DOCTORAL THESIS

Experience Feedback in Industrialised House-building

The Impact of Production Strategies

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Preface

Niels Bohr is quoted as having said that “en expert is [someone] who has made all the mistakes which can be made in a very narrow field”. What a very true and interesting philosophical idea about learning! Studying for a doctoral degree is most definitely a learning process. There is no way of really know how to conduct research on beforehand[1]. The methodological textbooks can only guide a Ph.D. student so far. One has to make the mistakes in order to learn what the book actually tried to tell you, and in what way the ideal description has to be distorted in order to fit the real world…

For me, these years of doctoral studies have provided me new “learning opportunities” in each new study, but also in all the other parts of my studies: taking doctoral courses; developing, holding, and teaching in undergraduate courses; and taking part in many collective activities, in the research group as well as in the whole division. It is here off course important to point out that not only do you learn from your mistakes, but from doing successful things as well. As long as you reflect on recent events, you have an opportunity for learning.

What a doctoral degree actually show is that the holder has some proficiency in the “trade” of conducting research. Some people have

[1] I thought I knew after having done my M.Sc. thesis, but instead the following years taught me that “I knew nothing, back then”.

likened it to a drivers licence for independently conducting research. To continue this allegory, as it takes many years of driving before one can call oneself an expert driver, getting the PhD is just the first step towards becoming good at conducting research.

There are several people that I would like to take the opportunity to thank for all the help you provided me over the years, on this journey towards this dissertation. First and foremost I would like to extend my gratitude towards my main supervisor, Thomas Olofsson, who “took me under his wings” all those years ago, after asking me if I would be interested in becoming a doctoral student. He always uphold a positive basic view of all his Ph.D. students, and his ability to help finding the grains of gold in all ours work has lifted my spirit on numerous occasions, when I “couldn’t see the forest for all the trees”.

My secondary supervisors over the years – Anders Vennström, John Meiling, and most recent Marcus Sandberg – have all been a tremendous support through our co-authoring of papers together, and all other matters around my studies. Here I’d also like to thank Gustav Jansson, who may not have been a supervisor on paper, but still a very much important co-author and colleague.

I also would like to extend a huge thank to all my other colleagues that have come and gone over the years, for being the good company you all have been on my journey. You have been great to have around for all those deep *fika* talks, on everything from the academic matters of being a doctoral student, and the methodological and theoretical matters in the world of construction engineering & management research. But perhaps even more important has been the social workplace aspects of you all, which on more than one occasion provided me the extra energy boost that I needed to be able to focus on the work at hand.

To friends and family – thank you for being what you are to me, and for simply coping with my unavailability to be there with you over extended periods of time. You still mean the most to me!

/Robert Lundkvist, Luleå, November 2015.

Abstract

Construction companies need to develop processes for experience feedback (EF) and knowledge-sharing in order to improve their performance over time. *Industrialised house-building* offers strategies for combating problems typical to project-based organisations such as adopting a more product- and process-oriented approach as well as different production strategies. However, few studies have investigated how industrialised house-building companies actually collect feedback experience and use it for EF.

Two research questions were asked: How do different types of production strategies in house-building influence the *collection* of feedback experience, and how do different types of production strategies in house-building influence the *utilisation* of experience feedback?

Based on a qualitative, multi-method research design, four studies were conducted: one survey in 2010 on experience feedback activities within large and medium-sized on-site and off-site house-builders, and three single case studies between 2011 and 2015 on the collection and use of experience feedback in house-building organisations with different production strategies: a firm with a traditional engineer-to-order (ETO_{ED}) strategy, another firm with a modify-to-order platform (MTO_{ED}), and a third with a configure-to-order platform (CTO_{ED}).

One way to characterize EF is by the “channels” used to feedback the experience. The building contractor using the traditional ETO_{ED} strategy used formal “push” channels in the production phase. The MTO_{ED} case

utilized similar production phase EF channels to those of the ETO_{ED} contractor but with additional design phase "pull" channels. In the CTO_{ED} platform, the main EF channel was personal and informal pulling knowledge to the platform developers but there were also formal channels (meetings). Unlike the other studied strategies, the CTO_{ED} strategy has no engineering design phase so all the EF channels were oriented towards the production phase and the client.

The studies show that in the *project-focused* ETO context, EF is used for *continuous improvement* of the project management processes. The later the customer order decoupling point is located, i.e. the more standardised the products become, the more EF focus on *product development*, with increasing number of EF channels aimed towards the client and the market.

The findings suggest that more product-focused industrialized house builders aim their EF channels towards customers and market. It also appears that house-builders using CTO_{ED} platforms primarily utilize their EF in production process improvements and product development whereas house-builders using MTO_{ED} platforms primarily focused their EF on the use of platform's assets in the design phase. Presumably, the next step for such builders would be to increase the standardisation of their construction methods.

The practical contribution of this thesis is that it could help construction companies to plan and implement their experience feedback processes. The thesis' main theoretical contribution is its characterisation of EF in relation to the different production strategies used in house-building.

Keywords: Experience feedback, production strategies, defects, continuous improvement, industrialized building

Sammanfattning

Byggföretag måste utveckla processer för erfarenhetsåterföring (EF) och kunskapsutbyte för att förbättra sina resultat över tid. Industriellt bostadsbyggande medför mer produkt- och processinriktade angreppssätt innefattande olika produktionsstrategier för att bekämpa problem som är typiska för projektbaserade organisationer. Däremot har få studier undersökt hur byggföretagen faktiskt samlar in återförd erfarenhet och använder EF.

Två forskningsfrågor ställdes: Hur påverkar valet av produktionsstrategi *insamlingen* av återförd erfarenhet, och hur påverkar valet av produktionsstrategi *användningen* av erfarenhetsåterföring inom husbyggande?

Grundat på en kvalitativ forskningsdesign, baserad på flera forskningsmetoder, utfördes fyra studier: En enkätundersökning 2010 om erfarenhetsåterföring inom stora och medelstora platsbyggande och fabrikstillverkande husbyggnadsföretag, samt tre fallstudier mellan 2011 och 2015 om insamling och användning av erfarenhetsåterföring i bostadsbyggande organisationer med olika produktionsstrategier: En organisation med en traditionell *engineer-to-order* (ETO_{ED})-strategi, en annan med en *modify-to-order* (MTO_{ED})-plattform, samt en tredje med en *configure-to-order* (CTO_{ED})-plattform.

Ett sätt att beskriva EF är genom de ”kanaler” som används för at återföra erfarenheterna. Byggentreprenören med ETO_{ED}-strategin använde formella, ”tryckande”, erfarenhetskanaler under produktions-fasen. Byggaren med MTO_{ED} uppvisade liknande EF-kanaler under

produktionsfasen som ETO-entreprenören, men med ytterligare ”dragande” kanaler under projekteringsskedet. I CTO_{ED}-plattformen var de viktigaste EF-kanalerna personliga och informella, men det fanns också formella kanaler, såsom olika möten. Till skillnad från de andra undersökta strategierna finns ingen egentlig projekteringsfas i CTO-strategin, varför alla EF-kanaler är inriktade på produktionsfasen och beställaren.

Studierna visar att i det projektfokuserade ETO-sammanhanget används EF för ständiga förbättringar av projektledningsprocessen. Ju senare *kundorderpunkt*, det vill säga ju mer standardiserade produkterna blir, eller ju mer produktfokuserad organisation är, desto mer fokuserar EF på produktutveckling och förbättring av tillverkningsprocessen och ju fler EF-kanaler är riktade mot kunderna och marknaden,

Resultaten tyder också på att bostadsbyggare som använder CTO_{ED}-plattformar främst fokuserar sin EF mot tillverkningsprocessen och produktutveckling, medan husbyggare som använder MTO_{ED}-plattformar främst inriktar sin EF mot användningen av deras plattformtillgångar under projekteringsfasen. Förmodligen skulle nästa steg för dessa byggföretag vara att öka standardiseringen av sina byggmetoder.

Den praktiska bidraget från avhandlingen är att den kan hjälpa byggföretag att planera och genomföra sina erfarenhetsåterförings-processer. Avhandlingens främsta teoretiska bidrag är dess karakterisering av EF i förhållande till de olika produktionsstrategier som används inom husbyggande.

Nyckelord: Erfarenhetsåterföring, produktionsstrategier, fel, ständiga förbättringar, industriellt byggande

Table of contents

Appended papers

PAPER I

Lundkvist, R., Meiling, J. & Vennström, A. (2010). Digitalization of inspection data; a means for enhancing learning and continuous improvements? *Proceedings of the 26th Annual ARCOM Conference*, Leeds, UK. 2 829-838.

PAPER II

Lundkvist, R., Meiling, J. H., & Sandberg, M. (2014). A proactive plan-do-check-act approach to defect management based on a Swedish construction project. *Construction Management and Economics*, *32*(11), 1051-1065.

PAPER III

Jansson, G., Lundkvist, R., & Olofsson, T. (2015). The role of experience feedback channels in the continuous development of house-building platforms. *Construction Innovation*, 15(2), 236-255.

PAPER IV

Lundkvist, R. & Sandberg, M. Experience feedback in an adapt-to-order – make-to-order industrialized house builder. Submitted to *Journal of Construction Engineering and Management*.

APPENDIX 1

Lundkvist, R. *Extended results from the survey*.

Other publications by the author

LICENTIATE THESIS

Lundkvist, R. (2011). *Expanding the use of contract inspections in construction – an approach to inter-project knowledge diffusion?* Luleå: Luleå University of Technology. ISBN 978-91-7439-357-6.

PROCEEDINGS PAPER A

Lundkvist, R. & Vennström, A. (2010). Requirements of an inter-project digital inspection system. *Proceedings of the CIB W78 2010*, Cairo, Egypt.

PROCEEDINGS PAPER B

Lundkvist, R. & Meiling, J. (2011). Towards an experience feedback system from building inspections through classification of construction works. *Proceedings of the CIB W78-W102 2011: International Conference*, Sophia Antipolis, France.

POPULAR SCIENCE ARTICLE

Meiling, J., Lundkvist, R. & Magnusson, O. (2011). Erfarenhetsåter-föring. *Samhällsbyggaren*, 2 2011, 16-21.

TECHNICAL REPORT

Meiling, J. & Lundkvist, R. (2010). *Förbättringsarbete genom erfarenhetsåterföring inom byggentreprenadföretag: Resultat från en webbaserad enkät,* (In Swedish: Experience feedback in Swedish construction contractor firms). Luleå: Luleå tekniska universitet.

1 INTRODUCTION

1.1 A need for knowledge-sharing and experience feedback in house-building

The house-building industry faces pressure both externally, as well as internally, to improve productivity and quality, and to decrease building costs. Here, experience feedback (EF) and the sharing of lessons learned can be used to improve their performance over time (Jabrouni, *et al.*, 2011).

House-building has traditionally been a project-based activity, conducted by *Project-Based Organisations*. Such organisations characteristically work on temporary systems (projects) that are embedded in more long-lived contexts (Sydow *et al.*, 2004). In such situations, short-term project performance objectives relating to time, cost, and quality seem to compete with longer-term business objectives that involve organisational learning, such as making ongoing improvements in the time-, cost-, and quality- performance of the firm's projects (Ekstedt *et al.*, 1999; Grabher, 2002). Research on project-based learning has repeatedly highlighted problems associated with attempts to capture, share, and diffuse knowledge and learning across projects (DeFillippi, 2001; Grabher, 2002; Prencipe and Tell, 2001). In other words, the project-based nature of house-building seems to create barriers to change and innovation by privileging short-term task performance over long-term knowledge accumulation (Bresnen, *et al.*, 2004).

Industrialised house-building offers strategies for addressing these problems that are based on a more product- and process-oriented approach to the construction trade (Lessing *et al.*, 2015). Industrialisation implies an increase in standardisation and the use of manufacturing and assembly methods. As such, it has the potential to reduce costs, lead-times, and waste while increasing quality, productivity, and predictability (Pan *et al.,* 2012). Industrialised house-builders can use different engineering and production strategies (Johnsson, 2013) that define their type and level of predefinition, design flexibility, production localisation, and management (Gibb, 2001). Many of these strategies have been implemented through *platform thinking* (Jansson, 2013) which helps developing and seeing the processes of an organisation as platforms that enable standardisation and reuse. Platforms can be created on the basis of many different production strategies, including *Modify-to-order* and *Configure-to-order* (Hansen, 2003).

The long-term success and survival of a firm that uses product platforms depends on continuous innovation and renewal (Meyer and Lehnerd, 1997). The organisation must therefore collect and use experience from different channels in the supply chain to support this renewal process. However, while knowledge and knowledge transfer are central to platform thinking, most research on the use of platforms in construction has focused on the design and implementation of platforms on large scales, with little emphasis on the importance of platform renewal or the role of collecting experience feedback (EF). Moreover, the construction management literature includes few case studies; consequently, most studies on knowledge management in construction have focused on *what* is done, not *how* it is done (Styhre and Gluch, 2010). There is also a lack of studies comparing real-world EF practices used with different engineering and production strategies.

1.2 Thesis aim and research questions

The aim of this thesis is to describe different aspects of EF in typical production strategies used in industrialised house-building, as well as “traditional”, on-site house-building. To provide a greater degree of focus, two research questions based on this aim were considered:

RQ 1: How do different types of production strategies in house-building influence the collection of experience feedback?

RQ 2: How do different types of production strategies in house-building influence the utilisation of experience feedback?

1.3 Disposition

The thesis has two parts – a cover paper (which you are currently reading), consisting of six chapters, and a part comprising four appended research papers. *Chapter 1* introduces the reader to the rationale and objectives of the thesis. *Chapter 2* presents the frame of reference of the research problem. In *Chapter 3*, the research process is presented. The applied research methods are described in detail, including how the data were analysed. *Chapter 4* summarises the appended papers, outlining their key results and showing how they help to answer the research questions. *Chapter 5* discusses the key results presented in the preceding chapters and their theoretical and practical contributions. The cover paper section concludes with *Chapter 6*, which summarises the implications of the findings, discusses their limitations, and provides some suggestions for future research.

The second part of the thesis consist of four appended papers, labelled Paper I-IV, and one appendix.

Paper I: *Digitalization of inspection data; a means for enhancing learning and continuous improvements?*

By Robert Lundkvist, John Meiling and Anders Vennström, published in the Proceedings of, and presented at the 26th ARCOM Annual Conference, September 6-8, 2010, Leeds, UK. (Awarded the ‘Paul Townsend’ Commemorative Award (best Ph.D. student paper) at the conference.)

As first author, I designed the study and collected the data, together with John Meiling. I then conducted most of the data analysis – with support from John – and I was also the main contributor to the conclusions. I wrote the paper together with John; Anders contributed conceptual ideas and feedback

Paper II: *A proactive plan-do-check-act approach to defect management based on a Swedish construction project.* By Robert Lundkvist, John Meiling and Marcus Sandberg, published in Construction Management and Economics, Volume 32, Issue 11.

This paper was based upon my licentiate thesis. As first author, I designed the study, collected the data, conducted the analysis, and drafted the paper. John and Marcus contributed by reading, commenting orally as well as in writing, and presenting suggestions for improvement, based or their reading.

Paper III: *The role of experience feedback channels in the continuous development of house-building platforms*. By Gustav Jansson, Robert Lundkvist and Thomas Olofsson, published in *Construction Innovation*, Volume 15, Issue 2.

An earlier draft of this paper was submitted by Gustav to Construction Innovation as part of his doctoral thesis. As second author, I contributed to the rewrites of the paper through discussion and by providing ideas for the theoretical perspectives, and by writing the sections connected to these ideas and perspectives. Thomas provided feedback and did some editing of the final paper.

Paper IV: *Experience feedback in an adapt-to-order – make-to-order industrialized house builder*. By Robert Lundkvist and Marcus Sandberg. Submitted to Journal of Construction Engineering and Management.

I designed the study, collected the data, conducted the analysis and drafted the paper. Marcus provided insightful and helpful feedback for improvement, and also contributed to writing a section of the frame of reference.

Appendix 1 presents further results from the survey study that formed the basis of Paper I (which focused on only a fraction of the responses collected in the survey). I conducted a new analysis of the entire dataset, based on comparing on-site and off-site builders, and wrote the appendix in the style of a working paper.

2 FRAME OF REFERENCE

This chapter presents the theoretical foundations of the thesis. It begins by introducing the concept of experience feedback and then presents the context of the work, describing production strategies and the use of product platforms in house-building. It then concludes with a brief overview of pre-fabrication and off-site construction.

2.1 Experience feedback and its use in house-building

Experience Feedback (EF) can be described as a structured process of creating knowledge through the analysis of a positive or negative event *(a* so-called "useful *case")* and then capitalizing on or re-using *this new knowledge.* EF is a bottom-up approach to knowledge management in that knowledge is built up gradually from a series of such events (Kamsu Foguem, et al., 2008). The term "event" can refer to occurrences of any kind that affect safety, health, environmental performance, quality, reliability *or production* (Jabrouni *et al.* 2011).

EF is thus a knowledge-creation and -sharing process. Nonaka and Takeuchi classifies knowledge as either *tacit* or *explicit* (Nonaka and Takeuchi, 1995); tacit knowledge is more skill-based, and therefore more readily transferred through people-centered techniques and social interaction. Explicit knowledge, on the other hand, is the expressed - that which can be written down or vocalised. As such, it is preferably transferred via IT systems (Carrillo, 2004).

Different approaches to EF can be found in the literature, including *lessons learned systems* (Weber *et al.*, 2001), and experience feedback *loops* (Faure *et al.*, 1999). In the *Organisational Learning* literature, experience has been identified as the basis for individual learning, which can be communicated and interpreted at the group level and eventually integrated into routines, diagnostic systems, rules and procedures at the organisation level (Crossan *et al.*, 1999). EF processes therefore involve learning at the individual, group and organisational levels. *EF should* convey experiential knowledge and lessons learned that are applicable to the different levels of the organisation and whose reuse *could* have a positive impact on the organisation's performance and results (Kamsu Foguem *et al.*, 2008).

EF methods require organisations to *utilise* diverse human and technological resources to reduce the reoccurrence of errors and to promote more effective practices (Worley *et al.*, 2005). Because information on failures and incidents is important in maintenance, EF from these events is also useful in that context (Potes Ruiz *et al.*, 2014). Much of the early research on EF involved statistical studies that were conducted with the aim of identifying trends and factors associated with failure. However, more recent publications in this area have argued that greater efforts should be made to gather EF from individuals with expertise in particular aspects of an organisation's activities (Jabrouni *et al.*, 2011). Studies on knowledge management systems have reported difficulties in achieving effective sharing of experts' knowledge due to a lack of motivation on the experts' part and a lack of context for their (often fragmentary) reports, which necessitates the involvement of a mediator to reduce the semantic distance between the experts and the knowledge management system (Henninger, 2003). In such cases, an EF system can provide structure and encourage a focus on the relevant context, thereby reducing the amount of effort involved in obtaining knowledge. This is particularly important in situations where knowledge becomes old relatively quickly, as is the case in continuous improvement processes (Weber et al., 2001).

2.1.1 Experience feedback for continuous improvement

Continuous improvement is a major component of the ISO 9000 family of standards (The International Organization for Standardization, 2008). Many industrial companies have therefore adopted approaches to EF based on standardised problem-solving methods such as PDCA (plan-do-check-act) or the Six Sigma DMAICS (define-measure-analyse-improve-control-standardise), in which experts investigate the causes of problems and attempt to eradicate them (Kamsu Foguem, et al., 2008). Four general steps common to all such methods were identified by Jabrouni et al. (2011):

- Context. This step involves establishing a general overview of the event and its background prior to its analysis, making it possible to define the problem. Documentation of this step is helpful for identifying risk criteria during a subsequent risk analysis.
- Analysis. The event is analysed against its context in order to identify the root cause of the documented effects. For this analysis, tools such as Fault Tree and Ishikawa/Fishbone diagrams are suitable for mapping out all the potential causes. Finding the most likely root cause is critical for the problem-solving process, since this affects where subsequent resources for correcting the problem will be used
- Solutions. This step involves defining and implementing corrective actions or improvements to solve the initial problem. It should also include an evaluation to verify that the solution is effective.
- Lessons learned. In the final step, the new solution is institutionalised by standardising the relevant designs or processes and documenting the event.

There have been few studies on the use of standardised problem-solving techniques in the construction industry. One notable work examined their use in traditional on-site construction in a hospital expansion project (Tiwari and Sarathy, 2012); the authors concluded that the method adopted by the project team was resource-intensive. A second study examined a hospital development project (Parrish *et al*., 2009) in which the project development team adopted the PDCA “A3” method (named after the ISO-standard paper size that it uses) to focus their conversations and direct their decision-making processes during the design stage. The A3 method was also used by Meiling, *et al*. (2014), in a case study on the quality assurance process used by an off-site industrialised house-building firm during on-site module assembly.

2.1.2 Experience feedback channels

Much of the literature on EF describes or proposes a single EF system such as a problem solving method or the development of a knowledge repository. However, a real organisation may have several different EF channels *(i.e.* knowledge transfer channels) for different types of event reporting from different senders. This was acknowledged by Maille and Chaudron (2013) in their study on combining data from two different EF channels in the context of flight safety management.

An EF channel is a function (a group of people or a technology) that relays a message from a sender to a receiver. Such channels can be classified as either *informal* or *formal*, *personal* or *impersonal*. Informal channels such as unscheduled meetings or coffee break conversations can be effective for promoting socialisation but may hinder the wide dissemination of knowledge (Holtham and Courtney, 1998). According to Fahey and Prusak (1998), such channels may be more effective in small organisations.

Meiling (2010) studied the context of house-building and found that the companies find it difficult to manage the large volume of report data generated during each of their projects, and to use these data to support continuous improvement. One reason for this was the absence of a central EF database and support system with which the report data could be developed into knowledge, utilised, and capitalised upon. Instead, construction managers seem to prefer to report problems (events) through more "traditional" business communication technologies for knowledge sharing, such as face-to-face meetings, telephone, and e-mail (Bresnen *et al.*, (2004).

2.1.3 Experience feedback for product development

Product development is preceded by a product planning process during which the planning team must first identify product development opportunities and then evaluate and prioritise corresponding development projects. The identified opportunities may relate to new *product platforms*[2], derivatives of existing platforms, incremental improvements to existing products, or fundamentally new products. Ideas for these may come from several sources within and outside the company, including in-house R&D, the product development team itself, manufacturing and operations organisations, current or potential customers (via the company's marketing and sales divisions), suppliers, inventors, and business partners (Ulrich and Eppinger, 2008). Ulrich and Eppinger (2008) advocate a proactive approach to generating opportunities based on techniques such as documentation of user complaints regarding current products, interviews with lead users, studying trends in lifestyle and demographics, competitive benchmarking, and analysis of emerging technologies.

Decisions made during product development can profoundly affect a product's manufacturability (Boothroyd, 2002). The usefulness of EF within product development was studied by Andersson, *et al.* (2008) in a dual case study on a manufacturer of aeronautical engine components and an automotive manufacturer. In both cases, experiences gathered during the production of one product were fed back into the development of subsequent products.

