resources to manage strategic improvement targets, enabling infrastructure and supporting toolkits for systematic problem-solving. Hence, CI can be viewed as an evolutionary process that needs to be constantly directed and managed (Chapman and Hyland, 2000; Bessant et al., 2001; Wu and Chen, 2006). However, managers tend to over-emphasise the elements of a Lean implementation that can be readily measured and quantified according to pre-set goals. Hence, Achanga et al. (2006) found that the importance of corporate strategic ambitions is over-emphasised in SMEs implementing Lean principles, with an accompanying risk of neglecting the need for contemporaneous evolution of management and personnel commitment.

Managing according to the 14 principles of the 4P-model can be seen as a prerequisite for sustainable improvements, whereby a company continuously solves root problems and becomes a learning organization. If so, it is clearly important to develop robust tools to measure the degree to which these principles have been adopted by companies aiming to espouse lean management. Doolen and Hacker (2005) present a literature review of seven industrial assessment tools for measuring various Lean aspects, and assess a range of
implemented lean practices and adoption levels of these practices within electronics manufacturers. In addition, Taj (2008) applied an assessment method in 65 manufacturing plants based on a method published by Lee (2004). However these methods were not constructed from a lean management perspective. The aim of the study presented here was to test a method to measure the degree to which the 14 management principles are applied in off-site construction companies, based on responses to a questionnaire that was distributed to both management and factory production personnel in two off-site construction firms in Sweden. The assessment method and identified strengths and areas with scope for improvement may facilitate managers’ attempts to implement Lean production concepts and CI.

CHOICE OF METHOD

To fulfil the aims of the study it was of interest to investigate management and production personnel’s experience of their companies’ attempts to implement Lean production principles. A survey seemed to be the most suitable research method, using a questionnaire based on the authors’ perceptions of best practices corresponding to each principle. Two questionnaires were constructed, one for management and one for factory production personnel to enable gap analysis. Different formulations were applied in the two questionnaires. Managers were confronted with direct formulations regarding the management principles, while the production personnel were asked questions related to each principle about actual working practices at their respective companies. The questions are formulated according to how person, team and organisation are related to each principle. In order to facilitate analysis of the answers efforts were made to construct the questions consistently, using a five-point Likert scale to measure the extent of respondent agreement with each statement, ranging from 1 (“do not agree”) to 5 (“fully agree”). In addition, open questions regarding the company vision were included.

The surveyed populations were chosen from two medium-sized Swedish module prefabrication companies, denoted A and B (see Table 1). Both companies self-reportedly used Lean as their overall improvement strategy. To assure that the questions were valid and could be understood, the questionnaires were initially tested on one management representative and a small group of production personnel at one of the companies. Following adjustment based on feedback from the pre-test, questionnaires were distributed and their completion was supervised by one of the researchers. In total, the questionnaires were submitted to 19 (out of 19) management and 146 (out of 189) production workers, covering 100 % of the management and 77 % of the production personnel in the two companies. The production personnel answered the questionnaire during a scheduled break, following a brief introduction by one of the authors. The personnel who did not receive a questionnaire were absent due to vacation, sickness or other reasons. In total, management personnel were asked 27 questions and factory personnel 32 questions, in each case including three open questions. The questions were limited in number so they could be answered in not more than 15 minutes. Levels of order intake are high at both companies, so including more questions would inevitably have affected the personnel’s willingness to answer.

The questionnaire yielded a response rate of 100 % to the Likert scale questions. One of the open questions, regarding time of employment, was answered by all of the managers, 52 out of 82 (63%) of the production personnel in company A, and 49 out of 64 (77%) of the production personnel in company B. Another open question, regarding company vision, was answered by 40 people (49 % of the total) in company A and 29 (45%) in company B.
Companies studied

The chosen companies are both medium-sized organisations with long experience of off-site construction. One of the authors has been involved in several research studies at both companies from 2006 to 2010 (Meiling and Johnsson, 2008; Johnsson and Meiling, 2009; Meiling and Sandberg, 2009) and thus had good access to the companies, as well as thorough knowledge of the processes they apply. Both companies have a clearly stated perception of being off-site construction companies with explicit interest in continuously improving their processes. The case companies compete in the same market, focused on the mid-south-east urban region of Sweden. Both companies have been producing multi-storey buildings since 1996 when the Swedish building code was changed allowing the construction of timber-framed buildings with more than two storeys.

Case company A has 150 employees and €34 million turnover, producing 1,400 modules annually. It is a fourth generation, family-owned company with one production plant that is connected to the sales, design and purchase departments via a recently constructed indoor walkway, enabling good communication. Major investments have been made during the last three years that have doubled the company’s production capacity. All processes are visualised following predefined paths. Wall production is partly automated with CAD-supported mounting of wall frames and nail portals for sheet covering. At the time of the survey the company had been implementing Lean production as their overall improvement strategy for a year, using a holistic approach. 5S had been implemented in all parts of the construction process, i.e. sales, purchase, design and manufacture of on-site assembly units. An effort to standardise some work tasks in the factory had been initiated but not completed.

Case company B has 99 employees and €18 million turnover, producing 900 modules annually. The company is part of a larger group with four production plants, all of which specialise in different types of products. Factory production is based on line-based team work using hand-held power tools. At the time of the survey 5S had been implemented in the factory production plant for two years, and the company was focusing on shortening lead times and enhancing flow and predictability in factory production, but without a clear goal to standardise work.

SURVEY ANALYSIS

The mean scores calculated for responses to questions related to each principle are not regarded as true values that could be generalised in the off-site construction sector; instead statistical analysis is focused on comparison of arithmetic mean scores obtained from the responses between and within companies A and B. Mean values indicating the degrees to which categories C1-C4 from the 4P-model had been fulfilled at the companies are presented in Figure 2. The five-point Likert scale applied implies that the values 3.0, 4.0 and 5.0 represent partly agree, agree and fully agree, respectively. Thus, the value 3.0 is here seen as the level at which improvement efforts according to Lean management principles should have become visible in the company, 4.0 represents maturity with respect to Lean practice, and 5.0 represents excellence. Only the overall management category C3 (People and partners) was graded higher than four (4.1), by managers at company A. However, no overall category (C1 – C4) was valued below 3.0. Company B was scored 3.3 for category C4 (Problem-solving) by its managers.
Scores for some of the underlying principles (P1 – P14) were lower than 3.0 (see Figure 3), indicating that strenuous efforts are required from both companies to become mature “Lean companies”. Overall, management scores for company A scores were higher than those for company B, possibly because company A has introduced the Lean concept in a more holistic manner, while company B has restricted efforts mostly to factory production tools, such as 5S. The results for the C2 – C3 categories also indicate that the relatively high commitment to Lean principles shown by management at company A has not been sufficiently deployed in the organization as a whole.
C1 - Long-term philosophy  
(principle 1)

Both management and production personnel at company A scored the company 3.9 for P1, indicating that the company (as a whole) is quite strongly committed to the long-term philosophy. In company B, both management and production personnel valued P1 lower (3.5 and 3.3, respectively). This probably reflects the differences in approach to Lean production, since company A implements Lean in a more holistic way.