Unlike manufacturing firms, construction firms traditionally only produce "prototypes" because they deal with unique products rather than serial production. Their production activities are organised into projects, each with a design phase during which the product is "developed" from a concept to a detailed set of production documents. Experience has traditionally been collected via post-project reviews during which all of the (mostly negative) events that occurred during the project are compiled and recorded in a way that decouples them from the production process and the context in which they occurred (Lee *et al.*, 2005). Thus, while there is no separate product development process per se, compiled project experience may be used as an input during the design of future projects. However, research has revealed important limitations in the way that experience is collected and compiled by construction firms, and in the way that it is utilised (Lundkvist and Vennström, 2010).

[2] See Section 2.3.

2.2 Production strategies

Companies can use different production strategies to satisfy customer demand (Winch, 2003). These strategies have been defined based on the point at which the client enters the supply chain, which is commonly referred to as the client order de-coupling point (CODP) (Hvam *et al.* 2008). Rudberg and Wikner (2004) defined the CODP as the point where decisions concerning client demand start being made on the basis of certainty or commitment rather than speculation and uncertainty.

Several authors have attempted to classify production strategies using a range of different perspectives, as shown in Table 1. Wiendahl and Scholtisesek (1994) identified four strategy classes: *engineer-to-order* (ETO), *make-to-order*, *assemble-to-order*, and *make-to-stock*. Hansen (2003) used a design and engineering perspective to distinguish between strategies in which specifications are created before the CODP. According to this classification, ETO strategies rely on norms and standards, *modify-to-order* on generic product structures, *configure-to-order* on standard parts and modules, and *select variant* on standard products.

Table 1. Established systems for classifying production strategies.

Wiendahl & Scholtisesek (1994)		Engineer to order				Make to order	Assemble to order	Make to stock
Hansen 2003		Engineer to order	Modify to order	Configure to order	Select variant			
Winch, 2003		Concept to order	Design to order			Make to order		Make to forcast
Hvam et al. 2008		-	-	-		Make to order	Assemble to order	Make to stock
Rudberg and Wikner, 2004	*ED:*	Engineer to order	Adapt to order		Engineer to stock			
	PD:	-		-		Make to order	Assemble to order	Make to stock

Winch (2003) instead focused on the point at which the client enters the *production information flow*. In his system, the traditional construction strategy is classified as *concept-to-order*, which is similar to the classification assigned to the strategies of other companies that operate in capital goods sectors (e.g. aerospace, shipbuilding, and machinery production) and have large, complex, project-based production systems. Conversely, Hvam *et al.* (2008) used a production perspective and identified three strategy types: *make-to-order*, *assemble-to-order*, and *make-to-stock*.

Most of the shown work in Table 1 has adopted a sequential view of the supply chain that begins with the concept and then progresses through design, engineering, manufacturing, and assembly before terminating with shipment. However, in reality some parts of the production process can be initiated before all of the design activities have been completed. This is explicitly acknowledged in the two-dimensional model of Rudberg and Wikner (2004), which has an engineering dimension (denoted ED) and a production dimension (denoted PD) as shown in Figure 1. The two dimensions are actually continuums; a company's strategy may be located at any point in the plane between the extremes of engineer-to-order (ETO_{ED}) and engineer-to-stock (ETS_{ED}) on one hand, and make-to-order (MTO_{PD}) and make-to-stock (MTS_{PD}) on the other. In the engineering dimension, any strategy of mass customisation – i.e. any strategy that involves modifying existing product designs at the design or engineering levels - is termed an *adapt-to-order* (ATO_{ED}) strategy.

This two-dimensional classification system was empirically tested by Johnsson (2013) in a multiple case study on industrialised house-builders that verified the system's applicability in classifying strategies with respect to the engineering dimension. By implementing one of these specific "engineering strategies", a builder could balance the level of standardisation against the design flexibility of their products. Many industrialised builders have successfully implemented these strategies through *platform thinking* (Jansson, 2013). However, all of the studied organisations' strategies were classified as make-to-order with respect to the production dimension Johnsson (2013).

A problem with this model is that the different classes are defined in such a way that all strategies can be considered to have at least some adapt-to-order character depending on their position relative to the extremes of the two axes. It may be more useful to have several classes based on “typical cases” for the engineering dimension rather than attempting to classify strategies by computing the fractional contributions of specific elements of the engineering process (Rudberg and Wikner, 2004). In addition, if house-builders only use the make-to-order strategy in their production systems, the value of the plane and the two-dimensional classification becomes questionable**.**

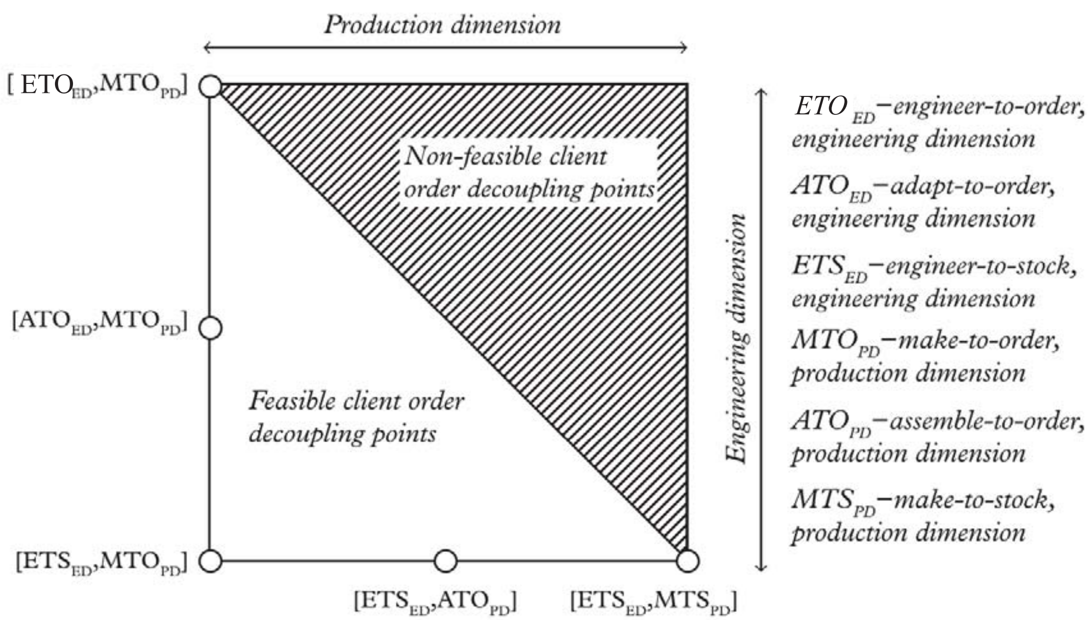

Figure 1. Two-dimensional CODPs for different production strategies. Reproduced from Johnsson (2013), revised from Rudberg and Wikner (2004).

Therefore, for the remainder of this thesis we shall use an analytical model based on the system proposed by Hansen (2003), and in order to acknowledge that design & engineering and production can occur concurrently, Rudberg and Wikner’s (2004) concept of two dimensions is retained, although none of the studied cases used a production dimension strategy other than make-to-order.

2.3 Platform thinking in industrialised house-building

Product platforms were first introduced in the manufacturing industries as a strategy for managing customer demand for greater product variety (Krishnan & Gupta, 2001) as product lifecycles shortened and technology began changing more and more rapidly (Ulrich, 1995; Pine, 1993). There are many different definitions of the platform concept (Halman, 2003; Jiao, Simpson, & Siddique, 2007). For instance, Meyer and Lehnerd (1997) defined a product platform in terms of product architecture as a set of subsystems and interfaces that form a common structure from which a stream of derivate products can be efficiently developed and produced.

Robertson and Ulrich (1998) simply defined product platforms as collections of assets that are shared by a set of products. Using platforms accelerates the development of new products, and the use of standardised and pretested components makes it possible to accumulate learning and general experience that may increase product performance (Halman, 2003). A product platform can therefore also be described as a repository for organisational knowledge of components, processes and relationships that is used to adapt a product for a specific customer (Meyer and Lehnerd, 1997; Robertson and Ulrich, 1998).

Jiao et al. (2007) presented a holistic “decision framework” for product family design and development that was based on the work of Suh (2001) and is shown in Figure 2. Five design domains – customer, functional, physical, process, and logistics – are sequentially mapped together. The customer attributes (CA) represent market segmentation and the demand for product families. The CAs are translated into functional requirements (FR) in the functional domain, and designers and engineers elaborate on how to match these requirements. In the physical domain, product family design solutions are generated by mapping FRs to design parameters (DP), based on the assets of the product platform. The mapping of DPs to process variables (PV) determines the design of the production process including production planning, and is situated in the logistics domain through which it is connected to the supplier platform.

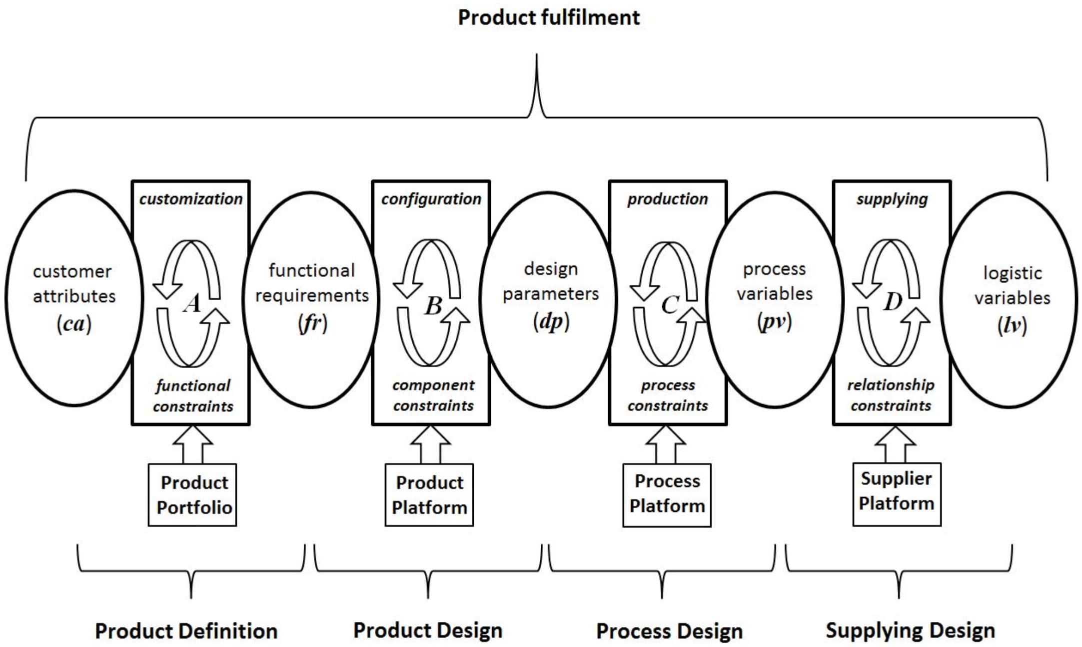

Figure 2. Decision framework for product family design and development along the spectrum of product realization (Jiao et al., 2007), based on the concept of design domains proposed by Suh (2001).

There are two categories of components in a product platform – those representing commonality and those representing distinctiveness. Common components are those that are used by the entire product family whereas distinctive ones are only used by individual products or a subset of the family. According to Meyer and Lehnerd (1997), finding the right balance between commonality and distinctiveness is a major challenge in platform development. To support this process, Bowman (2006) suggests that the products' market positioning should be defined on the basis of different customers' needs. Product platforms support the engineering work of the product customisation process by reducing development costs and times, manufacturing costs, production investments, and complexity Bowman (2006).

By implementing product platforms, house-builders have achieved better economies of scale while still meeting their target market segments' expectations of design flexibility. For instance, a German modify-to-order house-building platform managed to reduce its construction costs by more than 30% over the course of 14 years (Thuesen and Hvam, 2011). They showed that on-site construction methods could achieve high efficiency without the need for off-site manufacturing. In this context, platforms have been described as systems for storing knowledge and/or predefinitions of house-building components, related processes, as well as internal and external relationships (Jansson *et al.*, 2013). As such, they can also be seen as knowledge management systems for the company's knowledge assets.

A movement away from the ETO strategy typical of traditional construction to a more product-oriented production system based on a modify-to-order, configure-to-order, or select variant strategy represents a shift from a project focus to a greater focus on processes and products.

2.4 Experience feedback within product platforms

Platforms should explicitly support the incorporation of experience from within the production process, in order to support continuous improvement (Thuesen and Hvam, 2011). However, despite this, there have been few studies on EF in a product platform context. Chai et al (2012) stated that knowledge-sharing and having a product champion are seen as the most important factors when building competences for platform-based product development.

There are even fewer published studies on product platforms and experience feedback research in construction. Styhre and Gluch (2010) found that platforms could both bridge and bond the know-how and expertise in construction companies, and in this way act as enablers for knowledge sharing. The level of standardisation in house-building platforms is developed incrementally on the basis of experience that flows into the organisation from projects and is stored within the platform's predefinitions. They also found that modify-to-order platforms could be difficult to implement in the construction industry due to a general suspicion concerning the use of standardised solutions and pre-design of buildings in the ETO tradition, and a belief that modify-to-order platforms are a bit too general to effectively support knowledge sharing.

2.5 Prefabrication in house-building

Another important factor in industrialised building is the strategic choice of the level and type of pre-fabrication, i.e. the amount of work conducted on- rather than off-site. Off-site construction can be regarded as the intersection of the construction industry and manufacturing industries (Meiling, 2010a).

Gibb (2001) categorised the existing types of off-site production as *Component Manufacture and Sub-Assembly (CM&SA)*, *Non-Volumetric Pre-Assembly (NVPA)*, *Volumetric Pre-Assembly (VPA)*, and *Modular building (MB)*. The first type, CM&SA, represents components that are manufactured in factories (such as board material, structural components, etc.) as well as sub-assemblies that would not be considered for on-site assembly in most developed countries (e.g. door furniture or light fittings). NVPA items are assembled in a factory, or at least prior to being placed in their final position (e.g. precast stairwells, wall panels, structural sections and pipework assemblies). VPAs are volumetric units that are pre-assembled in a factory and usually assembled on site within an independent structural frame (e.g. bathroom pods, modular lift shafts). MB units are volumetric in the same way as VPAs, but they make up the building system itself, complete with self-bearing structure.

This factor is independent of the level of process and product focus. In addition, a given production system with a specific production strategy may use a multiple levels of prefabrication. For instance, a house-builder could have an ETO_{ED} and MTO_{PD} strategy that makes extensive use of both NVPA and VPA components. Similarly, an organisation with a CTOED strategy could potentially rely entirely on *CM&SA*, although this would perhaps be somewhat unlikely. The *level* of prefabrication should not be confused with the total or relative amount of components in the production system that are prefabricated in some way. This can be done using a variety of prefabrication levels; it is entirely possible for a company of this sort to employ a combination of MB, VPA and NVPA and CM&SA (the latter typically being used only in the construction of foundations and earth works).

3 RESEARCH PROCESS AND METHODS

This chapter presents the research design of the thesis, together with a description of how the different studies were carried out. There is also a discussion on how the matter of research quality has been handled.

3.1 Research process and design

The process of my doctoral studies can be described as long and winding, but also iterative, see Figure 3. The studies can be divided into two different projects, with somewhat different scope and aim. The first project was conducted between 2009 and 2011, and resulted in three conference papers and a licentiate thesis (Lundkvist, 2011), but also in a subsequent journal paper (Paper II). In this project we used a multi-method approach, including an exploratory survey and qualitative case studies. We decided that *qualitative case studies* was a suitable research method to study experience feedback in its natural context, and provide rich descriptions of the phenomenon (Miles and Huberman, 1994). Also, one cannot or does not need to control behavioural events in the qualitative case studies (Yin, 2009).

The first project studied the utilisation of inspection data for continuous improvement within construction companies, and the initial aim with the second project was to continue in the same direction, with an action research approach (Coughlan and Coughlan, 2002). However, the aim and research focus of this second project shifted over time, partly due to changing conditions within the participating companies in the project. After some time we decided that the second project should have a wider focus, and that I should study the actual experience feedback practices within house-building organisations.

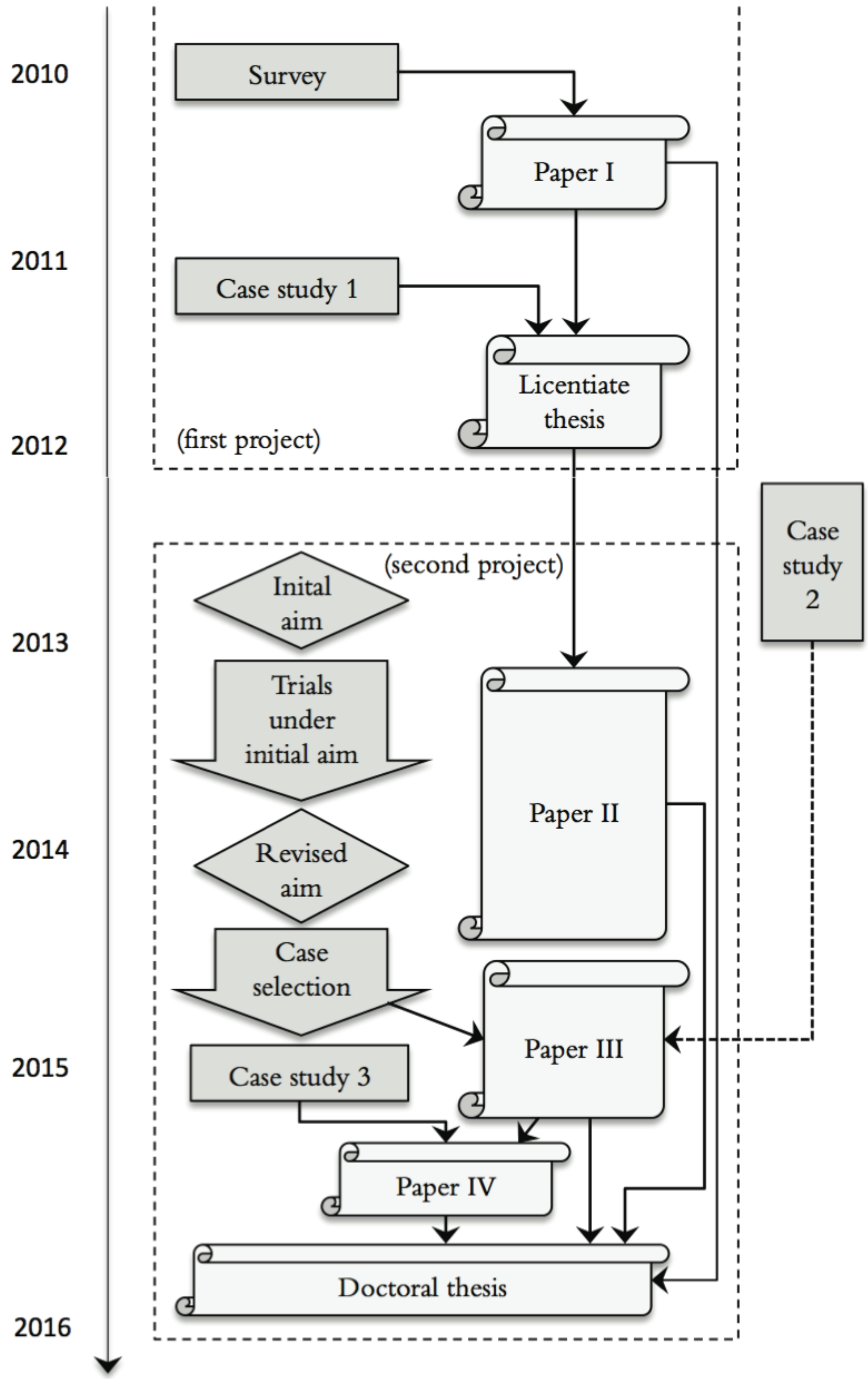

Figure 3. Visual representation of the research process.

Ideally, the choice of research method should be guided by the research questions to be addressed; however, the research questions were instead guided by the decision to conduct case studies. The actual research questions were also changed a couple of times in the second project, based on what the empirical data revealed, in an inductive, iterative way. The final questions were locked down during the writing of this thesis.

3.2 Epistemological view

Over the years I have also developed a rather constructivist epistemological view. In qualitative research the researcher is considered to be one of the most important analytical instruments (Miles and Huberman, 1994; Yin, 2008). As a researcher I therefore affect the design of the study, in the way I choose who to interview, what questions to ask, what theories to apply, etc. Truth and meaning are created through my interactions with the world. Meaning is *constructed*, not discovered. We therefore construct our own personal meanings, even in relation to the same phenomenon. Thus, there can exist multiple conflicting, but equally valid, interpretations of the world (Gray, 2013).

3.3 Research quality

When conducting research, it is important that it is reported in a way that gives an accurate and fair view of the study and its subject. It should also be possible for other researchers to replicate any reported findings (Fellows & Liu, 2008). For case studies and other empirical social studies, four tests are common (Yin, 2008): *construct validity*, *internal validity*, *external validity*, and *reliability*. According to Yin (2008), internal validity is relevant only for explanatory studies, for finding causal relationships. I will therefore not reflect further on internal validity in this thesis.

Construct validity is about identifying the correct operational measures for the studied concepts, and is done during data collection. Tactics for this test is to use multiple sources of evidence, establish a chain of evidence, and have key informants read the draft case study report (Yin, *ibid.*). In this thesis, all case studies used different types of data, and the paper drafts were read by a key informant in each case organisation.

External validity deals with the analytical generalizability outside the immediate case. This is done by comparing the empirical results with the templates of previously developed theories (Fellows & Liu, 2008; Yin, 2009), and is in this thesis done in the Discussion chapter.

Reliability should minimise the effects of bias and error on the study, ensuring that any researcher who attempts to replicate it will get the same results. To this end, the study must be rigorously documented; every step the researcher takes needs to be described in detail. Yin (2008) advocates two specific tools for addressing this issue in case studies: the *case study protocol* and the *case study database*. All the studies within this thesis were continuously documented through a master research log. The case study database was contained on a cloud-based data storage, where all the interviews and other data was saved in all its different “generations” – from audio files to transcripts, coded transcripts, and eventually in the form of case stories. In the survey all the original empirical data was saved on the web-based survey service, but also extracted to the cloud storage for backup.

3.4 Survey

3.4.1 Research design

The questionnaire was set up using web-based survey service, with individual participant links to the questionnaire. This made it possible to send out reminders to those who had not yet responded, in order to achieve a high response rate, and provide a certain level of assurance that company representatives selected for inclusion in the sample were the actual respondents. Answers were anonymised prior to data analysis. A cover letter with the appropriate individual link was sent out to each respondent, describing the study and its purpose. The letter also explained that the responses would be anonymised and that their contact information would not be used outside the study.