In addition to questions concerning the long-term philosophy an open question was posed regarding company vision. All the managers in company A, but only 40 % of those at company B, could correctly express the company vision. Among the production personnel at company A only 35 % could recall the vision correctly, but at company B none of them one could describe it. Hence, both companies need to further communicate their vision and connect the long-term goals with everyday work.

C2 - The right process will produce the right results  
(principles 2 to 8)

The seven principles underlying C2 relate to diverse aspects of the management of processes in Lean production, e.g. levelling out workloads, stopping to fix problems, standardisation, 5S, and application of thoroughly tested technology. This is probably the main reason why the respondents’ scores varied substantially. The production personnel in both companies scored process flow (P2) more highly than the managers, indicating that the production personnel knew what to do (while not necessarily knowing the process) and a lack of common understanding of the concept among management and production personnel. This is also reflected in the responses to questions regarding pull (P3), which production personnel scored low in both companies, i.e. they experience uneven pace. Both companies scored poorly for stopping production to fix problems in order to get quality right the first time (P5). As both companies started their journey towards Lean production recently, this finding is not surprising, especially since this principle can be regarded as a drastic measure. Another reason for the low scores may be the culture within construction, in which products are seldom rejected, identified problems are usually fixed later in the process, and there is still diffuse demarcation between approved and non-approved production tasks (Johnsson and Meiling, 2009).

Standardisation of work tasks (P6) is a relatively new approach in construction, partly due to the long history of craftsmanship in the industry. Therefore, the scores for production personnel at companies A and B are surprisingly high. Interestingly, the production personnel at both companies stated that they follow common routines and instructions, indicating a misunderstanding of the standardisation concept, since they lack documented guidelines (Meiling and Sandberg, 2009). Management in both companies rank this as an important principle (P6), but there is no broad, formal standardisation of work in either of the companies. Production personnel in both companies awarded low scores for their work with 5S (P7). Thus, even if the management has clear intentions to implement 5S, it has not yet had the intended effect of visualising problems. One reason for this could be that structured problem-solving is not yet fully applied. The responses indicate a lack of communication and resources regarding follow-up and routines for problem-solving.

Managers at company A awarded higher scores than those at company for the last principle (P8) concerning technology, i.e. industrial manufacturing methods or IT-support systems, possibly because company A has only recently spent time and resources to develop an IT-based production system connecting all parts of the production facilities (Jansson, 2010). The question related to this principle that production personnel were asked was whether or not
they agreed that “Machines and equipment support the way I conduct my work tasks very well”. The responses to this formulation can be interpreted as indications that the production personnel are generally satisfied with the production equipment. However, management does not seem to have based equipment procurement on careful analyses, especially not in company B.

**C3 - Add value to the organization by developing your people and partners**  
**(principles 9 to 11)**

Management at both companies A and B affirmed that their respective companies grow leaders from within, thus supporting their long-term visions (P9). However, low scores from the production personnel indicate that most workers do not have the opportunity to become formal leaders. Hence, insufficient resources have been allocated to human resource development in both companies. For questions regarding dedicated personnel (P10) production personnel gave higher scores than management at company B, indicating that the personnel are dedicated to the company business, even if this is not directed towards structured problem-solving in accordance with stated goals.

Managers at company A believe that they challenge and support their long-term cooperation with suppliers (P11). This principle can be seen as a management-focused aspect, and company A’s more holistic approach to Lean philosophy may explain its relatively high scores for P11. However, the experiences of the suppliers were not captured, as they were not included in the survey.

**C4 - Continuously solving root problems drives organizational learning**  
**(principles 12 to 14)**

The question regarding P12 was formulated to determine if management representatives visit the production site (work place) at least once a week, to assess whether managers are close to the production and “see for themselves”. The results imply that management involvement in company A could be improved. Production personnel in company A awarded the company higher scores in this respect than the management, indicating that the managers who visit the working place are mostly those who liaise directly with production personnel. Hence, not all managers in company A identify the factory production plant as the place “where problems are visible”. Principle P12 is related to a common view of problems and how they should be solved (or lack of such a common view), i.e. P14.

It is difficult to formulate a concise question regarding P13; “capture if decisions are made slowly by consensus, thoroughly considering all options and implement decisions rapidly”. The question posed to management was stated according to the description of the principle, while the question posed to production personnel was formulated as “I have time to reflect upon and improve my work”. The scores for P13 were low in both companies. However, production personnel scored P13 higher than management in company B, implying that improvement work is not formalised by management.

Management and production personnel in both companies scored (P14; “become a learning organisation through relentless reflection and continuous improvement”) quite highly (3.5-4.3), especially management at company A. This implies that there is commitment to the principle, but not measurement of the fulfilment of the principle. Both companies have been introduced to the PDCA method, as reported in Meiling et al. (2010), but without fully appreciating the importance of the planning phase, in which collecting facts from all parts of the organisation is a key, but time-consuming activity. There are no formal routines for garnering consensus through standardised communication of the problem-solving activities in either of the companies. A distinction between the companies is that management and
production are situated in one location in company A, but some managers in company B are separated from the production plants. The adverse implications for knowledge dissemination when management and production are separated have been pointed out by various authors, e.g. Nonaka and Kenney (1991) and Garvin (1993). According to the 4P-model, the category C1 at the bottom of the pyramid constitutes the foundation for category C2 and so on. Hence, management failings in terms of some of the principles in lower categories are likely to have effects on all of the higher categories. Structured problem-solving is a vital element of C4 and the need for training regarding problem-solving methods and tools is emphasised by several authors, e.g. Nonaka and Kenney (1991), Garvin (1993) and Choo et al. (2007b). Hence, there is a need for simultaneous evolution in C4 to support achievements in C2 and C3 in order to equip and commit the relevant personnel to focus on identifying and implementing continuous improvement.

Continuous improvement, knowledge, context and method

In order to manage and improve the preconditions for C4, it is important to thoroughly understand CI. According to Henry (1974), CI and its constituent elements can be analyzed by applying Knowledge Management (KM) theory, since fundamentally it is a learning process. KM is an extensive discipline, embracing a wide range of strategies and practices for handling the intangible assets of organizations. CI is not KM *per se*, but is described as a KM initiative by (inter alia) Carrillo et al. (2003), Choo et al. (2007b) and Hsu and Shen (2005). CI promotes and structures learning behaviours, an output of which is knowledge (Vera and Crossan, 2003), this can be illustrated as a CI process loop (see Figure 4).