The questionnaire consisted of 23 questions, grouped around matters ranging from general Quality Management 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 codified, in order to enable conclusions to be drawn from the data.

3.4.2 Populations and sampling

A list of companies was compiled from the member database of the *Swedish Construction Federation*, the trade and employers' association of the Swedish private construction industry. The federation has more than 3200 member companies, but we excluded all micro and small companies (<50 employees) and special trades in this study, focusing on medium-sized and larger contractors who primarily construct buildings. Most of the organizations on the list were traditional on-site builders, but off-site, industrialised house-builders were also represented and were classified as a distinct population.

This left us with 105 companies, all of which were contacted via telephone. We outlined the study to them and requested email addresses for as many site/ production managers and project/factory managers as possible. This was done to introduce as much randomisation as possible into the sampling process. However, most companies gave only the minimum number of addresses required for the survey. This introduced a bias problem in terms of defining the studied populations. We addressed this issue by letting the respondents represent their companies, i.e. we trusted that the companies would have selected representative respondents from within their workforces.

For surveying what contractors do and how they do it, this approach was considered sufficient. However, it should be noted that the responses to the more personal questions cannot necessarily be considered representative of the opinions of the full population of managers. We ultimately decided to weight the number of representatives from each company on the basis of their sizes, with companies that were active in several regions of the country having two extra respondents for each region in which they operated. 18 companies (17 % of those contacted) decided to take part in the study. After sampling the survey was sent to 66 site/production managers. 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 the reasons discussed below). Some companies supplied a sufficiently large list of contact details that it was possible to make a random selection of their employees in each category.

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.

3.5 Case studies

Case studies let researchers use multiple data collection methods and data sources (Eisenhardt, 1989), which is suitable when the boundaries between phenomena and context are unclear (Yin, 2009). Instead of statistical sampling, case studies use theoretical sampling (Glaser and Strauss, 1967), and thus case studies can also be used for theory building (Eisenhardt, 1989). Compared to laboratory experiments, which isolate phenomena from their contexts, case studies rather emphasize the real-world context in which the phenomena occur (Eisenhardt and Graebner, 2007). In this thesis, three single case studies were conducted. The cases are summarised in Table 2.

Table 2. Summary of single case studies in the thesis.

Case study	**Type of organisation**	**Unit of analysis**	**Data collection methods**
A	Contractor with engineer-to-order strategy	Data from third-party inspections	• Interviews • Observation
B	House-builder with modify-to-order strategy	EF flow in a MTO house-building platform	• Interviews • Archival data • Observation
C	House-builder with configure-to-order strategy	EF activities in a firm that has adopted a CTO strategy	• Interviews • Archival data

3.5.1 Case study A

In order to reduce the knowledge gap between *defect management*, *defect classification*, and *continuous improvement* we wanted to study how current third party inspection and subsequent defect management in the Swedish construction industry work within the real-life context of a construction project. Based on these conditions the case study method is suitable (Yin, 2009). We wanted to see how defect data was recorded in the course of a project, how this procedure shapes the look of the data and how the data is used in defect management, and thus the unit of analysis was data from third party inspections. Building upon results from previous research by the authors, it was possible to triangulate how inspection and defect management were used in general in Swedish construction, which was then analysed through the lens of continuous improvement and PDCA. The conditions for classification of defect data were then tested by attempting classification of the data of the final inspection reports in the project.

Case selection

The particular project for this study was selected because (1) the chief inspector of the project was well renowned, with over 15 years of educating other inspectors and more recently also responsible for this education, implying that the inspection and its reports should represent both best practice and, at the same time, be fairly representative of inspections in general in Sweden; and (2) the project was considered large, implying that a large number, and a wide variety, of defects were likely to be recorded. The project was conducted under a general contract with seven subcontractors. The inspection organization consisted of one chief inspector and eight sub-inspectors, each with different areas of expertise. The project had an inspection plan comprising both pre-inspections and final inspections. Owing to the size of the project, the inspections were carried out over a long period of time; individual parts of the building were inspected as soon as they were completed and accessible.

Data collection

We entered the project right after the final inspections had been conducted. One deep interview with the chief inspector, and an observation during one of the final inspections, were conducted. Inspection data were then collected from PDF versions of all pre-inspection and final inspection reports of the project.

Data analysis

All the inspection data was transferred to Excel and then interpreted. Location data was coded with BSAB 96 Spaces codes, where possible, and defect descriptions were coded using the classification system for industrialized building introduced by Johnsson and Meiling (2009).

3.5.2 Case study B

An inductive single case study was conducted to examine the contributions of four EF channels to the development of a MTO_{ED} technical platform within a large construction company. The adoption of the case study approach together with the analysis of systematised learning loops in the ETO process made it possible to extend the definition of platform development so that it could be applied within the studied context (Yin, 2008).

An analytical framework was established by using engineering design methods to assess the contributions of EF to platform development. The EF flow in the house-building platform was the unit of analysis, and the study was designed to describe how improvements can support continuous platform development over time. The case study provided an opportunity to study the roles of each channel in managing the flow of knowledge (i.e. EF) arising from operational work and the systematisation of that knowledge. The case study company was selected because of its investment in platform predefinitions, introduction of multiple channels for knowledge feedback from house-building projects and efforts to support continuous platform development. The effects of the EF on the platform's development were analysed using the learning loops framework of Henderson et al. (2013). The studied company uses on-site production in an ETO context and has been engaged in platform development and use for a relative short time. Because it performs multiple sorts of construction (not just house-building), the company has several platforms in addition to the ones examined here; nevertheless many of its current projects are traditional and not based on any platform at all.

Data collection

Data were gathered via interviews and observations, and by analysing platform documentation from ten building projects conducted between 2006 and 2012. The four EF channels used were observed and documented by taking notes. Structured interviews based on open-ended questions were conducted with four of the company's platform developers to gain a deeper insight into the purpose of the EF channels. Two of the interviewees worked with building platform development, one on process development, and one on system development. Archival data from the four channels (all of which were actively used within the company when the study was conducted) were collected from project-, platform-, log and feedback documentation.

Data analysis

First, the predefinitions of the platform were mapped onto the supply chain, and the predefinitions and feedback methods were categorised and quantified in accordance with the platform development model of Jiao et al. (2007). The EF channels, described below, were analysed in terms of learning modes (single- or double-loop) and knowledge pull and push.

The company introduced a feedback system called *Your point of view*, logging individual reflections, to gather feedback for improvement from across the organisation. It was implemented as part of the firm's enterprise resource planning system and was designed to support the expression and transfer of individual knowledge, experience and suggestions for platform improvement. The purpose of this channel was thus to enable continuous development of platform predefinitions using information sourced from all of the organisation's employees. Data concerning all of the studied projects were gathered from this channel.

Design optimisation is a process that the company introduced to gather feedback from each of its projects that could be used to improve the platform designs. More specifically, data from this channel are used to determine how the platform's predefinitions are used in practice and why project teams sometimes choose to violate or disregard them. Design optimisation was intended to be done twice in each project, by the platform developers. To support the process, building project teams prepare an internal review of their project one week in advance. Routines and documentation procedures have been established to facilitate the preparation of these reviews on the basis of the platform's design. Data concerning all of the studied projects were gathered from this channel.

Improvement meetings is a channel that is organised at a regional level. Developers, engineers and construction managers working on different projects met approximately once per month to analyse and improve their design work and the associated support methods from different perspectives. Topics were transferred to other groups for investigation or further improvement by platform managers, project managers or designers. Here, the first author in paper 3 documented, observed and participated in five of these meetings, and analysed the information obtained in conjunction with transcripts of interviews with platform managers that were conducted 2011. Meetings concerning five of the ten studied projects were observed and analysed in this way.

Client feedback meetings were performed by the company at the project level to capture the experiences of clients and project managers. These meetings are held after a project is delivered to document the client's experiences and perceptions of the project's delivery and quality, as well as their opinions on the company's communication. The clients were asked to fill out a questionnaire before attending the meetings, which have a predefined agenda. The aim of the client feedback meetings is to improve the platform but also to ensure that the customers are satisfied with the delivered projects. Data concerning all ten of the studied projects were gathered from this channel. The concepts of knowledge pull and knowledge push were drawn on to understand and describe how information from these different EF channels can help to balance platform development in the context of house-building.

To systemise the development of a house-building platform, Jiao et al.'s (2007) platform development framework was adapted for use in the house-building context. The balance between commonality and distinctiveness in platform development was translated and explained using data from the studied EF channels, which were analysed using theories of innovation and learning.

3.5.3 Case study C

This case, an industrialized building concept using a CTO_{ED} strategy was selected in cooperation with the same company as in case study B. Several different potential cases were considered, and the decision was mainly due to the positive feedback that we received from their manager, the head of division, concerning the access of data.

The studied case, hereafter also referred to as the *platform and product development division*, or just *the developers* in short, is a division within this large construction company that have local offices in many parts of Sweden. Because of this situation, they can work together with the different local construction units, hereafter referred to as *local assembly teams*, for the assembly on-site. The developers are responsible for market contacts, platform and product development, as well as supporting the building projects that are manufacturing the buildings.

Data collection

The data collection consisted mainly of interviews. Individual face-to-face interviews were conducted with key personnel in the central platform organization and a number of experienced representatives from local assembly teams (two of the interviews were conducted, and recorded, via video conference). From the development team, we interviewed the *head of division*, the *head of development and production*, two (2) project managers (PM), three (3) project engineers (PE), and a material purchaser. From the local assembly teams, two (2) project managers and one (1) site manager (SM) were interviewed. The interviewees where selected by the head of development and production, after the author had requested to interview main personnel of the central organization and a number of project managers and site managers of local organizations.

Each interview took about 90 minutes. The interviews were semi-structured, with open-ended questions. The main questions used for the analysis in this paper are found in Appendix 1. Based on the answers, follow-up questions where asked, in order to catch as complete record from each interviewee as possible. Each interview was audio-recorded and subsequently transcribed *a verbatim*.

Additional archival data, in the form of assembly instructions and public documentation on the company website, including product descriptions, were also collected.

Data analysis

The interview data was grouped in themes and coded, based on the Frame of reference. First, the type engineering and production strategy used by the case organization was identified, using the interview answers concerning platform content and utilization. Critical here was to identify the client order decoupling point, and then identify what engineering and production work that takes place before and after this point respectively. We classify the balance of commonalities and distinctiveness in the platform. Second, the different channels of EF were identified, and the type of information that these channels relayed. The channels have been analytically described in the following chapters. Finally, we identified how this information was taken care of within the platform and product development division for the purpose of platform and product development, i.e. how this information had been influencing the development of the platform, with its products and processes. These steps together answer the research question. We then discuss how our results relate to results presented in literature in the field.

4 SUMMARY OF APPENDED PAPERS

In this chapter, the appended papers are summarised and their contribution to the thesis is highlighted.

4.1 Paper I - Digitalization of inspection data; a means for enhancing learning and continuous improvements?

Background: The construction sector has been considered to perform poorly in terms of learning and improvement, and feedback and learning loops are often broken in project-based organisations. A prerequisite for continuous improvement is to measure and collect production data. In the Swedish construction industry, the conducting of final inspections in order to find potential defects in the product is a compulsory step towards project handover; however, it is unclear if this data is also used as an input to continuous improvement.

Knowledge gap: No previous study has investigated the use of inspection data for the use of continuous improvement.

Objectives: To investigate the extent to which Swedish construction companies regard final inspections as valuable sources of experience data for continuous improvement as well as the extent to which such companies use data derived from inspections and whether they feel that new IT tools are required to support such its usage.

What was done: Managers in large and medium-sized building firms in Sweden were invited to complete a web-based questionnaire on the usage of experience feedback in their company. In total, 43 managers responded in time for the analysis and 41 answered the questions concerning inspections. Open-ended questions were codified.

Results: The main results from Paper I, which examined the use of inspection data, are shown in Figure 4. 72.1% of the respondents claimed that *their company* regarded inspection defects as valuable information, while 83.7 % *personally* believed that defects included in inspection reports were a valuable source of information for their company[3]. 76.7% of the respondents stated that their company had an expressed goal to reduce the number of defects identified during inspections. 44.2% believed that their company actively analysed the root causes of defects.

However, 60.5% stated that their company had no system for compiling defect data from inspections. 48.8% believed that their company did not use these defect data in their improvement work, even though 59.1% of these respondents stated that their company regarded the information as useful and 67.7% of them that their company has an expressed goal of reducing the number of reported defects. When asked to specify their three most important sources of knowledge and project-related experiences, the respondents gave inspections a lower score than any other source.

The answers to the open-ended questions imply that many companies have started to store inspection reports in PDF format on project-dedicated servers. While data stored like this cannot be searched directly and mining of statistics must be performed manually, this approach does make the reports more accessible than they would be if they were simply stored as paper documents in a binder in some office. 4% of the respondents stated that their company saved defect data digitally between projects and 14% had formalised procedures for handling feedback associated with inspection reports.

[3] The figures presented here are percentages of the number of questionnaire invitations that were issued (50). The questionnaire’s overall response rate was 95.3% (48/50). Paper I presents the same results, but the percentages are calculated relative to the number of individuals who completed the questionnaire (48).

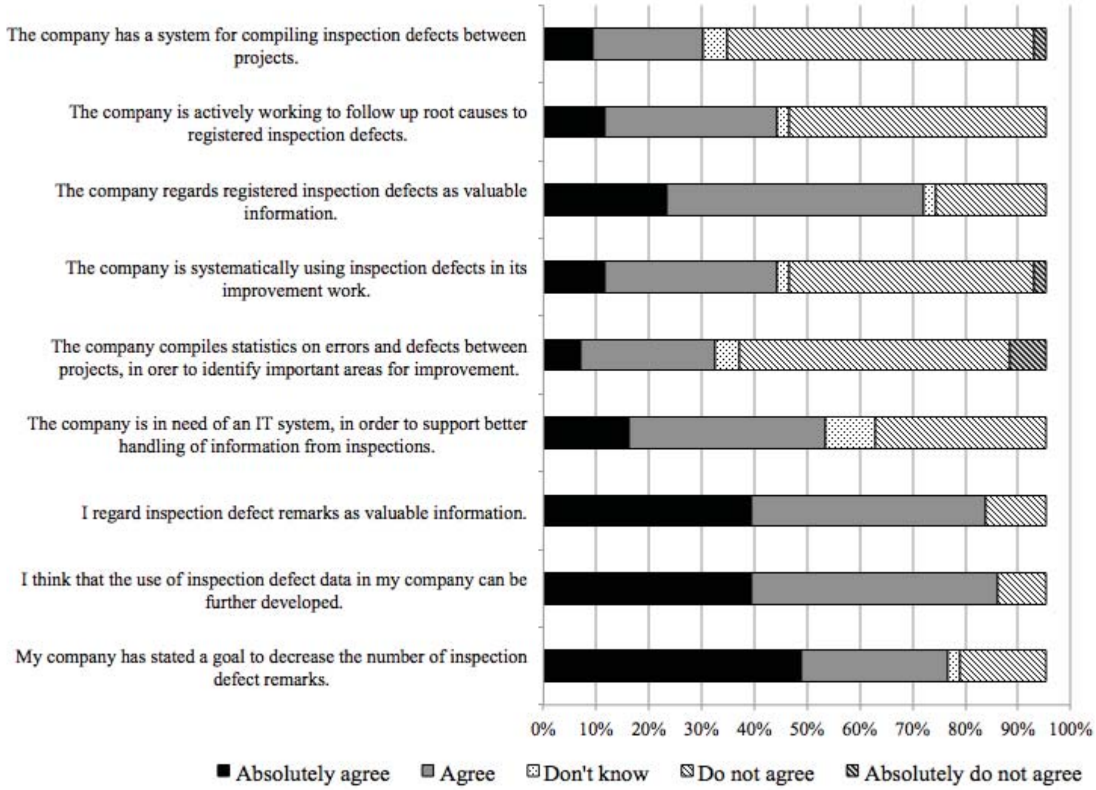

Figure 4. The use of defect data from inspections.

Conclusions: Although one would think that using defect data from compulsory inspections could improve continuous improvement processes in the construction industry, most of the studied companies had not yet adopted systems for this purpose. The questionnaire responses indicated that many companies wanted to integrate these data into their quality systems and continuous improvement work, but were not doing so in any systematic way.

Contributions: Inspection data could become an important source of experience feedback to drive continuous improvement.

Limitations: Most respondents represented large companies; few medium-sized builders chose to participate in the survey. Also, due to the limited number of respondents, statistical analysis could not be conducted. Being a survey, this study was only able to highlight discrepancies between the desire to reduce the incidence of defects in projects and the efforts made to actually address the problem systematically.

4.2 Paper II - A proactive plan-do-check-act approach to defect management based on a Swedish construction project

Background: Defects and nonconformities in construction projects increase costs and project times because they necessitate rework. Builders want to reduce the number of defects in their projects but few have made efforts to systemise their efforts in this area and defect data are rarely compiled and stored in a centralised fashion.

Knowledge gap: Previous studies have not tried to interlink the literature on defect management and continuous improvement. Moreover, defect management studies have only considered the reactiveness of current practice, i.e. the tendency for the status quo to be preserved. There has been no attempt to identify reasons for the industry's general failure to implement systems for using inspection data despite builders' positive views of such information.

Objectives: To reduce the theoretical gap between Defect Management, defect classification, and Continuous Improvement by developing a model for the inclusion of nonconformity data in a proactive strategy for continuous improvement.

What was done: We studied the inspection activities in a large and complex building project contracted by a construction company with an ETO_{ED} strategy. We interviewed the main inspector about his work process and methods, observed an inspection, and analysed defect remarks relating to all of the inspections conducted during the project.

Results: The inspection process was work intensive, involving many man hours on the parts of clients, contractors, and inspectors. It is therefore very costly. In total, there were 41 pre-inspections, 19 final inspections and 14 continued final inspections. The system for location coding was inconsistent; in many instances, information was missing. Many inspectors also have non-standardised ways of describing defects and writing inspection reports. Both the vocabulary and structure of the defect description sentences were inconsistent and unsystematic, even within reports from individual inspectors. Moreover the data were incomplete and inconsistent because they lacked references to specific building elements and other contextual data. This made coding and categorisation of defects difficult. Defect management was entirely a project-internal matter, with no central support process coordinating the work and the associated defect information.

The inspection process is clearly designed and conducted as an entirely reactive appraisal process that occurs exclusively within the confines of the project. There seem to be no corrective actions taken to avoid the recurrence of defects in future projects. Its sole purpose has always been to evaluate *projects,* whose organisation is always unique and thus different to that of their predecessors and successors. The contractor has no control over this evaluation. The information provided by the inspector and the structure of this information may differ from project to project.

This project lock-in does not support quality improvement or attempts to reduce the incidence of defects. The defects data in the inspection reports are virtually inaccessible to those outside the project organisation. Moreover, it only remains available for as long as the project-dedicated server containing the inspection reports is maintained after project completion. This make efforts to work proactively with this data very difficult and resource-intensive.

Viewing the existing defect management processes from a CI perspective using the PDCA framework, we conclude that the Act step appears to be missing; in this case, the Act step would correspond to a company-wide standardisation of improvements. To support classification, we strongly recommend that companies implement measures to promote standardisation and consistency between inspection reports. This could be achieved by the introduction of a centralised support system for managing experience feedback relating to nonconformities (see Figure 5).

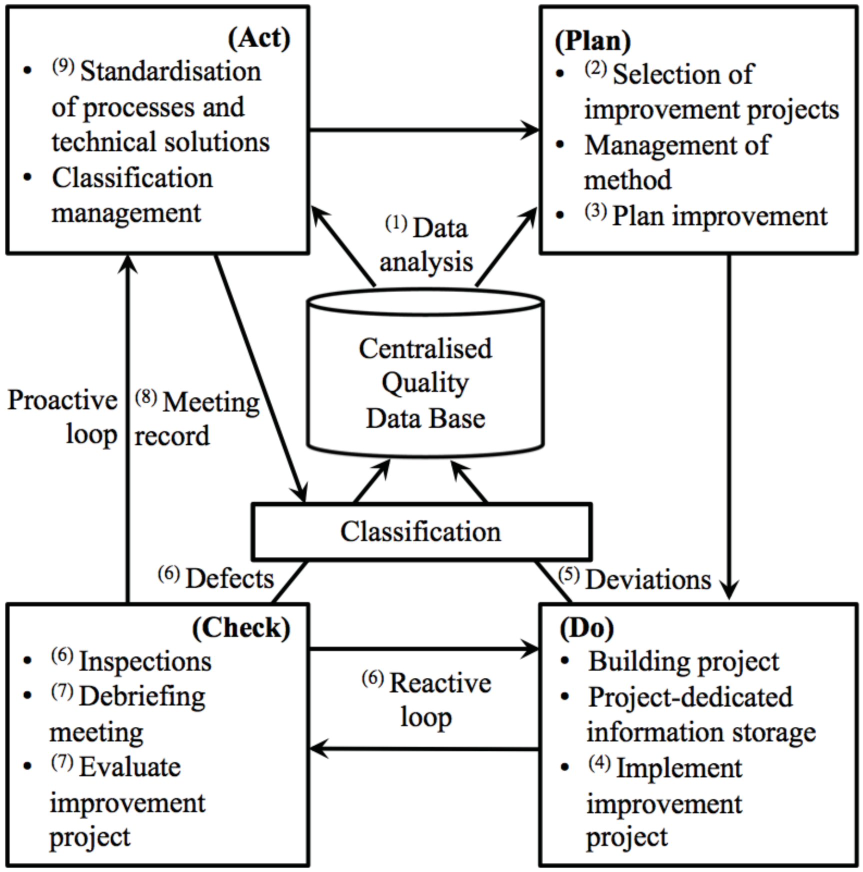

Figure 5. Proactive CI framework from nonconformity data.

Conclusions: One reason for the failure to use inspection defect data for continuous improvement is the project-based nature of current inspection activities. If all nonconformity data were entered into a central database, a central development team would be able to analyse this data continuously and thereby identify and design improvements that could be implemented and evaluated in subsequent projects.

Contributions: The presented model could be implemented as a framework for practitioners who wish to development a system for using nonconformity data generated during production as a source of experience feedback to support continuous improvement. From a theoretical perspective, this study connects continuous improvement to defect management, and suggests why defect data are not currently widely used in the industry.

4.3 Paper III - The role of experience feedback channels in the continuous development of house-building platforms

Background: House-building companies seek improvements to reduce costs and variability while improving flow. Industrialised house-building concepts based on product platforms with extensive predefinition provide a way of storing and reusing knowledge in project-based construction organisations. However, the innovation conducted within platforms is mainly incremental and based on EF from implementations in projects.

Knowledge gap: Previous studies have not explored the continuous development of product platforms, which involves a process of incremental innovation that occurs after the platform has been implemented as a system. Consequently, little is known about the process of capturing project experience and exploiting it as a source of knowledge for the house-building company.

Objective: To describe how experience feedback (EF) from project work could support incremental innovation in product platform development in the context of house-building.