![Figure 4 A CI process loop illustrating how methodological and contextual elements relate to learning behaviour and created knowledge, adapted from Choo et al. (2007a; 2007b).](image)

Two studies by Choo et al. (2007a, b) consider contextual and methodological elements that support quality improvement initiatives, learning and knowledge creation. The first was based on a questionnaire distributed to personnel at a large US-based computer manufacturer and the second on theoretical considerations. Three methodological elements that support learning and knowledge creation were identified from these studies: use of common metrics, adherence to a stepwise problem-solving approach, and analysis with an appropriate set of tools (Kagioglou et al., 2001). As a complement, Choo et al. (2007b) propose four contextual elements that support sustainable quality improvements. Firstly, leadership support, which is important for providing and sanctioning the direction in the process of learning and knowledge creation. Supportive leadership is characterized by (inter alia) the creation of an organizational system to design and produce products/services, which fosters a creative work environment, and provision of clear direction in all learning and knowledge creation efforts. Secondly, sufficient resources in terms of, e.g. facilities, equipment, information, and funds are required. Overall, the availability of adequate or more than sufficient resources contributes to creativity, autonomous behaviour, and more innovative personnel, leading (inter alia) to
higher levels of learning and knowledge creation (Wiersma, 2007). Thirdly, challenging work is both motivational and directional in the sense that employees and teams faced with challenging tasks can internalize the focus or goals leading to learning and knowledge creation (Choo et al., 2007a). The cited authors also refer to Ghoshal and Bartlett (1994), who describe challenge in an organizational context as an environment in which individuals voluntarily stretch their own standards and expectations, which is connected to the importance of shared ambition, collective identity and personal significance. Finally, building trust encompasses the construction of a psychologically safe environment, where employees have freedom and autonomy to take risks, experiment, explore and learn from failures. However, this element is often underemphasised in quality practice.

There are correlations between the 4P-model and the methodological and contextual elements. For example, the first category and principle stated by Liker (2004) emphasise the importance of long-term philosophy with clear management vision and goals, which is supposed to guide everyday activities and provide inspiration for personnel. The adoption and learning curve of this first category is mostly dependent on the company context, i.e. the degrees of supporting leadership, resource availability, engagement of personnel in the challenge of pursuing the vision and, as noted by Choo et al. (2007a), employees feeling sufficiently secure to initiate improvements that align with the company vision and goals. The next two levels in the 4P-model, process improvements and relations towards people and partners, are equally dependent on learning behaviours and created knowledge, thus they are interrelated to both methodological and contextual elements. In this sense, the top of the pyramid in the 4P-model should function and evolve simultaneously with its “prerequisites”. These important interrelations between CI and feedback, learning and knowledge capability have been highlighted and discussed by several authors, e.g. Garvin (1993) and Nonaka and Kenney (1991).

**RESULTS**

The implications of the results for companies A and B (summarised in Table 4) differ because of the difference in their Lean implementation strategies.

*Table 4 Implications of the results for companies A and B regarding Lean management principles.*

<table>
<thead>
<tr>
<th>Comp.</th>
<th>Princ.</th>
<th>Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>P2</td>
<td>Process flow is connected to defined processes, standardised work and takt time. Process flow is a major concern for management, implementation of takt times is mainly a methodological problem but it also relies on management decisions and resources, i.e. contextual elements.</td>
</tr>
<tr>
<td>B</td>
<td>P3</td>
<td>Pull is a quality measure of how well the processes are designed. Any improvements in the processes need to be carefully monitored to maintain pull.</td>
</tr>
<tr>
<td></td>
<td>P5</td>
<td>Fixing problems at once is currently a problem since due to the culture within construction products are seldom rejected; identified problems are fixed later on in the process. Enhancement requires a clear definition of deviations, i.e. standardised work (see P6).</td>
</tr>
<tr>
<td></td>
<td>P6</td>
<td>Lack of standardisation could be considered as the root cause of low scores for other principles. It will be challenging to implement as projects tend to differ in workload and required tasks.</td>
</tr>
<tr>
<td></td>
<td>P9</td>
<td>Growing leaders is scored low by production personnel, as commitment is high this issue relates to the ability of management to communicate goals and vision through visual metrics, i.e. methodology.</td>
</tr>
<tr>
<td></td>
<td>P11</td>
<td>Requires routines for communication</td>
</tr>
<tr>
<td></td>
<td>P12</td>
<td>Signals a lack of consensus in management of recognising the factory to be “where the action takes place”. As problem-solving is not transparent managers do not know when to visit the factory. The root cause for low scores falls back on P13.</td>
</tr>
<tr>
<td></td>
<td>P8</td>
<td>Choice of technology should focus on people and processes, supported by a structured selection method.</td>
</tr>
</tbody>
</table>

9
For both companies, the analysis displays several strengths and areas with scope for improvement. Management commitment is the driving force when implementing Lean philosophy (Achanga et al., 2006). Due to high scores for many of the principles, managers at company A seem to take that responsibility, as confirmed by the responses to the open question concerning the company vision. However, the approach towards Lean production applied by company B lacks a holistic view to obtain sustainable improvements. The outcome for company A could reflect the will and commitment to Lean philosophy among the managers, but their enthusiasm has not yet reached the production factory level. Company A is a private, family owned company, like Toyota, which might be important for the commitment among the management. Since company B’s businesses are geographically located in different places, the commitment and deployment of P1 is even more important than for company A. Production personnel at company B awarded relatively high scores for several of the principles, even when management at the company awarded them low scores, for instance: P2 (Create a continuous process flow to bring problems to the surface), P8 (Use only reliable, thoroughly tested technology that serves your people and processes) and P13 (Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly). The scores for responses of production personnel at company B indicate that the personnel are dedicated to the company business, which is a major strength when implementing organisational change. In that perspective, company B has good prerequisites to implement Lean management in a more holistic way than the present approach.

**DISCUSSION AND CONCLUSIONS**

The aim of the study was to test a method for measuring the extent to which Lean management via the 14 management principles is applied in off-site construction, identifying strengths and areas with scope for improvement. As representatives of off-site construction companies, two medium-sized timber-framed module prefabrication firms companies in Sweden have been studied. Two companies were considered sufficient to generalise the method. The case study results provide an overview of overall conditions within the studied companies. However, in order to obtain more generalised and detailed results a more extensive survey covering several companies, as well as more detailed case studies, and more questions regarding each principle are needed. However, the study highlighted several aspects that are important for management to be aware of when implementing Lean production in off-site construction.