What was done: A case study was conducted on a MTO_{ED} product platform developed by a Swedish house-building company in Sweden to investigate the acquisition and usage of EF in the platform. Data were gathered via interviews and observations, and by analysing platform documentation from ten building projects conducted between 2006 and 2012. The contributions of different EF channels were analysed, including their contributions to the platform's ongoing development.

Results: Based on the model of Jiao et al. (2007), the platform data were quantitatively categorised into functional requirements, component predefinitions, process definitions and relationship definitions. The platform's knowledge documents were shown to support and reinforce standardisation, serving as a link between physical systems (components), working methods (processes), and the organisation of resource operations (relationships).

The house-building platform was largely focused on design. For instance, it had as many as 383 different component definitions (detailed solutions, building elements, sub-systems, and layout solutions). Of its

398 process predefinitions, 251 related to design, 98 to production, and 49 to purchasing. With so many components to combine and configure in a modular design, architects have the ability to produce a virtually infinite variety of final designs.

Four different channels for experience feedback were identified:

(1) *Your point of view* was a suggestion system for gathering feedback for improvement from across the organisation.

(2) *Improvement meetings* was a channel organised at the regional level of the company, where engineers and construction managers working on different projects met, approximately once per month to analyse and improve their design work as well as the organisational relationships associated with design and production routines, contractual responsibilities, and interconnections. The purpose of these meetings was clear – to gather EF relating to platform use and development. Due to the developers' lack of involvement in and control over these channels, they were both classified as *knowledge push* channels.

(3) *Client feedback meetings* were held by the company at the project level, after the completed project had been delivered to the client. The purpose was to capture the client's and project managers' experiences and perceptions of the project's delivery and quality, as well as their opinions on the quality of the communication from the contractor within the project. The developers' only input to this process involved providing a questionnaire without free-text capability and then analysing the questionnaire responses.

(4) *Design optimisation* was a type of meeting introduced in order to gather feedback from each project undertaken using the platform, to acquire information that could be used to improve the platform's designs. This channel was purely focused on improving the project design phase. It was also the only channel in which the developers personally participated, chairing the meetings and setting their priorities. Based on this level of developer control, both of these channels were classified as *knowledge pull* channels. During design optimisation, the senders of feedback had personal connections with the receivers (the developers), whereas in the case of the client feedback meetings they did not.

The EF data from the different channels are quantified in Table 3.

Table 3. EF channels used by the case organisation, the aspects of the platform on which they provided feedback, and the nature of the feedback supplied.

Feedback channel		Variables (which could be adjusted to enable distinctiveness)	Solutions (which must be held constant to provide commonality)
Your point of view	Requirements 2 %	0 %	2 %
	Components 72 %	28 %	44 %
	Processes 18 %	4 %	14 %
	Relationships 8 %	0 %	8 %
Design optimisation	Requirements 0 %	0 %	0 %
	Components 75 %	24 %	51 %
	Processes 19 %	14 %	5 %
	Relationships 6 %	2 %	4 %
Improvement meetings	Requirements 0 %	0 %	0 %
	Components 20 %	2 %	18 %
	Processes 34 %	7 %	27 %
	Relationships 46 %	17 %	29 %
*Client feedback meetings**	Requirements 0 %	0 %	0 %
	Components 21 %	13 %	8 %
	Processes 26 %	26 %	0 %
	Relationships 53 %	30 %	23 %

Note: Percentages in each column denote the proportion of the feedback supplied via each channel relating to different aspects of the platform.

*The feedback meetings were analysed on the basis of the clients' responses to predefined questionnaires designed and supplied by the company.

Conclusions: The EF channels identified in this study all provided input for incremental development and continuous improvement of the platform. All of the four channels were formal, and defined within the platform. No spontaneous, informal and feedback seemed to have been taking place between project personnel and developers. Three of the four channels were also impersonal, i.e. involved no personal connection between senders and receivers. Impersonal channels are common in large organisations, but personal ones are generally more effective because they permit closer, richer two-way communication.

The knowledge push channels required the developers to manually sift through all of the provided suggestions and decide which were of sufficient quality to justify implementation in the platform. This created a degree of data overload, i.e. noise that made it difficult for platform developers to identify the most valuable feedback and reduced the efficiency of the innovation process.

The strategy for improvement, development and experience feedback used by the developers mostly focused on the project design phase. We believe this could be because they had a process focus but not a product focus, and that they used external architects and other technical consultants to design the houses based on the platform's predefinitions (i.e., they don't control the design process, only support it). At the same time, the MTO_{ED} strategy facilitates a project focus. The production process was also not defined in great detail because the construction methods used in the projects were those of traditional Swedish on-site house-building.

Limitations: Only EF channels from projects were identified and studied, i.e. market-oriented channels were disregarded.

Contributions: The study showcases one way of organising EF in a MTO_{ED} platform and the use of this experience to support the platform's continuous improvement.

4.4 Paper IV - Experience feedback in an adapt-to-order – make-to-order industrialized house builder

Background: Several industrialized building companies have successfully implemented *platform thinking*, in order to identify different customer segments and develop suitable product concepts (Jansson, 2013). The firm then needs to continuously innovate and renew the platform, in order for long-term success and survival (Meyer and Lehnerd, 1997). They therefore need to collect and use experience from different channels in the supply chain.

Knowledge gap: Research on platform development in construction has until recently not given particular interest to the importance of platform renewal and the role of collecting experience feedback (EF), so further research of this topic is needed.

Objective: To answer the research question: How is experience feedback being applied for the development of products, processes, and platform in a CTO_{ED} strategy in industrialized house-building?

What was done: A single case study on a house-building organization that had adopted platform thinking, and an adapt-to-order engineering strategy with highly standardized products, was conducted. The data collection consisted mainly of individual face-to-face interviews with key personnel in the central platform organization (the developers) and a number of experienced representatives from local construction teams.

Results: The products, and their subsequent production process, were highly standardised. Each production activity was described in detail in documents called *work descriptions*. The developers had conducted pilot projects of building the products, comparable to the prototypes used, for instance, in the automobile manufacturing industry. This enabled the developers to find and resolve many of the errors in the initial BIM, drawings, work descriptions, and other supporting documents.

A small amount of client choices had been developed, to enable some degree of customization. Some of these were connected to the building level, such as the type and color of the façade – others were on apartment level. Usually each choice was between one default and one alternative.

The developers decided from the beginning to limit the amount of prefabricated sub-assemblies and subcontractors in the projects, in order to minimize their dependence of external resources and problems they felt most traditional building projects had to face. They also decided to not invest in any in-house manufacturing facilities, in order to avoid the risks of not achieving return of investment for such facilities.

Collection of experience data

All the identified feedback channels are summarized in Table 4. The EF to the platform was dominated by informal and personal feedback channels. The development team contains a role called *project engineer* (PE). Each PE is assigned to about three projects at a time. In the project, it functions as a combination of the client’s project manager, and as a part of the site management, providing support and control. As they also work about 20% with development, they function in the project as the main channel for EF. Site management communicated their feedback to them via face-to-face conversation, phone calls, e-mail, written comments on drawings and work descriptions, and post-project experience meetings. The first three of these communication ways were told to be the most prominent for EF.

The PEs actively seek and collect EF from site management and workers. The PEs visit their projects every other week. During the visits, they meet with the site management, but may also walk around the site and chat with the workers. Besides the site visits, the PEs have contact with the SMs via e-mail or phone almost every day.

Project managers had most of their time in product development. They had their interfaces toward consultants, which the developers hire to help with the design and engineering of their products. The consultants are well aware of imminent changes in building code/code of practice, and bring the developers aware of those.

The central *purchaser* represents a two-way channel where, most prominently, the developers could send feedback to their centrally tendered suppliers.

The developers recently started to study how they better could manage the information contained in inspection reports. Remarks mostly concern damages to surfaces at the end of the projects.

EF was also directed through the sales personnel situated within the division, in the form end-customer demand, as expressed by current and potential future clients. However, they did not conduct any market research on end-customers (residents) themselves.

Table 4. Summary of experience feedback channels in the case organisation.

Channel	**Sender**	**Receiver**	**Type of feedback**
Project engineers	Local production team Suppliers	Platform	Production descriptions Manufacturing capability
Prognosis meetings	Local production team	PE, central PM	Project progress, prognosis/forecast
Project managers	Consultants	Platform	Changed code of practice
Purchaser	Suppliers Purchaser	Platform Suppliers	Manufacturing capability Supplier's quality
After-market	Tenants Inspectors	Platform Platform, project	Complaints Defects (inspection remarks)
Sales/market	Current and potential clients, municipalities	Platform	End-customer needs, local constraints
Experience meetings	Local production team Clients	Platform	Project outcomes, product performance

Use of experience feedback

Everyone in the development team works both with continuous improvement & product development, and project management. The priority of the developers was to continuously improve the products. They have been releasing bigger updates of the products twice a year. The developers have had lower priority on the development of new products in the product family. These are instead intended to be released when the developers feel that they are ready.

The EF from the local production teams through the PEs had been used both for initiating development of larger development steps in the products, as well as smaller adjustments of continuous improvement.

A number of product alternations were in development, due to client or local authority demand. In one variant, several units could be attached after another, which could extend the possibilities to build within city centers; another had four smaller apartments per floor, instead of three larger. One variant addressed the Norwegian market, with their building code differing from the Swedish.

Indications from consultants on imminent changes in building code provided revised functional requirements that the developers used to improve the related platform assets.

The developers planned to use statistics from inspection remarks to evaluate different subcontractors. The early projects used to receive more remarks than more recent ones, as the developers had responded to them through CI to different platform assets.

All the ideas for new products or suggestions for improvement to the current ones were put up on a common *gross list*. Each suggestion and idea was then investigated: What are the benefits? What is the cost? How does it affect buildability? Based on the results of this investigation, the suggestion is either dropped, or it is moved to a *development list*, and becomes prioritized and scheduled. This list is being reviewed bi-weekly, and then priorities may change.

The developers preferred that the site management were inexperienced, or that they at least expressed willingness to work with an entirely new philosophy for construction and in new ways.

Conclusions: All EF channels in this case were personal, and most of them were also informal. Informal and personal channels are inexpensive, flexible, and thus effective to the small organization. The different meetings within projects were formal situations, but they were also personal, as they were led by PEs, assisted by PMs. It seems like as long as the developers are deeply involved in every project there is no need for formal suggestion systems, as it is more effective to discuss improvements with the PEs themselves.

Basically, EF from projects fuelled continuous improvement and development of the existing products and platform, and EF from clients and other market-related channels was used for new product development. EF from consultants introduced changes due to revised building code or demands from local authorities.

The findings highlight the importance of having feedback channels from different stakeholders. The more a platform and its product family is standardised, the more importance of channels directed at the market, due to the risk of large investment in products with low market demand.

Contributions: The case study show how EF in an CTO_{ED} platform with very high degree of standardisation can be organised, and how to use EF for both continuous development of platform, products, and production process, as well as new product development.

4.5 Appendix 1 – Extended results from the survey

4.5.1 Background

The construction sector has been considered to perform poorly in terms of learning and improvement, and feedback and learning loops are often broken in project-based organisations. Off-site construction has often in literature been promoted as performing better than on-site construction in terms of learning and improvement (Gann, 1996; J. Meiling, 2010b). However, there is a lack of studies actually comparing the practices of EF in on-site and off-site construction. In this section the objective is to compare the practices of experience feedback in *on-site and off-site* building in the Swedish construction industry.

4.5.2 What was done

The results presented here were derived from basically the same survey data material as Paper I, but after conducting an additional analysis. Seven additional replies to the questionnaire, not present at the time of the analysis for Paper I, were also included.

However, in this chapter comparison between the on-site and of-site companies were needed. All of the off-site companies addressed a national market. It would therefore not be suitable to include the regional and local companies, as we wanted to control the factors of company size and addressed market. Additionally, these groups also provided a small amount of replies (a total of 13), in comparison. It was therefore decided to filter out the local and regional companies in the new analysis; left in the analysis were 37 respondents – 21 on-site builders and 16 off-site builders.

4.5.3 Results

Storing of new knowledge and experience

The on-site builders seemed to rely more on individual workers, closing meetings, experience feedback meetings, and binders, than the off-site builders did. The off-site builders were showed more variation, and thus it was difficult to draw any clear conclusions about the different containers. For instance – just as many of them reported that they didn't use a central database at all, as those who reported that they did so to great extent. Another example is the use of minutes from different meetings, where some reported use to little extent, and some to great extent.

Sources of new knowledge and experience from projects

The on-site builders reported greater use than what the off-site builders did of personal channels such as colleagues, sub-contractors, consultants, and clients, but also of the use of project-dedicated servers, which therefore seem to be the most important IT-based EF channel for on-site building projects.

The off-site builders used to look in binders/archives to greater extent, but they showed greater variation than the on-site builders in the use of several sources, such as compilations of experience from previous projects.

Systems for experience feedback

The off-site builders were a bit more confident about their company's system for storing EF than the on-site builders were. They were also more confident about errors not reappearing than the on-site respondents did, as they worked more actively with following up reported errors, compared to the on-site builders. The on-site builders, on the other hand, saw greater potential for improvement of their experience feedback process.

The use of inspection data

The off-site builders had introduced systems for compiling and using *inspection data* in-between projects to greater extent than the on-site builders, and their company also regarded inspection remarks as more valuable information than the on-site builders. However, voluntary free-text commentaries suggested that often the inspection reports were stored as scanned PDF documents on project-dedicated servers (project management systems), or paper-based archives. One on-site builder implied that it was difficult to measure quality through inspections, as he considered inspectors to be subjective and that no inspection report therefore was entirely comparable to one conducted by another inspector. He mentioned that their effort to analyse inspection remarks had not improved anything, only increased their administrative burden.

One free-text commentary from an off-site builder reported that one problem with inspection data is the amount of noise in the data, due to the sheer amount of it, and that mining this data for knowledge was an entirely manual process. Despite this, the off-site builders analysed the reports, to identify reoccurring defects. They also tried to connect these to the cost of rework after the final inspection and during the following two-year warranty period, as the managers wanted to decrease these costs. The outcome of this tracking of cost-related problems could then result in relevant parts of the building system being re-engineered.

Improvement suggestion systems

The use of *improvement suggestion systems* was strikingly similar between the two groups, although the off-site respondents were in general more positive to improvement suggestions than the on-site respondents.

The on-site respondents believed that their workers thought it was meaningful to hand in suggestions to greater extent than the off-site respondents did. In the off-site companies, they did not promote suggestions for improvements with any extra incentives, whereas this was quite common in the on-site companies. Some of the off-site respondents provided free-text commentary; saying that they didn’t need (or want) to provide any extra incentives to their employees, as the amount of suggestions they already got gave them plentiful of development work already. Such incentives would therefore not result in more improvements implemented.

Experience feedback meetings

The on-site companies seemed to have EF meetings to larger extent than what the off-site companies did, although the off-site respondent group were actually a bit more positive to these meetings as a good way to collect experiences from projects.

A few of the respondents from both groups also provided free-text commentaries. The on-site respondents reported that problems with their current practice was that there was no central receiver of the experience data, and that many important project participants have left the project before the meetings are conducted. One respondent mentioned that it’s important to hold separate EF and project-closing meetings, in order to focus fully on EF on that meeting.

One off-site respondent reported that dedicated EF meetings are only held in projects with a lot of problems, and that successful projects instead generate photos that are posted in the lunch room at the office. Another reported that they have reoccurring EF meetings every 6th week, and that they use these to go through the improvement suggestions that every station along the production line have handed in since last meeting. A third noted that EF meetings are a good way to collect EF, but that it is not sufficient, if they are only held at the end of the projects, due to the long lead times.

4.5.4 Conclusions

If clients look for other factors than ISO certification as a quality measure, a proprietary system should be more effective, as it could be “tailor-made” for the production system and its needs.

Both off-site and on-site builders used increased standardisation as a tool for improvement, but with different focus and by different means. Off-site builders had implemented *lean production* to improve their line-based production in factories, much similar to other manufacturing and assembly companies in other industries. The on-site builders hade instead developed product platforms and increased the use of prefabrication.

On-site builders preferred traditional channels for storing and acquiring new knowledge and experience, such as formal meetings, and informal, personal communication. Off-site builders instead preferred the use of *project binders* and *post-project compilations*.

The off-site builders had systems for storing experiences, and were also more dedicated to the following up of reported errors, than the on-site builders. They had also introduced systems for compiling and using inspection data in-between projects to greater extent than the on-site builders. Therefore, they also were more comfortable that errors would not reappear, than the on-site respondents did.

Limitations

Due to the limited number of respondents in the survey, statistical analysis could not be conducted.

Contributions

This is the first study to compare the different practices of EF in on-site and off-site construction.

5 DISCUSSION

This chapter answers the research questions of the thesis by cross-analysing the findings presented in the appended papers. The findings are also compared to related literature, as presented in the thesis' introduction.

5.1 Regarding production strategies

This thesis deals with production strategies used in house-building; the research questions ask how EF is collected and used in the context of industrialised house-building. The aim of the work included the study of companies with different production strategies, in order to explore the relationship between strategy and EF usage. The studies verified the initial information given to us while planning the research project. The cases studied in this work used a range of production strategies in the engineering dimension, including engineer-to-order (case 1), modify-to-order (case 2), and configure-to-order (case 3). However, all three used a make-to-order strategy in the production dimension. This is consistent with the findings of the multiple case-study conducted by Johnsson (2013). Therefore, for the purposes of this analysis, the 2-dimensional plane of Rudberg and Wikner (2004) can be simplified to a one-dimensional system.

It does not seem very likely that a house-building company would use any production strategy other than MTO_{PD}, because builders using a non-MTO_{PD} strategy would have to keep an inventory of platform sub-assemblies produced to forecast, waiting for a customer to place an order, at which point the final assembly of those sub-assemblies would be performed. The high monetary value of the produced goods would create very high inventory costs in terms of storage space and the value of the assembled goods (Johnsson, 2013).

5.2 How do different types of production strategies influence the collection of experience feedback?

Table 6 summarizes the observed characteristics of the EF channels used under the different production strategies in the studied cases. In case study 1, which examined a typical ETO project, the contractor used formal EF channels in the production phase, such as meetings with the client or the sub-contractors. There was no central product platform organization acting as a champion that could pull experience from the project, so the level of engagement for improvement was low.

The MTO project examined in case study 2 was quite similar to the ETO project, with the difference being the addition of the platform in the design phase. Consequently, the production phase EF channels were very similar to those seen in the ETO project, being formal push channels. However, there were also some additional channels associated with the design phase. Strikingly, these new channels were pull channels; the platform development team acted with engagement as champions seeking to improve the platform's use in design (and thus the design process itself).

Table 5. Characteristics of EF collection in the studied production strategies.

	Case 1	**Case 2**	**Case 3**
Production strategy	*ETO_{ED}*	*MTO_{ED}*	*CTO_{ED}*
Typical EF channels characteristics	Impersonal Formal Push	Impersonal & personal Formal Push & pull	Personal Informal Pull
Focus of EF collection	Production Phase	Design phase	Production Phase, Customers

In case 3 the main EF channel was personal and informal, although some formal channels also existed in the form of meetings. In this CTO_{ED} platform, there is no design phase in the projects – the entirety of the design work was done during product development. The EF channels are therefore oriented towards the production phase. The PEs' personal engagement as champions makes them a "pull channel", as they have control over the collection of experience.

Case study 3 showed that informal and personal EF channels work well for a smaller, centralised organisation such as the development team examined in the study, which is consistent with the findings of Fahey and Prusak (1998). The team members all worked at the same office and the PEs were personally involved in the local projects, visiting them weekly.

The team had not yet matured to the point that they had developed any formalised or structured processes for sharing knowledge between projects. The main mediators for knowledge sharing were a simple database in the form of the "gross list" and the "development list", together with the development and project meetings; these were the most formalised features of the system observed during the study. It is likely that this will change as the team grows: some of these systems will be superseded as the team undertakes more projects and their production increases. This will probably create a need for more formalised and structured technology-based knowledge repositories. The growing need for such a system was discussed by one of the interviewed PEs.

The more product-focused the organisation, the more EF channels they had aimed at their customers and the market. When an organisation is developing products, it should be proactive and survey the market for opportunities (Ulrich and Eppinger, 2008). We saw in case study 3 that the house-builder with a CTO_{ED} strategy had sales personnel taking feedback from clients and other sources of market demand. It was clear that the MTO_{ED} house-builder examined in case study B lacked an EF channel oriented towards the identification of functional requirements, i.e. customer attributes – none of the established EF channels contributed to this aspect of the platform.

5.2.1 Alternative explanations for EF collection

The structure of the organisation, i.e. its level of (de)centralisation, could also affect how the EF channels are organised and which types of channels are used. The three cases all had different degrees of centralisation. In the ETO case, the projects are independent and run by teams with a lot of control over their actions, so the organisation is quite decentralised. Case 2 represents an intermediate situation: the project teams retain most of their control over the project, but the platform developers provide a centralising contribution during the design phase. In Case 3 the development team has full control over the products, and share control over the implementation of the projects with local site managers. The PEs are involved in the projects but represent the central organisation. In terms of EF, this organisation is therefore fully centralised.

5.3 How do different types of production strategies influence the utilisation of experience feedback?

The production strategies define the degree of standardisation of the products: the later the CODP, the greater the degree of product standardisation and the greater the focus on product development as opposed to traditional project management capabilities. As the design phase shifts towards being a mere configuration activity, the focus of EF turns toward product and production process improvement (see Table 7).

House-builders using CTO_{ED} platforms primarily focus their EF towards the production process and product development. With only a short configuration process during the sales process instead of a design phase in every project, all of the potential for improvement and development exists in the production phase. The products' high degree of standardisation also lends itself well to standardisation of the production methods. The improvements to the production method and the product are based on a bottom-up approach to knowledge-sharing, as the ideas for opportunities come from the production team. In case study 3, the development team utilised EF to create derivatives of existing platforms, incremental improvements to existing products, and fundamentally new products, as categorised by Ulrich and Eppinger (2008). The EF from the production teams contributed primarily to incremental improvements to existing products, the platform, and the production process, whereas channels directed at the market initiated the development of the new products.

Table 6. Characteristics EF utilisation in the studied cases.

	Case 1	**Case 2**	**Case 3**
Production strategy	ETO_{ED}	MTO_{ED}	CTO_{ED}
Degree of standardisation	Low	Medium	High
Prefabrication levels	CM & SA	CM & SA, NVPA	CM & SA, VPA
Degree of off-site production	Low	Medium	Low
Focus of EF utilization	Improvement of project management practice	Improvement of the design process	Product development Production process improvement

House-builders using MTO_{ED} platforms first and foremost focus their EF towards the use of the platform assets in the design phase. The company needs a return on its investment in the development of the platform, which has many components and other assets that can be combined in many ways. The design phase is similar to an ETO project, but the architects and engineers are required to use the platform assets to design the building, and the design must be within the constraints of the platform. The most effective channels in *case study 2* focused on improving this design process, but also contained a lot of improvements to the design of pre-engineered components in the product platform.