The tested method generated results that reveal off-site company weaknesses from both bottom-up and top-down perspectives regarding context and method; the scores from the production personnel indicate both how well management has succeeded in the implementation of Lean philosophy and how well production personnel have succeeded in fulfilling management intentions. Even when management gave low scores for one principle, the production personnel at the same company could give the principle higher scores. If management commitment is an essential driving force to implement change, the study indicates that implementing Lean philosophy requires both a top-down and bottom-up approach. Action can be taken from these insights regarding the allocation of resources for training, implementation of new tools and further communication of goals and strategies. The results imply that both companies are weak in terms of both method, i.e. structured problem-solving, and use of quality tools. The results also show strengths in context, i.e. both companies have committed personnel. The Likert scores regarding the degree to which Lean principles have been applied in the two studied companies showed similar patterns (and similar differences between the management and production personnel’s responses), indicating that the results can be generalised within an off-site construction context.
The study shows that the companies have made good progress, considering the short time since they began implementing Lean philosophy (one and two years, respectively), and seem to be building a sound basis for further Lean implementation. The benefits of introducing the Lean concept with a more holistic view (as indicated by the 4P model, see Figure 1) are confirmed by this study. The scores for responses of production personnel indicate that off-site construction personnel are dedicated to the company business, which is a major strength when implementing organisational change, especially since the construction business and culture is strongly steeped in craftsmanship and individual work tasks. Focusing on and deploying a long-term philosophy is essential to obtain sustainable improvements. However, seven of the 14 management principles are focused on the process perspective, while just one focuses on the philosophy, which may lead management to believe that the main focus should be on the process, which is not sufficient if the aim is to excel in CI.

This study shows that the aspects represented by the top of the pyramid in the 4P-model must emerge and evolve simultaneously with their “prerequisites” at the lower levels. This is an important insight as it could affect the way management chooses to implement Lean production. The questionnaire would yield considerably more valuable information if it provided further clarification of contextual and methodological strengths and weaknesses, as well as top-down and bottom-up weaknesses within the investigated organisations. However, this would inevitably require a larger number of questions, which would complicate practical aspects of questionnaire completion and collection.

Proposals for future research

Considering the limited number of companies (two) and questions concerning major principles in Lean management, the results of this study only provide indications of overall conditions within the studied companies. A more extensive survey involving several companies and more questions related to each principle, and more in-depth case studies, are needed to obtain more general and detailed results. In addition, as Lean implementation evolves and CI capacity increases within the studied companies it will become important to measure sought improvements. Implementation of common metrics will become increasingly essential for Lean assessment and for shaping CI activities. In order to benefit from the assessment of Lean management it should be a reoccurring activity conducted on a regular basis.

ACKNOWLEDGEMENT

This work was conducted with support from the Swedish competence platform Lean Wood Engineering. Funding from VINNOVA and the Trelleborg AB foundation is gratefully acknowledged. The authors wish to thank the participating personnel for their time and effort.
## APPENDIX A, THE 14 MANAGEMENT PRINCIPLES

Table 1 Four categories from the 4P model and the comprised 14 principles describing management of TPS, from Liker (2004) and the corresponding questions to management and production personnel.

<table>
<thead>
<tr>
<th>Four categories:</th>
<th>#</th>
<th>14 principles:</th>
<th>Questions #</th>
<th>Questions #</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C1: Long-term philosophy</strong></td>
<td>P1</td>
<td>Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals</td>
<td>1,16,23</td>
<td>1,26</td>
</tr>
<tr>
<td><strong>P2</strong></td>
<td>Create a continuous process flow to bring problems to the surface</td>
<td>2</td>
<td>2,10</td>
<td></td>
</tr>
<tr>
<td><strong>P3</strong></td>
<td>Use pull systems to avoid overproduction</td>
<td>3</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td><strong>P4</strong></td>
<td>Level out the workload</td>
<td>4,17</td>
<td>3,4,19,27</td>
<td></td>
</tr>
<tr>
<td><strong>P5</strong></td>
<td>Build a culture of stopping to fix problems, to get quality right the first time</td>
<td>5</td>
<td>5,12,28</td>
<td></td>
</tr>
<tr>
<td><strong>P6</strong></td>
<td>Standardized tasks and processes are the foundation for continuous improvement and employee empowerment</td>
<td>6,7</td>
<td>13,20,29</td>
<td></td>
</tr>
<tr>
<td><strong>P7</strong></td>
<td>Use visual control so no problems are hidden, i.e. 5S (sort, straighten, shine, standardise, sustain)</td>
<td>8</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td><strong>P8</strong></td>
<td>Use only reliable, thoroughly tested technology that serves your people and processes</td>
<td>18</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td><strong>C2: The right process will produce the right results</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>P9</strong></td>
<td>Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others</td>
<td>9</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td><strong>P10</strong></td>
<td>Develop exceptional people and teams who follow your company’s philosophy</td>
<td>19,24</td>
<td>7,21,22,23</td>
<td></td>
</tr>
<tr>
<td><strong>P11</strong></td>
<td>Respect your extended network of partners and suppliers by challenging them and helping them improve</td>
<td>10,11,12,25</td>
<td>24,31</td>
<td></td>
</tr>
<tr>
<td><strong>C3: Add value to the organization by developing your people and partners</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>C4: Continuously solving root problems drives organizational learning</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>P12</strong></td>
<td>Go and see for yourself to thoroughly understand the situation</td>
<td>13</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td><strong>P13</strong></td>
<td>Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly</td>
<td>14,20</td>
<td>16,30</td>
<td></td>
</tr>
<tr>
<td><strong>P14</strong></td>
<td>Become a learning organization through relentless reflection and continuous improvement</td>
<td>15,21,22,26,27</td>
<td>9,17,18,25,32</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B, QUESTIONS POSED TO MANAGEMENT AND PRODUCTION PERSONNEL

Questions for production personnel

1. The company have a stated long-term philosophy and goals
2. In the production processes I know what is to be delivered to me, what I should deliver, when and to whom
3. When performing work tasks, material and tools are always available when they are needed
4. The management strive for a smooth working pace, considering employees and machines, without overtime work
5. Serious problems are dealt with immediately even if it means temporarily stopping production
6. Implementing 5S has led to fewer disturbances and defects
7. The management supports the production teams attempts to solve problems and make improvements
8. The management visits the production (working place) "to see for themselves" at least once a week
9. Within the company we focus on solving problems, not on who might have been causing them
10. Work processes, sub-processes and activities are easy to grasp
11. My working pace is even and I have time to deliver what is required in the next step in the production process
12. When production problems occur resources are always available for solving them quickly
13. The working teams strictly follow common routines regarding how work should be conducted
14. Machines and equipment support how I conduct my work tasks very well
15. Within the company I have the possibility for personal development and to make a career
16. I have time to reflect upon and improve my work
17. We are encouraged to submit improvement proposals
18. In the company we strive to solve problems systematically
19. I try to level out the work load in the team
20. In my work I apply common work routines/instructions
21. I enjoy my work
22. We apply work rotation
23. I try to influence and develop the way my work is conducted
24. I report any deviations regarding subcontractors
25. We continuously reflect upon and improve production processes
26. I feel involved in the company’s vision and its long- and short-term goals
27. Support is available when I need it, and I also support other co-workers
28. I am allowed to stop the production if serious problems occur
29. I am involved with formulating working instructions to help work to be conducted in the best way (efficiently and effectively)
30. I believe that the production management have confidence in me
31. I have confidence in our subcontractors
32. In our team we’re solving problems together