5.4 The cases in relation to the survey

The survey did not classify the respondents' companies in terms of their production strategies. Instead it identified them merely as "on-site" or "off-site" builders, meaning that they conduct either a minority or a majority of their production in factories. In reality, the off-site companies are publicly known as "industrialised house-builders" that produce their houses in factories.

Final inspections may be useful for identifying systematic problems with the performance of the companies involved in the building process. However, there is a need for further development of both inspection practices and systems for storing inspection data, of which this thesis provides some suggestions.

Literature has described difficulties for continuous improvement and knowledge management within ETO organisations in the construction industry (Styhre and Gluch, 2010). The findings presented here suggest that these organisations could learn a lot from industrialised builders, particularly from the way that central development teams acts as champions and use leadership and engagement to pull experience from projects into the organisation's improvement processes.

6 CONCLUSIONS

This thesis presents research on how experience feedback is collected and utilised within the house-building industry in Sweden. This chapter summarises the contributions made by this research, and outlines some ideas for future investigations.

In the ETO_{ED} project, the contractor used formal push channels in the production phase. In the MTO_{ED} platform, the EF channels from the production phase were similar to those for the ETO_{ED} platform but with the addition of extra pull channels in the design phase. In the CTO_{ED} platform, the main EF channel was personal and informal but there were also formal channels in the form of meetings. The EF channels in this case are pulling experience from the production phase and the market related factors.

The findings suggest that the more product-focused the organisation, the more EF channels they have aimed at their customers and the market, and that house-builders using CTO_{ED} platforms primarily focus their EF towards the production process and product development whereas house-builders using MTO_{ED} platforms focus their EF on the use of the platform assets in the design phase.

Builders using MTO_{ED} platforms orient their EF towards their platform's assets. The next step in this process will presumably involve increasing the standardisation of their construction methods.

6.1 Practical contribution

The findings in this thesis could be valuable to industrialised house-building companies in a few ways. The production strategy view could help them communicate the level of standardisation of their products, or the design flexibility for their clients. This involves both internal and external communication. After having identified their location in the production strategy taxonomy, the house-builders can draw upon the respective case studies herein as sources of inspiration when establishing and organising their own EF systems.

It should be especially valuable to the house-builders that are planning on changing their production strategy to consider the need for experience from different phases of the design and production process, and that they therefore adjust the focus of their EF activities in accordance. For instance, changing from ETO_{ED} to MTO_{ED} should involve greater focus on EF in the design phase of projects.

6.2 Theoretical contribution

The main theoretical contribution of this thesis is the characterisation of EF in relation to the different production strategies used in house-building – detailing which EF channels that can be expected and where the experience typically is collected for each strategy as well as indicating the level of industrialisation for each strategy. The thesis also provides both more width – due to the survey – and depth – due to the case studies – concerning the meaning of EF in house-building.

6.3 Limitations and suggestions for future research

This thesis provides only a limited study on an area of construction research that previously has only been briefly explored. The findings presented herein therefore need further verification based on new case studies. This is important because it is likely there have been some additional, unknown factors that were not identified or accounted for in these studies.

The thesis also only contained case studies from on-site based house-building, while the survey looked at “on-site” and “off-site” builders, a matter touched upon in Chapter 3. A clear limitation of this thesis is therefore that it did not include any cases from off-site house-building. Future investigations should therefore focus on off-site house-building to verify the ideas presented in this work.

It could be difficult to analytically generalise from case studies. For instance, how well do the findings herein hold up for contexts other than industrialised house-builders? For other branches of the construction industry? For other industries entirely? From an analytical standpoint, any other context sharing the same CODPs should be able to draw inspiration and evoke discussion from the cases herein. An organisation with an ETO_{ED} strategy *is* project-focused and may have a similar supply chain, with the roles of client, designers and engineers, contractors and sub-contractors. The organisation with the ETO_{ED} strategy in this thesis was not specifically a house-builder, but a general builder. However, the construction industry is the only to heavily rely on the “temporary factory” of on-site production. Similarities and differences aside – in order for further generalisation outside of house-building to be made further case studies in such contexts are strongly advised.

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Appended paper I

Digitalization 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 (Arnheiter 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.

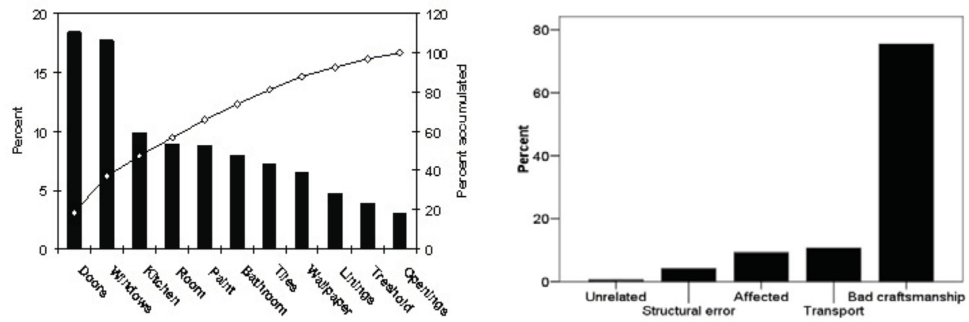

Figure 1. Summary of analysis of 2415 defects arising in 11 projects, from Johnsson and Meiling (2009).

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 indentified 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.

No. of respondents	Size	No. of employees	Annual turnover
3	Small	10-49	<10 €M
19	Medium	50-249	10-50 €M
16	Large	250-	>50 €M

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.

	Clients	Employees	Post-market	Sub-contractors	External sources*	Design consultants	Inspections
Percent	81	78	44	32	27	22	17
No. of responses	33	32	18	13	11	9	7

** 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.

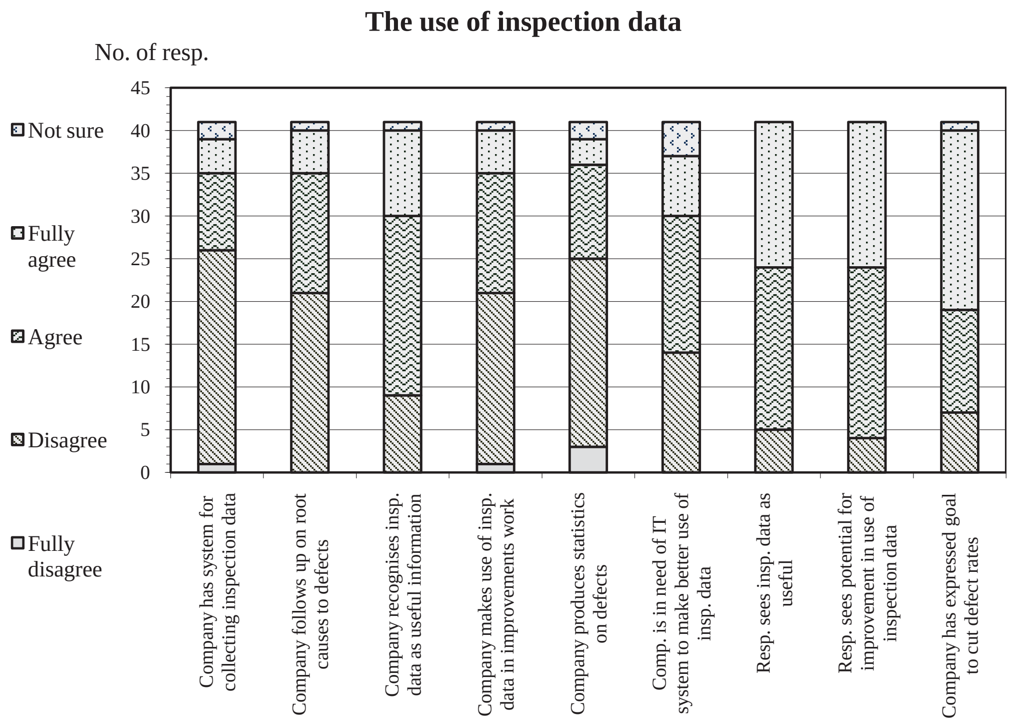

Figure 1. The use of inspection data.

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.

In what way are defect data from different projects saved within the company?

	Paper-based archive (e.g. binders)	Digitally within projects (e.g. in digital reports on project portals)	Digitally between the projecs
No. of comments	12	12	2

Lower level of accessibility ⟵⟶ Higher level of accessibility

In what way is information from inspection reports used within the company?

	No use at present	Ad hoc - no formalised routines for feedback or documentation	Through formalised routines for feedback
No. of comments	7	12	7

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 produces, 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.

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Appended paper II

A proactive plan-do-check-act approach to defect management based on a Swedish construction project

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A proactive plan-do-check-act approach to defect management based on a Swedish construction project

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In order to continuously improve quality and avoid reoccurrence of defects, defect management (DM) in construction needs to take a more proactive approach. The classification of construction information is important for the efficient exchange and integration of data between the many roles and phases of construction and facility management, but it also provides a framework for standardization, which in turn is paramount for improvement. In order to better understand how defects can be managed proactively we conducted a case study on inspection practices at a large construction project in Sweden, using observation and analysis of inspection reports. We identified opportunities and obstacles in the classification of defect data. The project's defect descriptions were often ambiguous and the records lacked important contextual information. We believe that this was because current practice is not designed with proactivity in mind, and there are only regulatory requirements on the data, making classification difficult. In addition, by viewing the project's practices through the lenses of continuous improvement and plan-do-check-act theory to identify missing or inadequate steps, we propose a framework for a proactive version of the current defect management process that could potentially help to prioritize improvement work and reduce the incidence of defects.

Keywords: Building defects, classification, continuous improvement, inspection, quality management.

Introduction

Defects and nonconformities contribute to cost and schedule overruns in construction projects (Love, 2002a, 2002b). Different studies over the years have found that direct costs associated with rework account for between 2% and 12.4% of the contract value (e.g. Burati *et al.*, 1992; Josephson and Hammarlund, 1999; Barber *et al.*, 2000). As the construction industry represents a significant part of the gross domestic product of our countries (Sveriges byggindustrier, 2009), initiatives that can reduce the waste of defects and nonconformities are of great interest.

Previous studies on defect management (DM) in construction can be divided into (1) studies analysing the causes of deviations (Burati *et al.*, 1992), defects (Josephson and Hammarlund, 1999) and rework (Love and Li, 2000) and their cost impacts; (2) studies focused on building information classification systems and the classification of defect data (Josephson *et al.*, 2002; Fayek *et al.*, 2003; Kim *et al.*, 2008; Johnsson and Meiling, 2009); (3) the development of domain ontologies for knowledge management in construction (Wetherill *et al.*, 2002; El-Dirabi and Kashif, 2005); and (4) the development of various ICT tools to improve on existing inspection-based DM approaches (Cox *et al.*, 2002; Kim *et al.*, 2008 and Dong *et al.*, 2009). Studies in the first category have provided good indications about situations in projects where problems are likely to arise. However, in order for contractors to get hard evidence about the situation in projects of their own, they need to monitor nonconformities and track down root causes themselves. The management of defects and nonconformities by means of inspections is inherently reactive (Dale *et al.*, 2007, p. 25). Moreover, current defect management techniques require a lot of manual labour (Gordon *et al.*, 2007), and are prone to error (Park *et al.*, 2013). Studies on defect classification, domain ontologies and the development of improved ICT tools could therefore

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all help improve the quality of the DM process itself while reducing its costs, thereby reducing the *appraisal* component of the quality cost. However, in order to do this while also reducing failure costs, a proactive prevention-based approach is needed (Rosenfeld, 2009) in which contractors work to address the root causes of defects via feedback systems (Meiling and Johnsson, 2008).

Park *et al.* (2013) addressed the lack of proactivity in existing practices by proposing a database with a domain ontology for defects that involved the classification of defect data. The classification process included a standard building information classification system (OmniClass) in order to enable different users to more easily search for explicit information on issues associated with specific building elements, production methods, etc. However, their concept seemingly fails to incorporate continuous improvement (CI) thinking, which is a fundamental component of the quality and operations improvement strategies (Chiarini, 2011) that are widely used by construction companies in Sweden (Lundkvist *et al.*, 2010). The CI philosophy focuses on achieving higher quality at a lower cost. This can only happen by reducing the cost of quality (CoQ), and these costs in turn can only be reduced if they are first identified and measured (Schiffauerova and Thomson, 2006).

In Swedish construction, compulsory third party inspections play a pivotal role in the management of defects (Svensk Byggtjänst, 2005b). While quality management systems encouraging CI are very common, contractors seem to not currently make use of data from inspections for purposes other than reactive correction, although many construction managers consider such data to have potential as a source of feedback and a means of driving improvement (Lundkvist *et al.*, 2010). Proactive DM could potentially contribute to CI in construction, but there is a need to further study current inspection practices and DM in order to identify obstacles that may hinder the adoption of proactive approaches.

The aim of the case study presented in this paper, on third party inspection in a large construction project in Sweden, was to reduce the gap between DM, defect classification, and CI. By analysing the defect data from final inspections generated in the course of the project, and by building upon previous research by the authors, we identified obstacles towards proactiveness in current DM practice. The plan-do-check-act (PDCA) cycle of improvement (Deming, 1986) was used as an analytical model for evaluating CI. Based on these findings we eventually propose a proactive framework that encompasses the full PDCA cycle during DM.

Frame of reference

The cost of quality and defects in construction

The terms *defect* and *nonconformitiy* have been used somewhat interchangeably in literature (Sommerville, 2007). In the ISO 9000 standards, a *defect* is defined as a 'non-fulfilment of a requirement related to an intended or specified use' and is distinguished from a *nonconformity* by being more severe and associated with liability issues (SIS, 2005, p. 13). ISO 9000 then defines *quality* as the 'degree to which a set of inherent characteristics fulfils requirements', enabling quality to be measured quantitatively or by using a qualitative scale that could for example range from poor, through good, to excellent (SIS, 2005, p. 7; Dale *et al.*, 2007). Similarly, the terms *rework* (Love and Sohal, 2003) and *correction* (Ashford, 1992) have been used in the literature, sometimes interchangeably, to describe the action applied to a nonconforming product to bring it into conformation with the requirements. However, whereas correction refer to all types of alteration of a nonconformity in order to achieve conformance (and therefore include things such as completing incomplete work, i.e. doing work for the first time), rework is preferably defined as 'doing something at least one extra time due to nonconformance to requirements' (Construction Industry Development Agency, 1995, pp. 59–63). Thus, rework also includes repair, i.e. 'the process of restoring a non-conforming characteristic to acceptable condition, even though the item may still not conform to the original requirement' (Love, 2002a, p. 138). A *corrective action*, on the other hand, is an action performed to eliminate the cause of a detected nonconformity or other undesirable situation (ISO, 2005). In other words, it is intended to prevent the nonconformity's recurrence by addressing its root cause and should therefore be defined as a proactive measure.

Estimates of the direct costs associated with rework in construction range from 2% to 12.4% of the contract value (e.g. Hammarlund *et al.*, 1990; Burati *et al.*, 1992; Barber *et al.*, 2000; Josephson *et al.*, 2002). However, the cost of nonconformities and rework is only one part of the total cost of quality (CoQ), and in order to evaluate actions for improvement, we need a fuller picture (Schiffauerova and Thomson, 2006). Feigenbaum (1956) and Juran (1951) pioneered the development of economic models for evaluating CoQ. Their classical P-A-F model divides CoQ into prevention, appraisal and (internal and external) failure. The first two categories are controllable, while the third is a consequence of investments, or the lack thereof, in the first one. A core concept of the P-A-F model is that investments in prevention and appraisal activities reduce failure costs, and that further investment in prevention will further reduce appraisal costs (Porter and Rayner, 1992; Schiffauerova and Thomson, 2006). However, this classic view suggests that there is an optimal CoQ at which the cost of ensuring higher quality exceeds the benefits of this higher quality. Later models also included opportunity costs (Modarress and Ansari, 1987; Carr, 1992; Sandoval-Chavez and Beruvides, 1998) and intangible costs (Juran *et al.*, 1974) and suggested that on the contrary, additional investments in prevention are *always* profitable in the long term (Burgess, 1996) and in dynamic situations (Fine, 1986) involving changing technologies and knowledge. Without a proactive focus on the root causes of failure, investments in appraisal may even increase failure costs due to more effective defect detection (Foster, 1996).

Insufficiencies in current construction defect management

Inspection is a method for detecting nonconformities 'after-the-fact' (Dale *et al.*, 2007). From a CoQ perspective, inspections are categorized as appraisal activities because they are conducted during the process in order to ensure conformity (Rosenfeld, 2009). According to Dong *et al.* (2009), inspectors conduct inspections and record their observations on drawings of the building or inspection forms. These are then taken back to the design office, where the designers identify the defects and decide on appropriate measures for their rectification. The process is time-consuming for various reasons including the need to re-enter data at several steps in the process; this can lead to data loss (Kim *et al.*, 2008). Contractors then correct the defects, after which there is typically a reinspection to confirm that appropriate corrections have been made. It is generally difficult to monitor the progress of the correction phase because both it and the inspection process involve collecting a lot of data over a relatively short period of time. During this time the construction crew will already have a heavy workload as it strives to meet the project's completion date (ibid.).

A survey by Lundkvist *et al.* (2010) on Swedish contractors' use of proactivity in defect management showed that 80% claimed that their company had set reducing the number of defects detected during inspections as a goal. Seventy-six per cent claimed that their company considered defect data to be valuable. This is a considerably greater proportion than that of contractors who actually *used* such data: 51% of the respondents claimed their company made no use of defect data during its improvement process. Moreover, 43% of the respondents' managers claimed that their company actively analysed the root causes of defects, although 63% of their companies did not have a central defect data repository. An interview study by Lundkvist and Vennström (2010) on a group of building inspectors, clients and building designers in Sweden, and their use of knowledge and experience feedback activities, showed that debriefing meetings, or lessons learned (see Gameson *et al.*, 2008) were the most widely used quality feedback activity. However, some of the participants complained that debriefing meetings were not always held due to problems scheduling a meeting that all the relevant major parties could participate in.

Examples of research on the development of ICT systems and tools that facilitate more efficient defect management include Cox *et al.* (2002), which suggested an information system for conducting safety inspections using a Pocket PC and a database for the recording of defect data. This system was intended to render the inefficient and error-prone method of taking field notes with pen and paper obsolete. Other benefits of this system included a reduction of total paperwork, automatic report generation, and rapid distribution of electronic data. Kim *et al.* (2008) introduced a web-based defect management system, together with a Personal Digital Assistant (a handheld device for the recording of defects) in an apartment housing construction project in South Korea. Similarly, Dong *et al.* (2009) introduced a horizontal tabletop ICT system for defect management. This system used augmented reality to ascribe defects to particular locations in building information models. Both Paterson *et al.* (1997) and Park *et al.* (2013) suggested the use of image recognition for the purpose of automating geometric inspection.

These systems provide short cuts and enable the simplification and standardization of the inspection process, which likely will save time and money on appraisal, but they are merely designed to support existing reactive systems and cannot by themselves address the need for a proactive approach. Moreover, in order to draw reliable conclusions from the data they generate or to identify meaningful patterns within it, the data must be refined in a way that makes it transparent and simple to analyse, which requires an effective data classification system.

Classification of building data

Information classification systems for construction works provide the industry with standardized terminologies and languages to be used throughout the life cycle of the entities within the built environment. A common language facilitates transparency and traceability of work results, and of the materials and resources used

(Svensk Byggtjänst, 2005a). While many of the relevant classification systems were originally developed for use with technical specifications and estimating (Ekholm, 1996), they are now being adopted within building information modelling, for instance to facilitate interoperability between different software packages (Eastman *et al.*, 2011).

Several national construction classification systems have been developed, many of which adhere to the ISO standard ISO 12006-2: *Organization of Information about Construction Works – Part 2: Framework for Classification Information*. For instance, OmniClass is a relatively new system that was developed in collaboration between Americans and Europeans and is intended to address some of the drawbacks of earlier classification systems such as MasterFormat and Uniformat (Eastman *et al.*, 2011). The Swedish BSAB 96 system is used by most of the Swedish construction industry. Five tables - Building Entities, Spaces, Elements, Designed Elements, and Work Result - have been developed so far (see Table 1). The system is actively and continuously developed in order to meet the needs of future use (Svensk Byggtjänst, 2005a). Given the purpose of these classification systems, and to allow effective feedback, defect data should be classified based on a standard used in the market context of the constructor and project (Park *et al.*, 2013).

Several researchers have proposed classification systems for defects. For instance, Fayek *et al.* (2003) suggested a Field Rework Data Collection System for quantitative measurement of defect data based on cost, schedule, etc. This system includes detailed defect cost categories that are integrated with the MasterFormat *Activity* and *Element* tables. Love and Irani (2003) presented a project management system for controlling quality costs that focuses on failure costs and includes problem descriptions, details on the problem's causes and whose responsibility it is, the trades of the relevant subcontractors, deviation type, and information on the costs of the failure and its time impact. Kim *et al.* (2008) suggested a database structure for quality inspection and defect management in fieldwork processes that provides information on the relevant facilities, trade contractors, material, space, element, and defect type. Johnsson and Meiling (2009) developed a classification system for defects in industrialized building that can be used to support continuous improvement and provides information on the affected building element, the defect type, the corrective measures applied, the phase of construction in which the defect occurred, and the defect's cause. However, this system is not based on any general building information classification systems.

Park *et al.* (2013) identified the need for proactivity, and addressed this need by suggesting a defect domain ontology. Their system consisted of a template for data collection and retrieval based on OmniClass. Classification frameworks of this sort enable different stakeholders to search for information in the accumulated data for their own purposes (ibid.). However, the focus of their empirical study was on testing the automation of inspection, rather than on evaluating their system in terms of its supposed proactivity. Therefore more research on proactive defect management is needed. The idea of 'proactive defect management' shows strong similarities to continuous improvement (CI) and the problem-solving methods therein.

Continuous improvement and PDCA

Continuous improvement (CI) is a central concept of most quality and operations improvement strategies, such as total quality management (TQM), Lean thinking and Six Sigma (Chiarini, 2011). To drive improvement, several structured problem-solving processes have been developed, such as plan-do-check-act (PDCA) (in Deming (1993) referred to as plan-do-study-act (PDSA)), DMAICS (define-measure-analyse-improve-control-standardize), 8D (form team, define problem, contain problem, identify and define root causes, choose corrective actions, implement corrective actions, prevent recurrence, reward team) and 9S (immediate actions, build the team, define problem, containment actions, identify root causes, define and select corrective actions, implement corrective actions, standardize and transfer knowledge, recognise team and close) (Jabrouni *et al.*, 2011). For the purpose of this study, the less strict PDCA cycle is considered to be a suitable basic theoretical framework for analysing the conditions for structured CI from defects data within Swedish housebuilding companies.