Questions for management

1. Decisions are based on a long-term philosophy, even at the expense of short-term financial goals
2. Company processes are transparent considering internal customers, process input and output.
3. We strive for pull in production, where each process only produces what is needed in the next step in production.
4. We strive for a smooth working pace considering machines and employees
5. Problems are dealt with directly, even if it means temporarily stopping production
6. Standardised work is a foundation for continuous improvement
7. Standardised work is a foundation for personnel involvement
The result of 5S implementation is that problems become visible and the workers can correct them. We identify and recruit leaders from within the company, which supports company vision and goals. We strive for long-term cooperation with suppliers. We place high requirements on our suppliers. We regularly give feedback to our suppliers. Management representatives visit the production (working place) “to see for ourselves” at least once a week. We strive to make decisions slowly and in mutual agreement, but implement them quickly. We strive to become a learning organisation by continuously reflecting upon and improving business processes. We communicate the company vision, long- and short-term goals to all employees. We strive to focus on the operator and operator support. We only introduce reliable and thoroughly tested technology. We strive to develop people and teams to work in accordance with the company vision and goals. Problem solving is systematically conducted, implying that problems do not reoccur. We use cross-functional teams to solve severe problems. Employees are encouraged to submit improvement suggestions. We formulate challenging production goals in order to motivate employees. We apply work rotation. Our employees report any deviations regarding subcontractors. We apply problem-solving systematically, to continuously improve processes. We are confident that the employees and the teams solve production-related problems in the best way possible.

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Dr. Fredrik Backlund is an Assistant Professor at the Division of Quality and Environmental Management, Luleå University of Technology, Sweden. His research activities are centred on total quality management and maintenance methodologies, such as total productive maintenance and reliability-centred maintenance.

Associate Professor Helena Johnsson is a senior lecturer at the Division for Structural Engineering – Timber Structures at Luleå University of Technology, Sweden. Her work focuses on research and development projects regarding the stability of timber structures in multi-storey buildings.
References


Appendix 1: Stepwise problem-solving methods
Appendix 2: Questionnaire; experience feedback practice
Appendix 3: Questionnaire; Lean principles – management
Appendix 4: Questionnaire; Lean principles - production personnel
### SWPS Methods

<table>
<thead>
<tr>
<th>SWPS methods:</th>
<th>Plan</th>
<th>Do</th>
<th>Check</th>
<th>Act</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Asaka &amp; Ozeki</strong>&lt;br&gt;(1990, p.112)</td>
<td>Understand problem&lt;br&gt;Set target&lt;br&gt;Factor analysis&lt;br&gt;Discuss improvement measures</td>
<td>Implementation of plan</td>
<td>Evaluate improvement result</td>
<td>Make improvement permanent</td>
</tr>
<tr>
<td><strong>Bergman &amp; Klefsjö</strong>&lt;br&gt;(2003 p.213)</td>
<td>Identify project&lt;br&gt;Appoint improvement team&lt;br&gt;Problem analysis&lt;br&gt;Look for causes&lt;br.Evaluate the result</td>
<td>Take steps</td>
<td>Measure and evaluate results</td>
<td>Make permanent the improved quality level</td>
</tr>
<tr>
<td><strong>Brassard</strong>&lt;br&gt;(1989 p.260)</td>
<td>Select problem&lt;br&gt;Describe current process&lt;br&gt;Describe possible causes&lt;br&gt;Develop effective solutions and plan</td>
<td>Implement solutions</td>
<td>Review and evaluate result</td>
<td>Reflect and act on learning’s</td>
</tr>
<tr>
<td><strong>De Feo</strong>&lt;br&gt;(2004 p.221)&lt;br&gt;DMAIC</td>
<td>Define: identify potential project&lt;br&gt;Measure: map and measure the problem process&lt;br&gt;Analyse: input and output variables</td>
<td>Improve: plan, conduct, optimise, evaluate, implement</td>
<td>Control: document improvements and implement new process</td>
<td>(New process)</td>
</tr>
<tr>
<td><strong>Deming</strong>&lt;br&gt;(1986 p.88)</td>
<td>Find improvement opportunity&lt;br&gt;What data is available?&lt;br&gt;Are new observations needed?&lt;br&gt;Plan a test</td>
<td>Carry out the test</td>
<td>Observe the effects&lt;br&gt;Study the results</td>
<td>Compile lesson learnt</td>
</tr>
<tr>
<td><strong>Hostani</strong>&lt;br&gt;(1989 p.74)</td>
<td>Select topic&lt;br&gt;Understand situation and set targets&lt;br&gt;Plan activities&lt;br&gt;Analyse causes</td>
<td>Consider and implement countermeasures</td>
<td>Check results</td>
<td>Standardise and establish control</td>
</tr>
<tr>
<td><strong>Imai</strong>&lt;br&gt;(1986 p.76)</td>
<td>Definition of problem&lt;br&gt;Analysis of problem&lt;br&gt;Identification of causes&lt;br&gt;Planning countermeasures</td>
<td>Implementation of solution</td>
<td>Confirmation of result</td>
<td></td>
</tr>
<tr>
<td><strong>Ishikawa</strong>&lt;br&gt;(1985 p.147)</td>
<td>Deciding on a problem (theme)&lt;br&gt;Clarifying as to why the theme is chosen&lt;br&gt;Assessing the present situation&lt;br&gt;Analysis, probing into causes,</td>
<td>Establishing measures and implementation</td>
<td>Evaluating results</td>
<td>Standardisation&lt;br&gt;Investigating remaining problems&lt;br&gt;Planning for the future</td>
</tr>
<tr>
<td><strong>Juran</strong>&lt;br&gt;(1992 p.401)</td>
<td>Identify problems&lt;br&gt;Describe symptoms&lt;br&gt;Theorise as to causes&lt;br&gt;Test theories by data collection and analysis&lt;br&gt;Identify causes&lt;br&gt;Propose remedy&lt;br&gt;Design remedy</td>
<td>Test remedy</td>
<td>-</td>
<td>Establish controls</td>
</tr>
</tbody>
</table>
## Some Existing SWPS Methods

### Appendix 1

<table>
<thead>
<tr>
<th>SWPS Methods:</th>
<th>Plan</th>
<th>Do</th>
<th>Check</th>
<th>Act</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Juran</strong> (1999 app. V)</td>
<td>Identify project</td>
<td>Remedy the causes: implement</td>
<td>Hold the gains: design control</td>
<td>Replicate results and nominate new projects</td>
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<tr>
<td></td>
<td>Establish the project: select team</td>
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<tr>
<td></td>
<td>Diagnose the causes: identify root causes</td>
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<td></td>
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<tr>
<td><strong>Kume</strong> (1985 p. 192)</td>
<td>Identification of problem</td>
<td>Eliminate causes</td>
<td>Confirm actions</td>
<td>Standardise</td>
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<tr>
<td></td>
<td>Investigate and collect information</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Analysis; find main causes</td>
<td></td>
<td></td>
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<tr>
<td><strong>Liker</strong> (2004 p. 256)</td>
<td>Problem perception</td>
<td>Countermeasure; neutralise harm</td>
<td>Evaluate measures</td>
<td>Standardise</td>
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<tr>
<td></td>
<td>Clarify problem</td>
<td></td>
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<tr>
<td></td>
<td>Locate point of cause</td>
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<tr>
<td></td>
<td>Reveal root causes</td>
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<tr>
<td><strong>Pascal</strong> (2006, p. 167)</td>
<td>Sense the problem</td>
<td>Implement countermeasures</td>
<td>Evaluate effect</td>
<td>Standardise and train</td>
</tr>
<tr>
<td></td>
<td>Problem statement</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Collect and analyse data</td>
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<tr>
<td></td>
<td>Casual analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Select and plan countermeasures</td>
<td></td>
<td></td>
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<tr>
<td><strong>Pyzdek</strong> (2001 p. 238)</td>
<td>Define goals of improvement activity</td>
<td>Improve system</td>
<td>Control new system and standardise</td>
<td>(Standardise)</td>
</tr>
<tr>
<td></td>
<td>Measure existing system</td>
<td></td>
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<tr>
<td></td>
<td>Analyse to define gap between goals and performance</td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>Quest Worldwide</strong> (2007, p. 8)</td>
<td>Define requirements and identify the problem(2)</td>
<td>Implement your plan</td>
<td>Track progress and sort out problems</td>
<td>Review your success and learning</td>
</tr>
<tr>
<td></td>
<td>Gather data</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Analyse problem</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Generate ideas and options</td>
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<tr>
<td></td>
<td>Make decisions</td>
<td>Make things stick</td>
<td></td>
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<tr>
<td></td>
<td>Plan for action</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rambaud, 8D</strong> (2006, p. 2)</td>
<td>Form a problem solving team(1)</td>
<td>Implement and verify interim containment Actions(3)</td>
<td>Define and Verify Root Causes(4)</td>
<td>Prevent recurrence(7)</td>
</tr>
<tr>
<td></td>
<td>Describe and define the problem(2)</td>
<td>Implement permanent corrective actions(6)</td>
<td>Verify Correction Actions(5)</td>
<td>Congratulate your Team(6)</td>
</tr>
<tr>
<td><strong>Shiba</strong> (1993, p. 86)</td>
<td>Select theme</td>
<td>Plan and implement solution</td>
<td>Evaluate effects</td>
<td>Reflect on process</td>
</tr>
<tr>
<td></td>
<td>Collect and analyse data</td>
<td></td>
<td>Standardise solution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Analyse cause</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Lillrank and Kano</strong> (1989, p.)</td>
<td>Select Theme</td>
<td>Countermeasures</td>
<td>Confirm the effect</td>
<td>Standardise</td>
</tr>
<tr>
<td></td>
<td>Grasp the current situation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Analysis</td>
<td></td>
<td>Identify remaining problems</td>
<td></td>
</tr>
</tbody>
</table>
Förbättringsarbete genom erfarenhetsåterföring inom

1. Information om enkäten

Tack för att du vill medverka till att skapa ny kunskap!

Avdelningarna för Byggkonstruktion och Byggproduktion vid Luleå tekniska universitet har under flera år samarbetat med byggindustrin, för att hjälpa till att utveckla nya arbetsmetoder, höja kvaliteten och minska kostnader. Syftet med denna undersökning är att ta reda på hur svenska byggföretag arbetar med systematiskt förbättringsarbete och erfarenhetsåterföring.


Enkäten genomförs av doktoranderna John Meiling och Robert Lundkvist och ingår i forskningsprojekt inom området erfarenhetsåterföring. Om du har frågor om enkäten och eller vår forskning, tveka inte att höra av dig till oss.

Med vänliga hälsningar

John Meiling, Avdelningen för Byggkonstruktion
john.meiling@ltu.se, 0920-491818

Robert Lundkvist, Avdelningen för Byggproduktion
robert.lundkvist@ltu.se, 0920-491044

Klicka Nästa för att börja svara.

2. Allmänna frågor

Allmänna frågor om dig som svarar.

* 1. Ålder?

* 2. Kön?
   - Kvinnla
   - Man

* 3. Vilken är din senast avslutade examen/utbildning?
   - Gymnasium eller motsvarande
   - Högskoleingenjör/Kandidat
   - Civilingenjör/Master
   - Licentiat- eller doktorsexamen

* 4. Hur många år har du arbetat i byggbranschen?
Förbättringsarbete genom erfarenhetsåterföring inom

5. Hur många år har du arbetat i företaget?

6. Hur stor marknad arbetar företaget på?
- Rikstäckande
- Regionalt
- Lokalt

7. Hur stort är företaget du jobbar på?
   Antal anställda: _______________________
   Omsättning (Mkr): _____________________

8. Huvuddelen av mitt företags produktion sker
   - Platsbygg
   - i fabrik (element/moduler/prefab)

3. Platsbyggare

9. Vilken befattning har du vid företaget?
   - Platschef
   - Arbetschef eller motsvarande
   - Annat, i så fall vad?

4. Fabrikstillverkare

10. Vilken befattning har du vid företaget?
    - Arbetschef/Montagechef
    - Platschef/Fabrikschef
    - Annat, i så fall vad?
### Förbättringsarbete genom erfarenhetsåterföring inom

**11. Vilket kvalitetssystem har ditt företag?**

- [ ] Vi är certifierade enligt ISO9000-serien
- [ ] Vi följer ISO9000-serien men är ej certifierade
- [ ] Det följer ej ISO9000-standard
- [ ] Annat/Egetutvecklat kvalitetssystem
- [ ] Vi har inget kvalitetssystem
- [ ] Vet ej

**Frivillig kommentar:**

**12. Har företaget ett pågående program/projekt för att effektivisera produktionen/tillverkningen?**

- [ ] Ja
- [ ] Nej
- [ ] Vet ej

Om ja, beskriv vad programmet går ut på.

**13. Välj de tre viktigaste källorna till ny kunskap och erfarenheter i ditt företag?**

- [ ] Egen personal
- [ ] Kunder (beställare)
- [ ] Besiktningar
- [ ] Konsulter
- [ ] Underentreprenörer
- [ ] Eftermarknad (slutkunders klagomål/reklamationer)
- [ ] Annat

Om Annat, ge exempel.