Table 1 Illustrative BSAB 96 codes from different tables

BSAB 96 Table	BSAB 96 code
Building Entities	SB – Buildings for housing
Spaces	214.C – Spaces for cooking, storage of foodstuff
Elements	43.CB – Inner walls (non-structural)
Designed Element	43.CB/41 – Inner walls (non-structural) – board and steel frame
Work Result	LCS.2212 – Painting of walls, columns and similar indoors

Deming (1986) described the steps of PDCA as (1) Plan: study the current situation and knowledge, plan for a change or test; (2) Do: carry out the change or test, preferably on a small scale; (3) Check: observe the effect and report the results to those who make decisions; and (4) Act: study the results and identify the changes that are needed to improve and standardize the process. The other methods all have similarities with PDCA, but they all differ in detail regarding which steps of the cycle are emphasized and expanded upon (Chiarini, 2011). They all involve the capture of experience data, followed by transfer and evolution into standardized solutions. Meiling *et al.* (2013) empirically tested one version of the PDCA method in a double case study of an industrialized housebuilding company in Sweden. They showed that the PDCA method could also work for less industrialized processes, although finding root causes and embarking on permanent process actions in such cases is likely to be resource-intensive. Therefore we should further study the use of PDCA in construction to enable proactive defect management.

Method

Case study

In order to reduce the knowledge gap between DM, defect classification, and CI we wanted to study *how* current third party inspection and subsequent defect management in the Swedish construction industry work within the real-life context of a construction project. Based on these conditions the case study method is suitable, as it lets us use multiple data collection methods and data sources (Eisenhardt, 1989) when the boundaries between phenomena and context are unclear (Yin, 2009). Instead of statistical sampling, case studies use theoretical sampling (Glaser and Strauss, 1967), and thus case studies can also be used for theory building (Eisenhardt, 1989). Compared to laboratory experiments, which isolate phenomena from their contexts, case studies rather emphasize the real-world context in which the phenomena occur (Eisenhardt and Graebner, 2007).

We wanted to see how defect data is recorded in the course of a project, how this procedure shapes the look of the data and how the data is used in defect management, and thus the unit of analysis was 'data from third party inspections'. Building upon results from our previous research, we managed to triangulate how inspection and defect management are used in general in Swedish construction, which we analysed through the lens of continuous improvement and PDCA. The conditions for classification of defect data were then tested by attempting classification of the data of the final inspection reports in the project.

A background to standard contracts and inspection in Swedish construction

In order to understand the role of inspection in the Swedish construction industry, one should know about the role of standard contracts, of which there is a strong tradition. The current versions used of the most central standard contracts are AB 04 (for bid and construct contracts) and ABT 06 (for design and construct contracts). Both require the construction work to be inspected by an independent, third party inspector before the project is handed over to the client. The purpose of these inspections is to ensure that the work is 'without defects' (Svensk Byggtjänst, 2005b). The work may be inspected on several occasions, via *pre-inspections*, *final inspections* and *continued final inspections* as shown in Figure 1 (ibid.). Pre-inspections are suitable, for instance, if some parts of the work will be inaccessible on final inspection. Failing a final inspection, e.g. due to the discovery of defects of significant number or stature, results in a continued final inspection. The inspector plans for when to conduct every inspection through the design of an inspection plan.

Case selection

The particular project for this study was selected because (1) the chief inspector was well renowned, with over 15 years of educating other inspectors and more recently also responsible for this education, implying that the inspection and its reports should represent both best practice and, at the same time, be fairly representative of inspections in general in Sweden; and (2) the project was considered large, implying that a large number, and a wide variety, of defects were likely to be recorded.

The net area of the conference centre that was being built in the project was to be 20 000 m^2. It can accommodate around 3000 congress attendees and about 1000 conference attendees. The project was conducted under a general contract with seven subcontractors. The inspection organization consisted of one chief

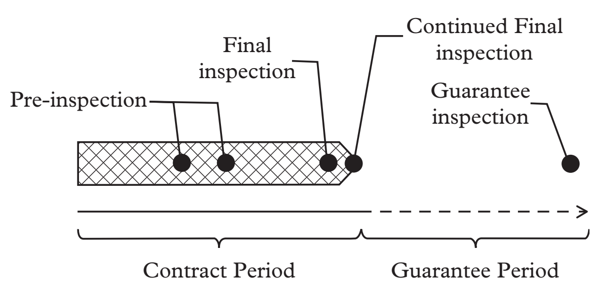

Figure 1 Schematic plan of inspection for a typical construction project

inspector and eight sub-inspectors, each with different areas of expertise. The project had an inspection plan comprising both pre-inspections and final inspections. Owing to the size of the project, the inspections were carried out over a long period of time; individual parts of the building were inspected as soon as they were completed and accessible. We entered the project right after the final inspections had been conducted.

Data collection

First, we interviewed the chief inspector in order to obtain a first-hand description of his working methods and a description of inspections in general. Pre-written questions were asked, but as the interview developed, new questions were posed in order to elaborate on an interesting theme or to develop a more thorough understanding of a concept by rephrasing or complementing a question. The interview was recorded and transcribed verbatim.

Secondly, we observed one of the project's many days of continued final inspection. The purpose of this observation was to study how inspections in such large projects are conducted, how data is recorded, and to see whether a better understanding of the defects data could be obtained by participating in a site inspection directly. Observational data was collected in the form of notes and photographs.

Classification of inspection data

Finally, we analysed the data of every available pre-, final and continued final inspection data report, including data for different building services/subcontracts. However, as pre-inspection reports from building services/subcontracts were unavailable to us we focused our analysis on the reports concerning the work of the main contractor. The number of recorded defects that were connected to the work of the main contractor was, in some of the reports, up to 100 times greater than those for the different building services.

The analysed dataset contained information on just over 2000 defects. All of the defects data was manually copy-pasted from PDF files into a spreadsheet. We then attempted the following for each defect:

(1) Adding BSAB 96 space codes; this succeeded for defects where sufficient information was provided in either room or defect description.
(2) Classification based on the *defect descriptions*. Since BSAB itself does not contain any tables for the classification of defect descriptions, we used a version of the classification system for industrialized building introduced by Johnsson and Meiling (2009), modified to incorporate a more generalized set of classes (see Table 2).
(3) Adding the date when each defect was first noted in a report, in order to determine how long each defect was left 'un-rectified'.

Unfortunately, classification on building elements was not possible because no references to these were present in the data.

Results

Inspection on the case project

The project had involved extensive pre-inspections as part of a so-called 'continual inspection' approach. According to both the client and the chief inspector, continual inspections allow problems and nonconformities to be discovered at an earlier stage and thus to be corrected in good time before project completion, compared to having only one single final inspection.

Prior to the final inspection, the construction works, roof, facades, balconies and glasswork alone had been subjected to a combined total of 41 pre-inspections over the course of just over a year. The number of participants in these pre-inspections was unavailable, but two is an absolute minimum and three to four is more likely. A total of 19 different *final inspections* (different building services) were conducted over the course of six days. About two weeks later, the *continued final inspections* would then consist of one round of 16 inspections spread out over seven working days plus a second round of 14 inspections over five working days two weeks later. According to the chief inspector, many officials can spend weeks participating in various inspection activities during projects of this scale.

The observed inspection began with an initial meeting where a plan for the inspection at hand was set by the representatives present, based on the parts of the building and total works that were considered ready for inspection. Aside from the chief inspector and his partner, the group consisted of three deputy inspectors with different areas of expertise. The other participants were the project manager, representing the client, and representatives from the general and subcontractors. The contractor's project and facility documentation was checked along with the contractually prescribed quality plans and self-inspection records. The group then decided to split into two: the chief inspector led one sub-group on a tour starting from the top floor and working downwards, while his colleague led the other team, working from the bottom floor and upwards.

The teams then proceeded systematically, progressing in a clockwise fashion on a floor-by-floor, room-by-room basis. The representatives of the various parties could comment on the defects that the inspector

Table 2 Classification legend for the defect descriptions (adapted from Johnsson and Meiling, 2009)

What was defective?				
0 Unrelated	2 HVAC	3 Opening	4 Lining	7 Floor
1 Int. installations	2-1 Radiator	3-1 Windows	5 Wall	7-1 Clinker
1-1 Radiator	2-2 Pipes	3-2 Doors	5-1 Tiles	7-2 Carpet
1-2 Pipes	2-3 Electricity	3-3 Openings	5-2 Wallpaper	7-3 Parquet
1-3 Electricity		3-4 Linings	5-3 Painting	8 Completions
		3-5 Threshold	6 Ceiling	8-1 Balcony
				9 Information

Defect type?	Correction measures?		When (phase)?	Why did it occur?
0 Unrelated	0 Unrelated		0 Unrelated	0 Unrelated
1 Unfinished	1 None		1 Structural design	1 Transport
2 Missing	2 Cleaning		2 Prefab	2 Damaged
3 Damaged	3 Adjustment		3 Transport	3 Bad craftsmanship
4 Erroneous	4 Completion		4 Assembly	4 Structural error
	5 Repair		5 Warranty time	
	6 Exchange			

identified as we progressed. For example, the client and contractor could have agreed that certain defects did not require correction, or that they disagreed on whether something was or was not a defect. The inspector may record the parties' decisions concerning the identified problems but he alone is responsible for deciding what is to be recorded as a defect and the opinions of other parties should not be included in the report, it should only reflect the 'emotionless' neutrality of the inspector. Each record contained (1) a location reference in the form of floor and room number (often combined with the room description); (2) the serial number of the defect; (3) the contractually responsible part (client or contractor); and (4) the defect description. In the defect description, the inspectors used a simple coding of specific building elements for the location of defects, e.g. 'W3' denotes the third wall of the room, counting clockwise (i.e. the wall opposite the door).

According to the chief inspector in this case study, the inspection organization, which often consists of micro- or small consultant firms, usually differs from project to project. Many inspectors also have their own way of describing defects and writing inspection reports even though AB 04/ABT 06 stipulates the minimum requirements. Our observed chief inspector used a tripod-mounted laptop in order to make his work more ergonomic and efficient, and to avoid data loss, by entirely skipping handwriting and the retyping of data. Defects were recorded using a word processor, namely MS Word. This allowed for partial automation of typing, as extensive AutoCorrect word lists allow swift typing of common defect description vocabulary, and advanced, macro-containing document templates, where the requirements of AB 04/ABT 06 are considered. This setup can be considered best practice, but it is not standard equipment for inspectors in Sweden.

Eventually the inspection ends with a closing meeting where the inspector declares whether the project has *passed* or *failed* the inspection. The inspector should pass the project if the works *do not contain significant defects* or a significant number of lesser defects. In this case the decision was that the project *failed*.

The use of the computer to write the final report already during the inspection allows the chief inspector to e-mail the lists of defects to the contractor as soon as the closing meeting has finished, together with a spreadsheet version, which makes the data easier for the contractor to work with during the defect management process. The contractor used the defect lists as checklists for the correction process. The date for when the last defect eventually was corrected was noted in the very last inspection report. The reports were subsequently archived on the project's joint server.

Classification of inspection data

During the exporting of the data from the different inspection reports (pre-inspection, final inspection and continued final inspection) to a spreadsheet, we discovered that the enumeration of the unique identity number (UID) of the defects unexplained had been reset to 1, both between the final and the first continued final inspections as well as between the two final inspections. It is thus evident that a large number of defects were counted more than once. However, since this was not a quantitative study this problem was simply noted, although it resulted in a loss of traceability for specific defects throughout the project. Questions such as 'when was the defect first discovered?' and 'how long did it take to correct it?' are therefore difficult to answer.

The BSAB 96 space coding became somewhat problematic, as the room/section field for about 300 of the roughly 2000 defects only contained the room/section number (see Table 3). By reading the defect description or by looking at other nearby defects, an additional 65 spaces could be identified. For example, the words 'wash basin' and 'mirror' (see Table 4) clearly indicated what kind of space was being inspected. To some extent the observational data was helpful in assigning appropriate space codes because it could be compared to the report data. Additional suitable design documents, e.g. drawings, would have solved this problem entirely.

The next step was to classify the *defect descriptions*. Table 5 contains a list of defect descriptions based on the labels 'What' (from Table 1), and 'Defect type' and 'Correction measure' (from Table 2). Merely analysing the inspection reports was not sufficient to codify the 'when' and 'why' fields; these required further investigation. The observational data, and especially the photographs, was helpful in this process.

Many descriptions mentioned several missing articles within a single defect record, e.g. '*Rubber mat* AND *wooden skirting* missing'. This problem was handled by dividing them into several records.

Analysis

Conditions for CI from defect data in current DM process

Our results regarding inspection as a method for achieving quality further adds to the description found in literature of it as resource-intensive. The use of dedicated resources for appraisal is by itself an expensive way of achieving a given level of quality even before one considers failure costs arising from rejected work (Winch, 2010, p. 332). Although continual inspection allow problems and nonconformities to be discovered at an earlier stage, it does not however eliminate the fact that inspections necessarily result in fixing mistakes after they have been made rather than preventing them from happening in the first place. From an AB 04/ABT 06 perspective, third party inspections are clearly designed and conducted as entirely reactive appraisal processes. It is therefore evident that third party inspections by AB 04/ABT06's definition do not support improved quality or reduce the occurrence of defects.

Figure 2 shows the various routes that inspection information follows in building contractor firms in Sweden, where I_n denotes the inspection activity. After the inspection report has been written, it is sent back to the contractor, who can begin correcting the defects reactively immediately. According to Lundkvist and Vennström (2010), people at many levels of the involved organizations, from skilled workers to inspectors to CEOs, complain that the same defects keep reoccurring in project after project. Thus, there seem to be no *corrective actions* taken to avoid the recurrence of defects in future projects (Lundkvist *et al*., 2010).

Just as project organizations change from project to project, so do the inspection organizations, and different inspectors have different ways of conducting and documenting inspections. This can lead to uncertainties for contractors regarding how to interpret the defect data from project to project. In this case study, for several reasons, the defect data recorded in the inspection reports was difficult to classify. Both the vocabulary and structure of the defect description sentences was inconsistent and unsystematic, even within reports from individual inspectors. In order to support classification, standardization and consistency of these is strongly advised. Moreover the data was incomplete, as it lacked references to specific building elements, and other contextual data (the metadata of the nonconformity). Owing to the impact of our chief inspector on the education of building inspectors in Sweden, and the uniform requirements for inspection reports and the role of the inspector under the standard contracts, we believe this situation to be fairly representative of many other projects. Only a portion of the records was referencing the room or space with anything more than a number, which was problematic to our

Table 3 Representative BSAB spaces, codified from section/room descriptions

No.	Floor	Section/Room	BSAB spaces
235	2	30233	
236	2	30233	
237	2	30233	
238	1	General, floor 1	22 – Spaces for public activities
239	1	30118 Fan room	261.D – Ventilation unit spaces
240	1	30118 Fan room	261.D – Ventilation unit spaces
241	1	30118 Fan room	261.D – Ventilation unit spaces

Table 4 BSAB space classifications from defect descriptions, translated from Swedish

No.	Floor	Section/Room	BSAB spaces	Defect description
289	3	30307	228.BE Toilet space	Wall left of inspection hatch teething towards …
290	3	30307	228.BE Toilet space	Openings wall angle each side of mirror + against …
291	3	30307	228.BE Toilet space	Inspection hatch missing beneath wash basin
292	3	30310-14		Not inspectable
293	3	30305		Floor not inspectable

Note: Defect descriptions are abridged.

Table 5 Excerpts of coded defects from the original (Swedish) defect descriptions

	BSAB spaces	Defect description	What	Defect type	Correction measures
8	22 – Spaces for public activities	Not fixed electrical outlet in walls at speakers	5 Wall	1 Unfinished	4 Completion
9	231.G Elevator space	Rubber mat and wooden skirting missing	7-2 Carpet	2 Missing	4 Completion
10	231.G Elevator space	Hole in ext. wall at cable throughputs not closed	5 Wall	1 Unfinished	4 Completion
11	231.G Elevator space	Lining sheet to elevator missing	3-4 Linings	2 Missing	4 Completion

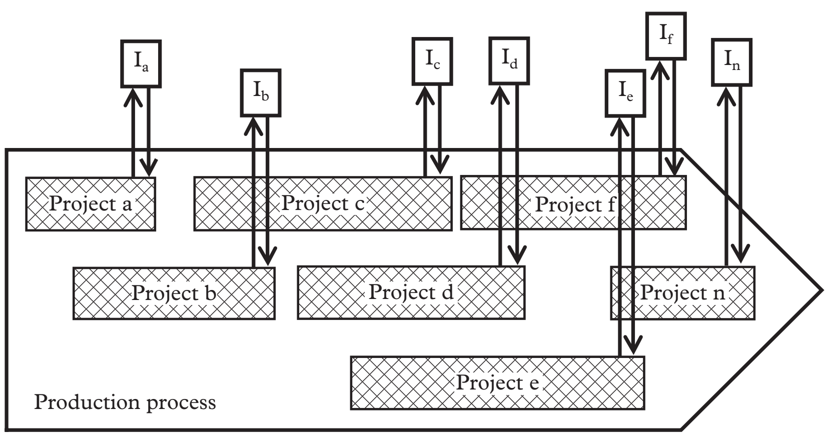

Figure 2 Reactive information routes of final inspection data, current state

classification. However, if we had received access to floor plans or other sufficient specifications, this would easily have been remedied.

Defect management, on the other hand, is a completely internal activity within the project, with no central support process coordinating the work between projects. As the inspection reports are often eventually stored digitally on a server for project-dedicated information (PDI) (Lundkvist *et al.*, 2010), the defect information becomes virtually inaccessible to those outside the project organization. The information remains available for as long as the project-dedicated server is maintained after project completion. Any attempt to work proactively from this data becomes therefore very difficult and resource-consuming.

The inspection reports are often discussed during a debriefing meeting. Here, the documented defects offer an opportunity for evaluation of the project and the analysis of possible problems, experience that should be fed back to different participants. *If* the meeting is held, and those certain participants are attending, that is.

Our analysis of a current DM process through the PDCA framework showed that there is a gap between the current process and a full PDCA cycle. This gives one explanation for why continuous improvement through problem-solving fuelled with inspection data has not yet achieved a wider recognition in Swedish construction. The analysis indicated that the *Act* step was missing (see Figure 3). As this step involves company-wide standardization of test results (Deming, 1986), it cannot be the responsibility of the project organization. Instead it should be run by a supporting, inter-project improvement team. The same is suggested for the *Plan* step; however, in an ad hoc approach this step *can* be initiated from within the planning phase of a construction project. Data for analysis may then be sourced from project-dedicated information (PDI) from earlier projects (step 1 in Figure 3). This would be done by having project managers search through the available information for similar projects and/or methods and trying to find 'experience' data that would then be used to help decide what to do and what not to do in the project. This approach implies that the nature of the construction project would guide the construction management in the selection of appropriate improvement initiatives (2) as the support is missing.

Supposing that the project now has selected an improvement initiative, the *Do* step tests the improvement in a real-world situation, i.e. the building project. Here, nonconformities may be reported, reactively addressed, and documented. These can then be stored in the PDI server of the construction project (3). The third party inspections are conducted and the defects are corrected in a reactive loop (4). The improvement should then be evaluated at the end of the production phase, representing the *Check* step. As the project is finished, a debriefing meeting is held (5) in order to evaluate how well the project objectives were met. Naturally, this evaluation can and should include a discussion of the intended improvement. The inspection reports and debriefing meeting records are then archived in the project-dedicated data storage (6). This experience data (derived from the evaluation of the improvement initiative) should subsequently be made available for use in other projects.

The lack of a dedicated, inter-project process and team for improvement and solving of defect-related problems is problematic, as improvement initiatives have to be initiated on an ad hoc basis with the impetus coming from within the project or its immediate organizational vicinity. In the absence of a systematic approach, initiatives might be poorly chosen and of comparatively low value to the organization, as described by Juran *et al.* (1999). After this point, the experience generated within the project is archived in the project-dedicated data storage and the memories of the people involved in the project. These individuals are responsible for remembering where the knowledge acquired during each project is stored.

The sum of these identified problems with implementing CI from defect data within the current DM process calls for a revised process that remedies these shortcomings.

Proposition of a CI framework for proactive utilization of quality data

We here propose an improved process in which a supporting CI team manages (a) the analysis of existing

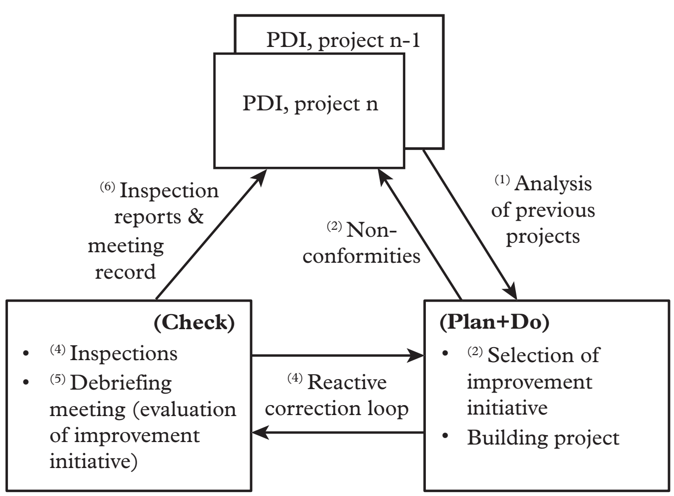

Figure 3 Current ad hoc approach to CI: quality data stored as individual documents on a project-dedicated server

defect data, (b) the selection of appropriate improvement initiatives, and (c) the planning of improvement initiatives would quite closely resemble a PDCA cycle (see Figure 4). The work of such a team would also involve the identification of appropriate construction projects on which to pilot proposed improvements, and the evaluation and ultimate standardization of those that prove successful. This is where the classification of data according to a domain ontology should be really useful. Rather than just ad hoc browsing the database at the beginning of new projects, a supporting team can continuously monitor production in the entire company, and prioritize improvements based on what creates most value. The ability to straightforwardly retrieve knowledge from this body of data represents a valuable contribution to the contractor's CI strategy, as also proposed by Meiling (2010).

Moreover, by transferring their defect data to a centralized data storage repository, such a team could make this valuable information accessible from anywhere within the organization (Park *et al.*, 2013). The data needs to be easily compiled and compared in order to keep appraisal costs down, and the method used should readily support its structuring and classification based on element, location, defect description, root cause, and so on (in keeping with the domain ontology; there will always be a need to be able to incorporate new types of information and add new categories, so a degree of flexibility is suggested). The natural solution for such storage is a database, here referred to as a centralized quality database (CQDB). Because the root causes of defects are, to a certain extent, outside the contractor's areas of responsibility (Josephson and Hammarlund, 1999), the domain ontology should be extensive enough to support analysis from the perspectives of many different project participants, including clients, designers and engineers.

This PDCA cycle begins with the supporting CI team's continual analysis of the accumulating body of data stored in the CQDB (step 1 in Figure 4), involving the identification of the reoccurring defects associated with the biggest costs and most severe missed opportunities in the studied projects, finding the most plausible root cause of each problem, and suggesting a way to address each root cause. This process concludes with the selection and initiation of an improvement project (2). The improvement team then selects an appropriate building project on which to pilot the improvement, after which they plan (3) and implement (4) the change within the chosen project. The planning process should also generate objectives for the improvement project, as well as a protocol for assessing its success.

An ICT interface, incorporating the domain ontology for classification and the standardized language for nonconformity and defect descriptions, is used over the course of the building project to register and classify

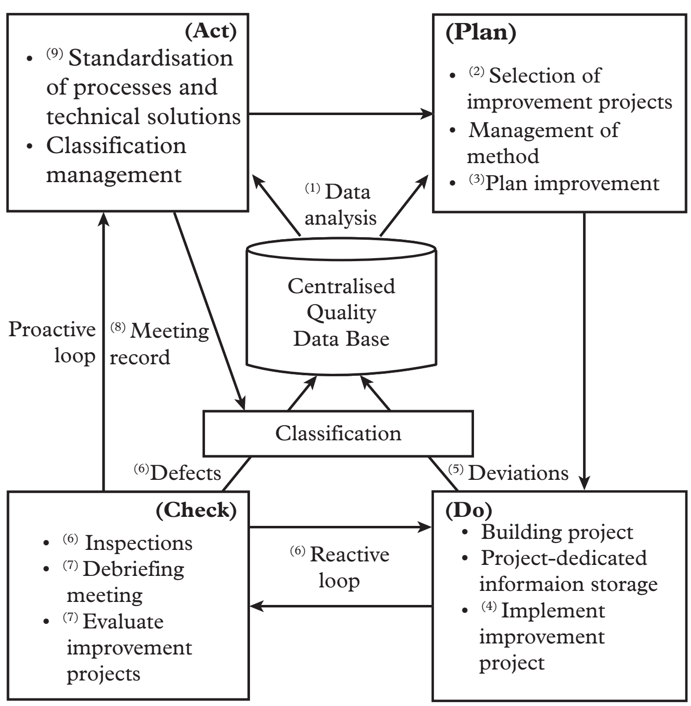

Figure 4 Proposed proactive framework for CI
Note: Numbers indicate order. Same numbers equals somewhat concurrent process steps.

nonconformities in the CQDB (5). The interface should also be used during the correction process for nonconformities. It is thus suggested that the contractor's personnel within the project do the registering and classification. An advantage of using the defect database also during the reactive part of the DM process is the improved traceability of defects, as every record is given a unique identity number (UID). The risk of actually double-registering defects into individual records is minimized as defect data is never deleted, it only changes status, and the input interface tracks the current location and all of the data associated with it, so this should not be a problem. In similar manner, defects recorded through pre- and final inspections will still be dealt with reactively, as well as recorded in the database for proactive reasons (6). As the inspectors should use the same, or at least compatible, tools, the addition of additional metadata to the records, as well as the classification of the defects, should be easy to handle. Rich data, such as photographs, audio and/or video recordings and drawings could help the analysis of defects during both earlier and later stages, and should thus also be included in the database structure and the data-recording interface. The defect management process should monitor and record the cost of correction of each defect in the database. This important step is what enables the prioritization of improvements of future PDCA cycles.

The building project will probably also use a project-dedicated information storage system, but all quality-related data will also be saved in the CQDB. Eventually the building project will conclude with a debriefing meeting, at which point the improvement project is evaluated (7). This evaluation is then forwarded to the supporting CI team (8). Successful initiatives should then be standardized and implemented company-wide (9). If the objectives are not met, the support team should, in accordance with PDCA methodology, revise their initial plan and conduct more trials. Except for the responsibility for improvement initiatives, the team should also manage the domain ontology and the structure of the database because these aspects of the system will also in themselves require CI.

Discussion

The primary reason for contractors to accumulate nonconformity and defect data is to enable quantification, in order to allow prioritization of improvement initiatives. This is what enables further use of the data. Thus, the proposed framework enables a data collection strategy that is missing in current CI processes within Swedish building contractors.

In our case study, the project was far from complete when the final inspection was conducted. Thus, all the missing objects or pieces of work were recorded as defects: *missing*, with the obvious correction measure *completion*. Such defects do by definition not lead to rework, but knowledge of their impact may help the contractor to improve the planning of future projects, as they are by themselves nonconformities in the project management.

Although debriefing meetings have been shown to be the most common channel for feedback (Lundkvist *et al.*, 2010), it is a discontinuous one. The wider apart the meetings are, the more likely it is that minor, chronic problems will be overlooked in favour of more spectacular, but sporadic, ones. Systems based upon the proposed framework are therefore important as a complementing continuous feedback channel.

Our case study attempted classification of defect data from the current imperfect process. The obstacles to efficient high quality classification found in the data leave us with the firm conviction that implementation of a system based on our framework should not involve building up a stock of classified data from old projects, but rather should involve 'turning over a new leaf' using only fresh data. This provides an opportunity to control, from the outset, proper requirements on the content and structure of defect data, based on the proposed framework.

Although defects and nonconformities represent assessment to only the 'minimum requirements', and a majority of the defects documented during final inspections in construction are superficial (you can only inspect what you can see), a focus on nonconformities is helpful. The reporting of production problems is the key driving force for improvement. Therefore, any initiative that can successfully collect information about problems can potentially lead to improvements. Consequently, we believe that the *first* objective must be to better comply with these minimum requirements, i.e., to reduce the occurrence of non-conformities, and *then* further develop the quality strategy upstream through the building process. This need not be daunting because the collection of defect data is a part of the existing process. Therefore, the new quality strategy would only require the refinement of existing processes rather than the introduction of new ones. As such, the systematic collection and proactive use of defect data can be regarded as 'low-hanging fruit' that will enable considerable quality improvement at relatively low cost.

Conclusions

This case study aimed to provide better understanding of how defects and nonconformities can be managed proactively in construction companies with the purpose of continuous improvement (CI). If we intend to learn from experience regarding defects and nonconformities, classification of defect data is important. Therefore, based upon the analysis of classification of defect data from one large building project, as well as analysis of the current DM process from a PDCA perspective, we identified opportunities and obstacles for defect and nonconformity-based CI.

We believe that the difficulty of classification and the inaccessibility of previous data are important reasons why defect and nonconformity data has not been used for continuous improvement on a wider scale within the construction industry. Data is difficult to classify if there is a lack of common vocabulary and structure, and important types of contextual data within the chosen ontology are missing. If building contractors intend to use defect data proactively they need to become more involved in the collection of it by stating new requirements, besides those in AB 04/ABT 06 and what simply is needed in order to correct the defects (i.e. the symptoms).

A dedicated central team that is responsible for the improvement work based on defects and nonconformities, organized within defined *Plan* and *Act* steps can focus on long-term goals. Through continual analysis of defect and nonconformity data, the team identifies systematic problems, finds root causes to the problems, values them based on impact, and then selects and initiates the proper improvement. This measuring on quantitative data, based upon the entire production, provides an opportunity for making more well-founded decisions concerning improvement initiatives. This, to the building industry novel approach to DM and defect and nonconformity data, has potential to become an important, integral part of the quality management systems of building contractors.

The build-up of experience that the framework enables leads to new best practice, and the more the owner of the system is willing to share with its project partners, the better. However, as standardization is a trait of the system, we believe that the companies that will become the most rewarded are those developing different industrialized building systems.

Our results are important to building contractors that struggle with the development of CI. They themselves have stated that quality management in general is underdeveloped and that they see defect data as a virtually untapped source to fuel improvement. Because it is always difficult to implement entirely new processes, a mere revision of the current defect management process should be more likely to succeed. The insights from this case study could therefore guide building contractors that are to develop similar systems.

The main contribution of this paper is that the presented framework theorizes CI in construction, beyond the development of supporting technology. The main limitation of the research is that the proposed framework has not been evaluated in practice. Future studies should therefore include such evaluations.

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Appended paper III

The role of experience feedback channels in the continuous development of house-building platforms

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The role of experience feedback channels in the continuous development of house-building platforms

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Abstract

Purpose – House-building companies seek improvements to decrease costs, improve flow, and decrease variability. Industrialised concepts using predefinitions in product platforms have -fields in house building companies.
Design/methodology/approach – Qualitative data were gathered via interviews, archival studies and observations, and analysed to identify the underlying structures used to manage the incorporation of EF during platform development. Four different EF channels were studied at one Scandinavian house-builder. The data are explained using an analytical framework based on diffusion of innovation, product platforms and EF.
Findings – EF is distributed over the value chain to improve the platform over time. By using multiple channels with differing contents, it is possible to balance client demands and variation with production efficiency. Platform development using feedback channels provides opportunities for double-loop learning. Operative work on projects and the strategic decisions made by developers continuously improve the platform through a combination of knowledge pull and push.
Originality/value – A combination of different EF channels and strategies for developing knowledge pull are shown to be essential for the incremental development of product platforms in project-based house building organisations. The development of product platforms requires a shift away from the construction industry's dominant project focus towards a more product-oriented view of house-building. Integrating the design phase with the supply chain enables variety but also creates a need for continuous platform development.
Keywords Knowledge management, Innovation, Construction management, Housing, Housing design, Organisational learning
Paper type – Case study

Introduction

House-building is traditionally a project-based activity. The main challenges faced by organisations engaged in such activities derive from the tendency of decentralisation, short-term emphases on project performance, and distributed working practices to create their own logic of action that inhibits knowledge transfer within the organisation (Bresnen *et al.*, 2004) and innovation (Pan *et al.*, 2012). To address these problems, innovative industrialisation ideas have been introduced that rely on extensive predefinition of components, systems and related processes to increase project performance while reducing time and costs (Winch, 2003; Voordijk *et al.*, 2006; Vrijhoef *et al.*, 2009). However, Gann and Salter (2000) argue that to be innovative, companies involved in projects must integrate their project experience within their internal business processes.

Most studies of innovation in construction have focused on product innovations and implementations upstream of the contractor (McCoy *et al.*, 2009; Boland *et al.*, 2007). However, supplier-led innovations are problematic from the builder's perspective because they need to manage the legal and market risks associated with potential future liabilities arising from failures in the functionality of the presumably untested innovative products (Sexton and Barrett, 2003). It is therefore worth studying innovations that originate from developers and builders in order to obtain a different perspective on the diffusion of innovations in construction.

Kamar *et al.*, (2011) argues that industrialised building systems (IBS) and innovation are similar concepts because they can both be interpreted as implementations of new products and processes in a traditional project-based industry. The introduction of product platforms (Robertson and Ulrich, 1998) is an example of such a radical innovation in the house-building industry (Jonsson and Rudberg, 2013). Platforms are based upon predefined product architectures of components and sub-systems that permit the incorporation of experience from utilisation to support continuous improvement (Thuesen and Hvam, 2011). House-building platforms have become systems for storing knowledge and predefinitions of house-building components, related processes, and internal and external relationships (Jansson *et al.*, 2013).

The complexity of platform development in industrialised house-building does not stem from the process of defining the physical building system but from striking a balance between predefinitions that give economies of scale and the diversity of product features that provide customer value for the client (Voordijk *et al.*, 2006; Hofman *et al.*, 2009; Brege *et al.*, 2014). Because the client enters the process during the design phase in an engineer-to-order (ETO) supply chain, the organisation of the design work plays a central role in matching the house-building production system with the predefinitions of the supply chain (Gosling and Naim, 2009).

A systematic process for relaying EF from projects to the platform is required to support the continuous updating and improvement of the platform's assets, i.e. its components, processes, knowledge and relationships (Styhre and Gluch, 2010; Henderson *et al.*, 2013). Previous studies on product platforms have not attempted to explore their continuous development, which involves a process of incremental innovation that takes place after the platform as a system has been implemented (Ingemansson, 2012; Jonsson and Rudberg, 2013). Consequently, little is known about the process of capturing project experience and exploiting it as a source of knowledge for the house building company (Gerth *et al.*, 2013; Lam and Wong, 2009). However, Meiling (2010) has described some ways in which different method for incorporating EF can promote continuous improvements of industrial house building systems.

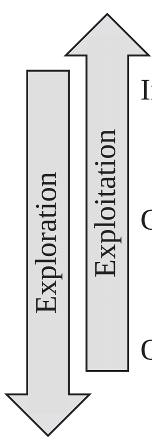
The aim of this paper is therefore to describe how EF from project work can support incremental innovation in product platform development in the context of house-building. In this case study, four different channels of feedback that supports platform use and development in a Scandinavian developer/builder organisation has been studied. The focus has been on the different attributes of the channels and how different channels might complement each other.

Learning and knowledge in construction

Knowledge Management (KM) and Organisational Learning (OL) are related areas of research that have attracted great interest over the last few decades (Henderson et al., 2010). KM deals with the creation, capture, storage, sharing, and exploitation of knowledge in an organisation (Egbu *et al.*, 2001), while OL aims to link cognition with action (Crossan *et al.*, 1999). Both concepts stress the importance of exploring and exploiting knowledge for the success of the enterprise.

The 4I framework of OL contains four related sub-processes – intuiting, interpreting, integrating, and institutionalising, and three levels – individual, group, and organisation. Intuiting and interpreting occur at the individual level, interpreting and integrating at the group level, and integrating and institutionalising at the organisation level, as shown in Table 1 (Crossan *et al.*, 1999).

Table 1. The 4I framework of OL (developed from Crossan et al., 1999).



Level	Process	Inputs/Outcomes
Individual	Intuiting	Experiences Images Metaphors
Individual / Group	Interpreting	Language Cognitive map Conversation/dialogue
Group / Organisation	Integrating	Shared understandings Mutual adjustment Interactive systems
Organisation	Institutionalising	Routines Diagnostic systems Rules and procedures

Organisational learning involves a tension between assimilating new learning (exploration) and using what has been learned (exploitation) (March, 1991). Exploration relates to the transfer and transformation of learning from individuals and groups into learning that becomes embedded (or institutionalised) in the form of systems, structures, strategies, and procedures (Hedberg, 1981; Shrivastava, 1983). Exploitation is the reverse process, whereby institutionalised learning is used by groups and individuals (Crossan *et al.*, 1999).

The 4I model does not address the importance of the concepts of supply push and demand pull in the context of knowledge transfer. The quality of the exploration process may depend strongly on whether knowledge is pulled or pushed through the individual, group, and organisation levels (Boland *et al.*, 2007; Maqsood *et al.*, 2007; Meiling, 2010). For instance, if relevant knowledge from project meetings is pushed, it does not become useful unless it is targeted to someone in the supply chain (Meiling 2010).

Single loop learning has been defined as the process that occurs when organisations respond to changes in their internal and external environments by addressing the symptoms of problems rather than their causes (Fiol and Lyles, 1985; Barlow and Jahapara, 1998). These symptoms are remedied as they arise in a "fire-fighting" manner that does not lead to any change in organisational behaviours, beliefs, or values (Argyris, 1994). In double-loop learning, on the other hand, symptoms are treated as indicators of problems and the focus is on addressing the root causes in order to establish new ways of working (Argyris 1992). Systemic solutions address the underlying problems (Kululanga *et al.*, 1999). Double-loop learning is a way to better integrate innovation infrastructure and the innovation integrators (Winch, 1998). Argyris and Schön (1978) also presented the concept of deutero-learning, as “to learn how to carry out single- and double-loop learning”, i.e. “going meta on single- or double-loop learning” (Argyris, 2003). The ideas of learning loops also progressed further into triple-loop learning (Swieringa and Wierdsma, 1992), however, this concept may not provide significant benefits to organisations and could even present major risks if adopted (Tosey *et al.*, 2011).

The construction industry is currently considered to primarily rely on single-loop learning in isolation (Henderson *et al.*, 2010), and it is argued that the adoption of double-loop learning would enable continuous improvement in terms of quality, efficiency and effectiveness (Henderson *et al.*, 2013). Eriksson (2013) argues that the main industry-related barriers that may make it difficult to realise the benefits of exploration and exploitation knowledge flow (i.e. double-loop learning) are an excessive emphasis on short-term objectives and project mentalities that focus exclusively on the project at hand.

Innovation processes in construction

Broadly, innovation can be defined as "an idea, practice, or object that is perceived as new by an individual or other unit of adoption" (Rogers, 2003). There are three key stages of innovation: idea generation, adoption, and implementation (Shepard, 1967). Adoption is the process that leads to the decision about whether to adopt or reject the idea.

When the adopter of an innovation is an organisation, several individuals are involved in the decision process, and the actual implementers are often different from the decision makers. These individuals are usually either champions or opponents of the new idea (Rogers, 2003, p. 414). In construction, technically competent champions are important for the successful adoption and implementation of innovations (Nam and Tatum, 1997).

The knowledge of an innovation can also create a perceived need and trigger the organisational decision-making process. Different *communication channels* play different roles at each stage in the innovation-decision process, and different *sources* – individuals or institutions that originate messages – may use different *channels* to convey their messages to a receiver (Rogers, 2003, p. 204). The innovation process outlined by Rogers (2003) is related to the 4I processes of OL presented by Crossan *et al.* (1999) as shown in Table 1; once implemented (routinised), the innovations can be exploited throughout the firm. For instance, Egbu *et al.* (2001) argue that KM and effective management of intellectual capital are important for creating an environment of human creativity and freedom of thought, which facilitates both incremental and radical organisational innovation in project-based industries.

Product innovation is about the introduction of new products, whereas *process innovation* deals with the process by which a product is developed and whereby new ideas lead to new, often more sophisticated methods of production (Egbu *et al.*, 2001). The construction industry has focused its innovation efforts disproportionately on products, leaving processes comparatively neglected (Gann *et al.*, 1992).

Shepard (1967) distinguished between *radical* and *incremental* innovation. Radical innovations are usually adopted as a response to a crisis or a threat from the external environment. In such situations the organisation is open to and searching for new solutions to the basic problem of survival (Shepard, 1967). A radical innovation could represent an entirely new paradigm regarding how to carry out a task (Rogers, 2003, p. 426). However, according to Egbu *et al.* (2001), incremental innovation based on step-by-step changes has been more common in the construction industry.

Construction does not follow the traditional product development model in which firms develop new products on the basis of market signals and then produce these products in volume, selling them to a mass market. Under this model, innovation initially has a strong product focus but gradually shifts to the production process over time (Winch, 1998). The *complex product systems* model may be more appropriate for describing innovation in construction (Gann and Salter, 2000; Winch, 1998). In studies on innovation, the firm is typically regarded as a single, bounded entity, e.g. Chandler (1990) and Penrose (1995). When applied to organisations involved in the production of complex products and systems, this perception seems unsuitable. In many project-based firms, value is created and profits are generated within the projects, which are operating at the firm's boundaries (Gann and Salter, 2000).

Innovation in construction has multiple sources, and the different actors involved are embedded in innovation networks. Initiatives may be adopted by firms and implemented within projects from the outset; alternatively, they may originate from problem solving work conducted in ongoing projects. The adoption of initiatives arising from problem solving work can only occur if the solutions generated in this way are learned, codified, and applied to future projects (Winch, 1998). Therefore, firms constructing complex products and systems need to manage both project *and* business processes (Gann and Salter, 2000). Business processes are generally on-going and repetitive whereas project processes are temporary and unique (Gann, 1998; Brusoni *et al.*, 1998). Routines are usually developed within these recurring business activities where they can stimulate innovation and provide opportunities for standardisation and process improvements (Gann and Salter, 2000).

The platform concept – a carrier for innovation?

A product platform is a repository of a manufacturing firm's knowledge of components, processes and relationships that is used to adapt a product for a specific customer (Meyer and Lehnerd, 1997; Robertson and Ulrich, 1998). In a state-of-the-art review of product families and platform development, Jiao *et al.* (2007) elaborated upon Suh´s (2001) framework for product realisation (see Figure 1).

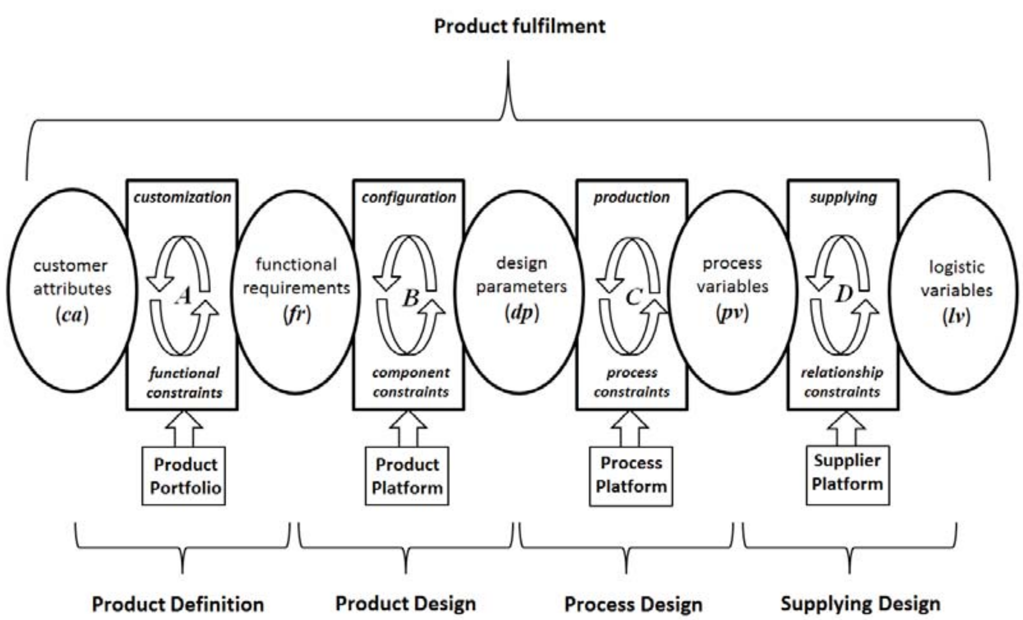


Figure 1. Product fulfilment by platform and portfolio planning (Jiao et al., 2007) based on the work of Suh (2001).

The framework involves mapping and transformation between five domains in the value chain by aligning the product portfolio for a specific market segment with a Make-To-Order (MTO) or Assembly-To-Order (ATO) supply chain. In the product customisation process, product platforms support the engineering work by reducing development costs, time, manufacturing costs, production investments and complexity (ibid). Simplifying or trivialising the engineering work in the customisation process can have negative consequences such as losses of innovative capability, organisational resistance, and constraints on product differentiation in favour of economies of scale (Karlsson and Sköld 2007).

The platform's development is normally separated from its application and daily use. Striking a good balance between commonality (which minimises costs and supports flow) and distinctiveness (which enables uniqueness and differentiation) in products is a major challenge in platform development. In order to provide customisation and maximise the economy of operations, Bowman (2006) suggests that market positioning should be defined with respect to customer needs. Distinctiveness can be increased without compromising economies of scale by adopting a modular design and/or delaying the product differentiation of parts and modules in the MTO supply chain (Robertson and Ulrich 1998).