**14. Företaget har IT-stöd för hantering av reklamationer.**

- [ ] Nej
- [ ] Ja

Om ja, ange typ av IT-stöd (ex. webbaserat)
### Förbättringsarbete genom erfarenhetsåterföring inom

<table>
<thead>
<tr>
<th>15. I hur stor omfattning lagras ny kunskap och erfarenheter, från företagets produktion, på följande ställen?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Som personliga erfarenheter hos ansvarig platschef</strong></td>
</tr>
<tr>
<td><strong>Som personliga erfarenheter hos yrkesarbetarna</strong></td>
</tr>
<tr>
<td><strong>I protokoll/anteckningar från slutmöte</strong></td>
</tr>
<tr>
<td><strong>I protokoll/anteckningar från erfarenhetsåterföringsmöte</strong></td>
</tr>
<tr>
<td><strong>I en för företaget central databas</strong></td>
</tr>
<tr>
<td><strong>I en nätverksanslutet dator, t.ex. på det lokala kontoret</strong></td>
</tr>
<tr>
<td><strong>I arkiv/pärmar</strong></td>
</tr>
<tr>
<td><strong>På annan plats (obs! frivillig)</strong></td>
</tr>
<tr>
<td><strong>Om på annan plats, i så fall var?</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>16. I hur stor omfattning anskaffar du erfarenheter, från andra projekt inom företaget, från följande ställen?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Från kollegor på möten/fikaraster, etc.</strong></td>
</tr>
<tr>
<td><strong>Från sammanställningar av erfarenheter från avslutade projekt</strong></td>
</tr>
<tr>
<td><strong>Genom att söka på en projektportal</strong></td>
</tr>
<tr>
<td><strong>Genom att söka i arkiv/pärmar</strong></td>
</tr>
<tr>
<td><strong>Från underentreprenörer</strong></td>
</tr>
<tr>
<td><strong>Från konsulter</strong></td>
</tr>
<tr>
<td><strong>Från beställare</strong></td>
</tr>
<tr>
<td><strong>Från annan plats (obs! frivillig)</strong></td>
</tr>
<tr>
<td><strong>Om från annan plats, i så fall var?</strong></td>
</tr>
</tbody>
</table>

### 6. Allmänt förbättringsarbete & erfarenhetshantering

Dessa påståenden tar reda på hur eft företag arbetar med återföring av ny kunskap och erfarenheter från projekt tillbaka till nya projekt. Erfarenheter kan röra allt från utvärdering av nya produktionsmetoder till uppkomna fel i slutprodukten.
Förbättringsarbete genom erfarenhetsåterföring inom 

17. Hur väl håller du med om följande påståenden?

<table>
<thead>
<tr>
<th></th>
<th>Håller absolut inte med</th>
<th>Håller inte med</th>
<th>Håller med</th>
<th>Håller absolut med</th>
<th>Vet ej</th>
</tr>
</thead>
<tbody>
<tr>
<td>Det är lätt att få tag på erfarenheter inom företaget.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Företaget har ett fungerande system för att registerasvara erfarenheter.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Företaget arbetar aktivt med att följa upp rapporterade fel.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Företaget vill förbättra sin process för erfarenhetsåterföring.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jag ser klar förbättringspotential inom företagets hantering av erfarenheter.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jag känner mig trygg i att fel ej återupprepas i framtida projekt.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Företaget arbetar fortlöpande med förbättringsarbete.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Företaget arbetar med stegvis problemlösning som metod.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Frivillig kommentar: 

7. Besiktningsanmärkningar i förbättringsarbetet

Inom byggentreprenader finns ett antal olika typer av besiktnningar. Följande frågor syftar på alla former av entreprenadbesiktnningar, såsom slut- och garantibesiktning, som utförs av en av beställaren utsedd besiktningsman.
## Förbättringsarbete genom erfarenhetsåterföring inom företaget

### 18. Hur väl håller du med om följande påståenden?

<table>
<thead>
<tr>
<th>Håller absolut inte med</th>
<th>Håller inte med</th>
<th>Håller med</th>
<th>Håller absolut med</th>
<th>Vet ej</th>
</tr>
</thead>
<tbody>
<tr>
<td>Företaget har ett system för att sammanställa besiktningsanmärkningar mellan projekt.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Företaget arbetar aktivt med att följa upp grundorsaker till noterade besiktningsanmärkningar.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Företaget ser besiktningsanmärkningar som värdefull information.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Företaget utnyttjar besiktningsanmärkningar systematiskt i sitt förbättringsarbete.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Företaget tar fram satsastik på fel mellan projekt, för att identifiera viktiga förbättringsområden.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Företaget är i behov av ett IT-stöd för att bättre hantera informationen från besiktningar.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Jag ser besiktningsanmärkningar som värdefull information.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Jag anser att användningen för besiktningsanmärkningar inom företaget kan utvecklas.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Företaget har ett uttalat mål att minska antalet besiktningsanmärkningar.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

Frivillig kommentar:

---

### 19. Beskriv med egna ord på vilket sätt besiktningsanmärkningar från olika projekt sparas inom företaget?

---

### 20. Beskriv med egna ord på vilket sätt information från besiktningsanmärkningar nyttjas i företaget?

---

### 8. Förbättringsförslag från medarbetare
## Förbättringsarbete genom erfarenhetsåterföring inom företaget

### 21. Hur väl håller du med om följande påståenden?

<table>
<thead>
<tr>
<th>Påstående</th>
<th>Håller absolut inte med</th>
<th>Håller inte med</th>
<th>Håller med</th>
<th>Håller absolut med</th>
<th>Vet ej</th>
</tr>
</thead>
<tbody>
<tr>
<td>Företaget har ett fungerande system för att hantera förbättringsförslag.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Företaget värdesätter förbättringsförslag från personalen.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Förståget implementerar kontinuerligt goda förbättringsförslag.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personalen tycker att det är meningsfullt att lämna in förbättringsförslag.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personalen upplever att de får tillräcklig feedback/återkoppling på sina förbättringsförslag.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Företaget implementerar kontinuerligt goda förbättringsförslag utan onödigt dröjsmål.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>De förbättringsförslag som lämnas in är i regel relevanta.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jag ser ett värde i att få förbättringsförslag från övriga medarbetare.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jag anses att företaget borde kunna få in fler relevanta förbättringsförslag från medarbetarna än idag.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jag anses att förbättringsförslag inom företaget kan uppmuntras mer.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 9. Erfarenhetsmöten

22. I hur stor omfattning gäller följande, för förbättringsförslag från medarbetare, i ditt företag?

<table>
<thead>
<tr>
<th>Omfattning</th>
<th>Inte alls</th>
<th>I liten omfattning</th>
<th>I viss omfattning</th>
<th>I stor omfattning</th>
<th>Vet ej</th>
</tr>
</thead>
<tbody>
<tr>
<td>De kan lämnas in via någon form av &quot;förslagslåda&quot;.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>De kan lämnas in anonymt.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>De kan lämnas till närmaste chef.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>De uppmuntras genom någon form av &quot;morot&quot;.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Frivillig kommentar:

---

**APPENDIX 2**

Page 7
Förbättringsarbete genom erfarenhetsåterföring inom

Avslutande erfarenhetsmöten är ett möte som projektdelegatgärna håller efter avslutat möte för att tanka av enskilda projektdelegatgar/parter deras erfarenheter från det avslutande projektet, med syfte att finna förbättringsmöjligheter.

Slutmöten hålls i regel mellan beställare/kund och general/totalentreprenör för att reglera de sista frågorna kring kontraktet mot ett godkännande av entreprenaden.

23. Hur väl håller du med om följande påståenden?

<table>
<thead>
<tr>
<th>Håller absolut inte med</th>
<th>Håller inte med</th>
<th>Håller med</th>
<th>Håller absolut med</th>
<th>Vet ej</th>
</tr>
</thead>
<tbody>
<tr>
<td>Företaget genomför erfarenhetsmöten efter avslutat projekt.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Företaget utnyttjar slutmötet till att finna förbättringsmöjligheter.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Företaget utnyttjar slutmötet till erfarenhetsåterföring på något sätt</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Företagets erfarenhetsmöten följer en standardiserad mall/dagordning</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Jag anser att erfarenhetsmöte efter avslutat projekt är ett bra sätt att samla in erfarenheter.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Jag ser klar förbättringspotential kring erfarenhetsmöten.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Frivillig kommentar:

10. Frivilliga kontaktpuppgifter

Om du vill vara med i utloppningen av biobiljetter, fyll i e-postadress eller telefonnummer nedan.

Avsluta enkätten genom att klicka på Lämna in.

Tack för din medverkan!

24. E-post:

25. Telefon:
1.27 Att arbeta med 5S har medfört att personalen själva upptäcker problem och kan rätta till dem.
### 1. Frågor

1.28 Företagets vision lyder:

1.29 Egna kommentarer:

### 2. Bakgrundsfakta

2.1 Mina arbetsuppgifter:

2.2 Antal år på företaget:
# Appendix 4

<table>
<thead>
<tr>
<th>EvaSys</th>
<th>Arbetaplatsernät för produktion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luleå Tekniska Universitet</td>
<td>John Melling</td>
</tr>
<tr>
<td>Träbyggnad</td>
<td>Ständiga förbättringar i industrielt byggnade</td>
</tr>
</tbody>
</table>

Mark as shown: ☐ ☐ ☐ ☐ ☐ Please use a ball-point pen or a thin felt tip. This form will be processed automatically.
Correction: ☐ ☐ ☐ ☐ ☐ Please follow the examples shown on the left hand side to help optimize the reading results.

## 1. Frågor

| 1.1 Företaget arbetar med längsiktiga visioner och instämmer ej | 1.1 Instämmer helt |
| 1.2 I produktionen vet jag vad som skall levereras till mig, och vär | 1.2 Instämmer helt |
| 1.3 I mitt arbete har jag alltid tillgång till material och verktyg när jag behöver det | 1.3 Instämmer helt |
| 1.4 Ledningen eftersträvar en jämn belastning på medarbetare och maskiner | 1.4 Instämmer helt |
| 1.5 Om allvarliga problem uppstår rättas de till direkt, även om det medför att produktionen stannar tillfälligt | 1.5 Instämmer helt |
| 1.6 Arbetet med SS har medfört (att arbetet får) färre störningar och fel | 1.6 Instämmer helt |
| 1.7 Ledningen stödjer att arbetslagen gemensamt arbetar med problemlösning och förbättringar | 1.7 Instämmer helt |
| 1.8 Personer från ledningen besöker produktionen minst en gång i veckan | 1.8 Instämmer helt |
| 1.9 Inom företaget fokuserar vi på lösning av problem, inte på vem som kan ha orsakat problemen | 1.9 Instämmer helt |
| 1.10 Vi arbetar med tydliga processer, delprocesser och aktiviteter | 1.10 Instämmer helt |
| 1.11 Jag har en jämn arbetstakt och hinner leverera det som efterfrågas av nästa led i produktionen | 1.11 Instämmer helt |
| 1.12 När produktionsproblem uppstår finns alltid resurser för att snabbt åtgärda problemet | 1.12 Instämmer helt |
| 1.13 Varje arbetsslag följer gemensamma rutiner för hur arbetet skall utföras | 1.13 Instämmer helt |
| 1.14 Maskiner och utrustning stödjer väl det arbete som skall utföras | 1.14 Instämmer helt |
| 1.15 Jag har möjlighet till personlig utveckling och karriär inom företaget | 1.15 Instämmer helt |
| 1.16 Jag har tid att reflektera och ständig förbättra mitt arbete | 1.16 Instämmer helt |
| 1.17 Vi uppmuntras att lämna förbättringsförslag | 1.17 Instämmer helt |
| 1.18 Inom företaget eftersträvar vi att lösa problem systematiskt | 1.18 Instämmer helt |
| 1.19 Jag försöker bidra till en jämn arbetsbelastning i laget | 1.19 Instämmer helt |
| 1.20 Jag följer gemensamma rutiner/instruktioner för hur arbetsuppgifter skall utföras | 1.20 Instämmer helt |
| 1.21 Jag trivs med mitt arbete | 1.21 Instämmer helt |
| 1.22 Vi tillämpar arbetsrotation | 1.22 Instämmer helt |
| 1.23 Jag påverkar och utvecklar mitt sätt att arbeta | 1.23 Instämmer helt |
| 1.24 Jag rapporterar avvikelser som rör underleverantörer | 1.24 Instämmer helt |
| 1.25 Vi arbetar ständigt med att reflektera och förbättra verksamheten | 1.25 Instämmer helt |
| 1.26 Jag känner mig delaktig i företagets vision samt lång- och kortsiktiga mål | 1.26 Instämmer helt |
| 1.27 Vid behov får jag hjälp i mitt arbete, och har också möjlighet att hjälpa andra | 1.27 Instämmer helt |
| 1.28 Jag får stoppa produktionen om jag upptäcker allvarliga problem | 1.28 Instämmer helt |
| 1.29 Jag hjälper till med att ta fram instruktioner för hur arbetet skall utföras på bästa sätt | 1.29 Instämmer helt |
1. Frågor (Continue)

| 1.30 | Arbetstidningen har förtröende för hur jag utför mitt arbete | Instämmer ej | ☐ | ☐ | ☐ | ☐ | Instämmer helt | ☐ |
| 1.31 | Jag känner förtröende för våra underleverantörer | ☐ | ☐ | ☐ | ☐ | ☐ |
| 1.32 | I arbetet löser vi problem tillsammans | ☐ | ☐ | ☐ | ☐ | ☐ |
| 1.33 | Företagets vision är: |  |

1.34 Egna kommentarer:

2. Bakgrundsfakta

2.1 Mina arbetsuppgifter:

2.2 Antal år på företaget:
Doctoral and licentiate theses
Division of Structural Engineering – Timber Structures
Luleå University of Technology

Doctoral theses


2004 Max Bergström: Industrialized Timber Frame Housing – Managing Customization, Change and Information. 2004:45D.


2008 Matilda Höök: Lean Culture in Industrialized housing – A study of Timber Volume Element Prefabrication. 2008:21D.


Licentiate theses


2008 Annicka Cettner: Kvinna i byggbranschen – Civilingenjörers erfarenheter ur genusperspektiv. 2008:05L.

2008 John Meiling: Product Quality through experience feedback in industrialised housing, 2008:36L.