The customisation of house-building products involves the same process of transformation between domains as outlined in Figure 1 but in an ETO supply chain (Gosling and Naim, 2009; Johnsson, 2013; Jensen *et al.*, 2014). This is because some parts of the designs used in house-building projects are unique and not part of the platform (Jansson *et al.,* 2013). Therefore the MTO concept is not applicable and platform configurations must be complemented with traditional engineering design. The customer order decoupling point is located at the design stage in the ETO supply chain, when the product becomes differentiated from its predecessors (Gosling and Naim, 2009). This variation is reflected by the level of standardisation in housebuilding platforms (Jensen *et al.*, 2012), which are developed incrementally on the basis of experience that flows into the organisation from projects and is stored within the platform's predefinitions (Styhre and Gluch, 2010). Gerth *et al.* (2013) claim that when using a house-building platform, project experience should not be analysed and improved in separate product development process. Instead, the product configuration during the design phase should affect the entire supply chain for each building project, enabling continuous improvement of the entire system (ibid.).

The introduction of house building platforms in the construction industry must be seen as a radical innovation because it reflects the introduction of an operational strategy for controlling the house-building supply chain (Gann and Salter, 2000). The new platforms can be extended in a continuous and incremental fashion based on experiences gathered during their use in projects. In this way, house-building companies that have adopted and implemented platforms have overcome many of the problems arising from the project-based nature of construction work, successfully rebalancing the relative emphasis on project and business activities to focus more heavily on the firm's routines and long-term objectives (McCoy et al., 2009). The defined processes of the platform collectively constitute a systematised carrier of incremental innovation, in the form of feedback streaming towards the platform through different channels. The assets within the platforms provide a basis for standardising project processes, which do not otherwise lend themselves readily to systematic repetition (Gann and Salter, 2000). However, the success and further development of these platforms will depend on how efficiently experiences from projects can be collected, interpreted and institutionalised (Meiling, 2010).

This study is the first to explore the continuous development of ETO platforms. It is evident that such development involves double-loop learning, as it involves the transfer and transformation of experience-based learning, from the individuals and groups of the building process, to the organisation as a whole, through exploration and exploitation.

Research Methodology

An inductive case study was conducted to examine the contributions of four EF channels to the development of a single housebuilding company's ETO product platform. The adoption of the case study approach together with the analysis of systematised learning loops in the ETO process made it possible to extend the definition of platform development so that it could be applied within the studied context (Yin, 2003). An analytical framework was established by using engineering design methods to assess the contributions of EF to platform development. The EF flow in the house-building platform was the unit of analysis, and the study was designed to describe how improvements can support continuous platform development over time. The case study provided an opportunity to study the roles of each channel in managing the flow of knowledge (i.e. experience feedback) arising from operational work and the systematisation of that knowledge. Studying a single house-building company with a decentralised organisational structure meant that it was possible to observe challenges in platform development associated with several different parts of the supply chain.

The participating company was a large Scandinavian house-builder, which was selected because of its investment in platform predefinitions, introduction of multiple channels for knowledge feedback from house-building projects, and efforts to support continuous platform development. The developer/builder context was selected because its fragmented and decentralised organisational structures limits the scope for collaboration and knowledge transfer in production systems (Karlsson and Sköld, 2007), which presents a challenge given the need to manage platform development while building projects are ongoing. The effects of the EF flow on the platform's development were analysed using the suggestions of Henderson et al. (2013) concerning learning loops.

The studied company uses on-site production in an ETO context. The client and principal contractor meet during the design phase, and the platform developers have made efforts to standardise the firm's building components and processes. The company has only been engaged in platform development for relatively short time. Because it performs multiple sorts of construction (not just housebuilding), the company has several platforms in addition to that examined herein, but many of its current projects are not based on any platform at all.

Data were gathered via interviews and observations, and by analysing platform documentation from ten building projects conducted between 2006 and 2012. The four EF channels were observed and documented by taking notes. Structured interviews based on open-ended questions were conducted with four of the company's platform developers to gain insights into their areas of focus and the purpose of the EF channels. Two of them worked on building platform development, one on process development, and one on system development. Archival data from the four channels (all of which were actively used within the company when the study was conducted) were collected from project-, platform-, log and feedback documentation. To map the house-building platform's predefinitions onto the supply chain, the predefinitions and feedback methods were categorised and quantified in accordance with the platform development model of Jiao *et al.* (2007). This resulted in the definition of four main categories: *functional requirements, components, processes* and *relationships.* The EF channels, described below, were analysed in terms of learning modes (single- or double-loop) and knowledge pull and push.

The company introduced a feedback system called *Your point of view,* logging individual reflections, to gather feedback for improvement from across the organisation. It was implemented as part of the firm's enterprise resource planning (ERP) system and was designed to support the expression and transfer of individual knowledge, experience, and suggestions for platform improvement. The purpose of this channel was thus to enable continuous development of platform predefinitions using information sourced from all of the organisation's employees. Data concerning all of the studied projects were gathered from this channel.

Design optimisation is a process that the company introduced to gather feedback from each of its projects that could be used to improve its platform designs. The channel collects knowledge from projects that can be used to evaluate individual aspects of the platform design and determine whether they should be retained, reworked, or abandoned. More specifically, data from this channel are used to determine how the platform's predefinitions are used in practice and why project teams sometimes choose to violate or disregard them. Design optimisation is intended to be done twice in each project, by the platform developers. To support the process, building project teams prepare an internal review of their project one week in advance. Routines and documentation procedures have been established to facilitate the preparation of these reviews on the basis of the platform's design. The purpose of the channel is to compare the costs incurred and choices made during production to the platform's design parameters. Data concerning all of the studied projects were gathered from this channel.

Improvement meetings is a channel that was organised at the regional level. Developers, engineers and construction managers working on different projects met approximately once per month to analyse and improve their design work and the associated support methods from different perspectives. Topics were transferred to other groups for investigation or further improvement by platform managers, project managers or designers. These cross-organisational meetings were an interesting data source because of their focus on platform alignment and the relationships and processes in house-building projects. The first author documented, observed and participated in five of these meetings, and analysed the information so obtained in conjunction with transcripts of interviews with platform managers that were conducted during the year 2011. Meetings concerning five of the ten studied projects were observed and analysed in this way.

Client feedback meetings were performed by the company at the project level in order to capture the experiences of clients and project managers. These meetings are held after a project is delivered to document the client's experiences and perceptions of the project's delivery and quality, as well as their opinions on the company's communication. The clients are asked to fill out a questionnaire before attending the meetings, which have a predefined agenda. The aim of the *client feedback meetings* is to improve the platform but also to ensure that the customers are satisfied with the delivered projects. Data concerning all ten of the studied projects were gathered from this channel.

The concepts of knowledge pull and knowledge push were drawn on to understand and describe how information from these different EF channels can help to balance platform development in the context of house-building. To systematise the development of a house-building platform, Jiao's (2007) platform development framework was adapted for use in the house-building context. The balance between commonality and distinctiveness in platform development was translated and explained using data from the studied experience feedback channels, which were analysed using theories of innovation and learning.

Predefinitions in the studied platform

The studied company had continuously documented its platform predefinitions (indicated by the hatched fields in Figure 2). Its house-building projects have a cycle time of about 2-3 years, which corresponds to the time required to design, build, and deliver a complete multifamily house to the client. In all of the cases examined herein, the client was the company's own development division.

The company's housebuilding platform was largely focused on design and planning for the production process. Its predefinitions exist to support customisation, configuration, production and material supply.

About 80 functional requirements were documented in the platform (hatched area of the product portfolio column in Figure 2), with the purpose of supporting early communication with clients and project stakeholders. In accordance with Swedish building codes, the functional requirements defined within the platform were assigned to one of eight distinct categories: layout shape, sustainability, fire, inner climate, usability, acoustics, safety and energy. Less than half of the functional requirements were linked to the platform's components, processes, or relationships.

Of the platform's 383 components (hatched area of the product platform column in Figure 2), 225 were defined as detailed solutions (e.g. sockets, windows, doors), 110 as building elements (e.g. curtain walls, balcony solutions, stairs) and 23 as building sub-systems (e.g. ventilation, structural, or roof systems). The remaining 25 were layout solutions that describe interior and exterior layouts of the building and its elements, from service shafts up to site layout predefinitions. The solutions were transferred to projects by support methods and also stored as templates and solutions in CAD (Computer Aided Design) systems.

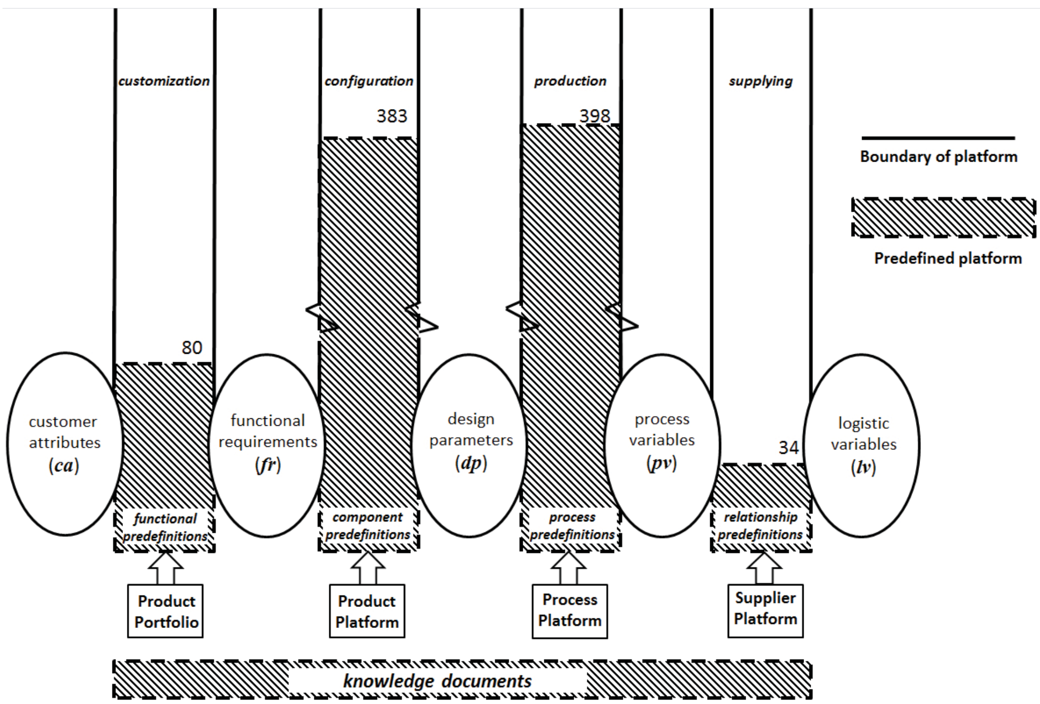


Figure 2. Predefinitions of different aspects of the company's platform.

Process platform activities were stored and organised in sequential order without predefined timelines. Detailed descriptions including checklists, delivery plans, and recommendations for the execution of design and manufacturing activities were provided for each activity. Of the 398 documented platform activities (hatched process platform bar in Figure 2), 251 related to design, 49 to purchasing, and 98 to production. Individual project managers use these platform activities when planning projects in order to streamline work and optimize its flow. Early design-phase activities in the process platform focus on economic forecasts, investigations, interrelations and cooperative agreements. Later design phase activities focus on deliveries of models, reports, contracts, descriptions, drawings, schedules and purchasing documents.

Relationship predefinitions within the supplier platform were stored in both early steering documents and purchasing documentation. These predefinitions included rules and recommendations that were designed to enable the reuse of knowledge concerning suppliers. Among the predefined relationships were the contact details of the engineers responsible for managing environmental, energy, moisture, and fire issues within projects designed according to the platform. Of the 34 predefined relationships in the supplier platform, 28 were intra-company agreements and 6 were contractual relationships with suppliers.

The platform's knowledge documents support and reinforce standardisation. Knowledge documentation serves as a link between physical systems (components), working methods (processes), and the organisation of resource operations (relationships). They facilitate decision making by describing the benefits and disadvantages of using certain components and explaining how specific choices affect the client and the requirements of the production process. Knowledge documentation describes properties in terms of nine factors: structural stability, fire, internal environment, safety, acoustics, energy, maintenance, aesthetics, and user-friendly dimensions.

Platform feedback channels

The platform was developed by a group of experts on the basis of their collective experience of managing house-building projects as well as input from specialists in diverse technical and functional disciplines (structural engineering, energy, moisture, acoustics, aesthetics, usability, HVAC, ground, and foundations). These platform developers use the EF from the four channels studied in this work (see Table 2) to refine and further improve the platform. The channels were also used to measure the extent of the platform's use within the organisation.

The only one of the studied channels that provided any EF relating to *requirements* was *Your point of view*, which supplied feedback on predefined solutions for issues relating to energy, fire, moisture, and acoustics. Suggestions for platform improvement with respect to *component* predefinitions came from all of the studied channels; around one third of these suggestions related to *variables* (e.g. windows should have STC ratings of < 40 dB, plinth heights should be < 400 mm) while the remaining two thirds related to *solutions* (e.g. the storey height must be 2860 mm, the air gaps in facades must be 30 mm). The *process* solutions for which feedback was provided generally related to production predefinitions (concerning the conduct of casting, sheet metal work, painting, etc.) while the process variables mostly had to do with design and planning predefinitions (concerning CAD drawing, cost estimation, planning, etc.). The majority of the feedback on *relationships* from the studied channels related to solutions. The only channel for which this was not true was the *Client feedback meetings*, where feedback was collected using a questionnaire in which respondents were (in some cases) only permitted to answer in terms of variables.

Table 2. EF channels studied in this work, the aspects of the platform on which they provided feedback, and the nature of the feedback supplied. Percentages in each column denote the proportion of the feedback supplied via each channel relating to different aspects of the platform.

Feedback channel		Variables (which can be adjusted to enable distinctiveness)	Solutions (which must be held constant to provide commonality)
Your point of view	Requirements 2 %	0 %	2 %
	Components 72 %	28 %	44 %
	Processes 18 %	4 %	14 %
	Relationships 8 %	0 %	8 %
Design optimisation	Requirements 0 %	0 %	0 %
	Components 75 %	24 %	51 %
	Processes 19 %	14 %	5 %
	Relationships 6 %	2 %	4 %
Improvement meetings	Requirements 0 %	0 %	0 %
	Components 20 %	2 %	18 %
	Processes 34 %	7 %	27 %
	Relationships 46 %	17 %	29 %
*Client feedback meetings**	Requirements 0 %	0 %	0 %
	Components 21 %	13 %	8 %
	Processes 26 %	26 %	0 %
	Relationships 53 %	30 %	23 %

*The feedback meetings were analysed on the basis of the clients' responses to predefined questionnaires designed and supplied by the company.

Design optimisation was conducted by the platform developers twice in each project. Most of the component suggestions arising from this process concerned layouts (of things such as WCs/bathrooms, stairwells, shafts, etc.). The feedback from this channel focused on detailed components and their use. However, a quarter of the suggestions concerned processes and the organisation of teams to improve design delivery.

The properties of the four feedback channels are illustrated in Figure 3. Individuals used *Your point of view* to push their ideas for improvement directly to the platform developers, without involving the developers in the process.

In the *Design optimisation* channel the individual, group, and organisational levels were bridged by extensively involving the platform developers in the process. As such, this channel combined both single loop learning (within the projects) and double loop learning through platform development. The priorities that the platform developers brought in to this process meant that there was a knowledge pull via this channel that supported targeted development.

Improvement meetings dealt with organisational relationships associated with design and production routines, contractual responsibilities and interconnections. These meetings had a clear purpose – to answer questions relating to platform use and development - and questions were only posed to gather EF in order to support platform development rather than to influence projects in progress. Although the EF from this source was more structured than that from the *Your point of view* channel, it was pushed to the platform developers, who did not have any input into these meetings.

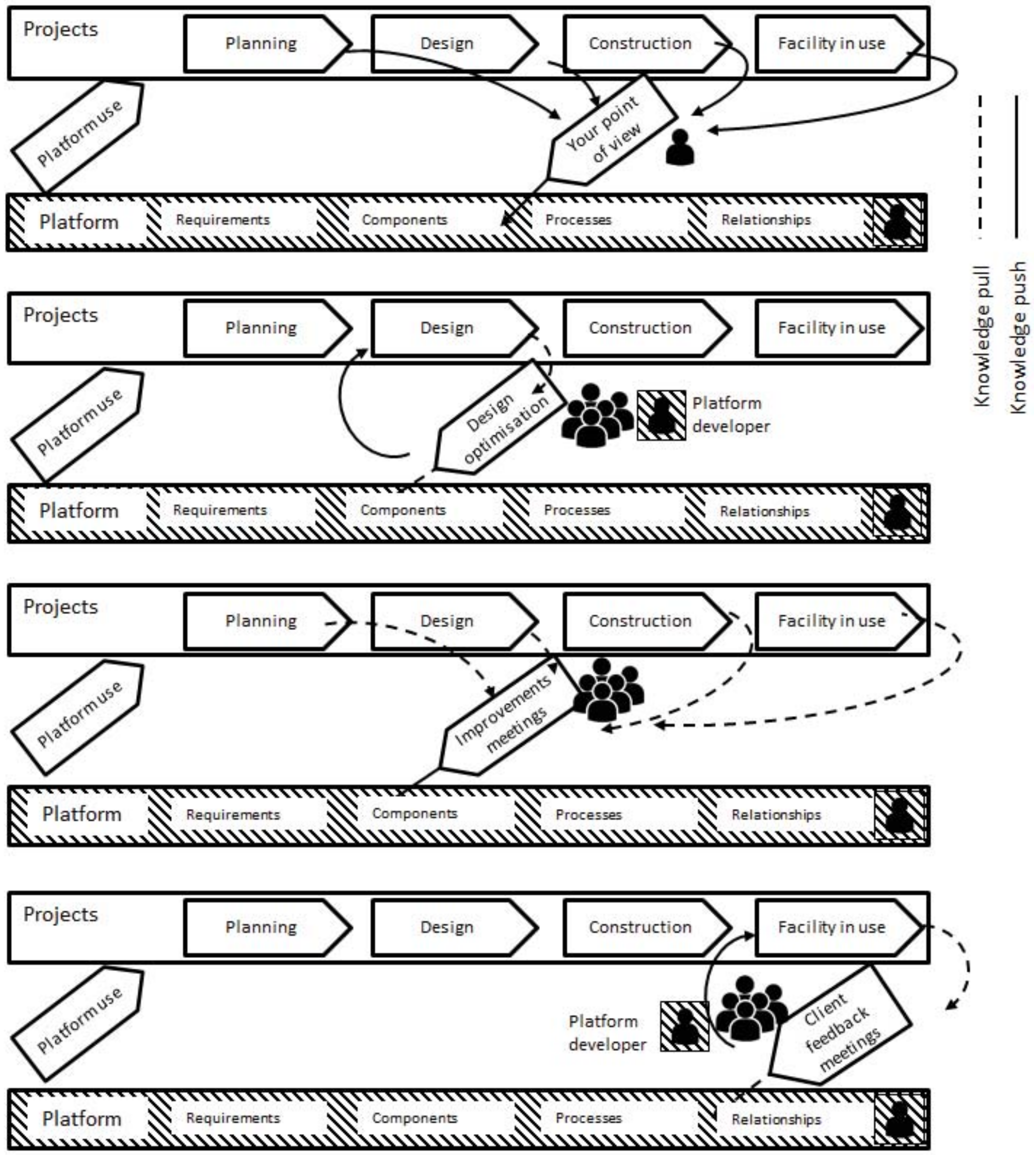


Figure 3. Feedback loops for the four feedback channels.

Client feedback meetings were held by the contractor partly of the project organisation, together with the internal client, sub-contractors, and suppliers. A questionnaire designed by the platform developers was used to collect information on client experiences. The responses mainly focused on relationships (53%), both internal and relationships with subcontractors and suppliers.

In both Improvement meetings and Your point of view, EF was pushed to the organisational platform level from all building phases in a double-loop. However, there was no single-loop learning feeding back into the ongoing project. The Design optimisation and Client feedback meetings supported both single and double-loop learning by involving the platform developers in the channels, causing EF to be pulled into the platform.

Platform development in an ETO context

In an MTO context, the product platform is developed downwards starting from the top level (Robertson and Ulrich, 1998), while in an ETO context one must detail the physical system at the same time as defining higher-level functional requirements. Management of the platform's predefinitions is therefore important for the entire supply chain. For instance the knowledge pull from the organisation that improves the platform in *Design Optimisation* also provides a knowledge push for direct improvements of operational work in the actual building project. The development and routinisation of design and production activities has been shown to help the creation of these active double-loop learning processes (Lu *et al.*, 2011).

EF represents the main source of incremental development in ETO platforms. It is therefore vital to have multiple complementary feedback channels that collectively provide feedback on all of the platform's building blocks. The channels studied in this work differed in terms of their knowledge push/pull mechanisms and the knowledge flow between the individual, group, and organisational levels. The *Design optimisation* meetings focused on the detailed design, its organisation and use of components. The *Improvement* and *Client feedback meetings* both provided methods for managing organisational relationships in the platform and provided valuable opportunities for differentiation.

The on-site activities were less extensively standardised than the design activities. This could partly be due to the pushing of production knowledge via the *Your point of view* and *Improvement meetings* channels. A problem with directly pushing knowledge from individuals working on projects to the organisational level is that the quality of ideas and suggestions for improvement varies (Crossan *et al.*, 2000) and could also cause information overload (Meiling, 2010). Incorporating a group learning level and including the platform developers in the feedback process pulls innovations into the platform more efficiently.

In addition, there is a need for more sources of feedback on site activities and live capture of knowledge from on-site work to support greater standardisation (Keegan and Turner, 2001; Robinson *et al.*, 2001). Gerth *et al.* (2013) suggested that product solutions should be evaluated using predefined criteria to ensure that knowledge from operational work is fed back into the design and production planning process, i.e. to enable double-loop learning.

The inclusion of platform developers in the *Improvement meetings* provided an effective way of funnelling EF into the platform's organisational development. This was also the only channel that provided EF from aspects of the project work involving stakeholders from the entire supply chain. The project supply chain perspective is important to consider when attempting to understand the consequences of platform standardisation in an ETO context. The incremental development of platforms should therefore be planned using a combination of strategic expertise (platform developers) and users' (i.e. project stakeholders') operational experiences (Bresnen, 2004).

The housebuilding platform was analysed on the basis of Styhre and Gluch's (2010) discussion of KM in terms of stocks and flows, as shown in Figure 4. The foundational stock of knowledge in this case is represented by the links between the platform's assets. The case study results showed that knowledge flows from the platform to the project are exploited during the company's ETO process, and that exploration of the EF flows, via the feedback channels, works in the opposite direction. In order to support controllable knowledge transfer between the individual, group and organisational levels (Crossan *et al.*, 2000), EF should be organised in predefined channels so as to feed new knowledge into the platform's knowledge stock, i.e. the building blocks and links. Hence, the platform also works as a system for the support of incremental innovation in the organisation via the platform.

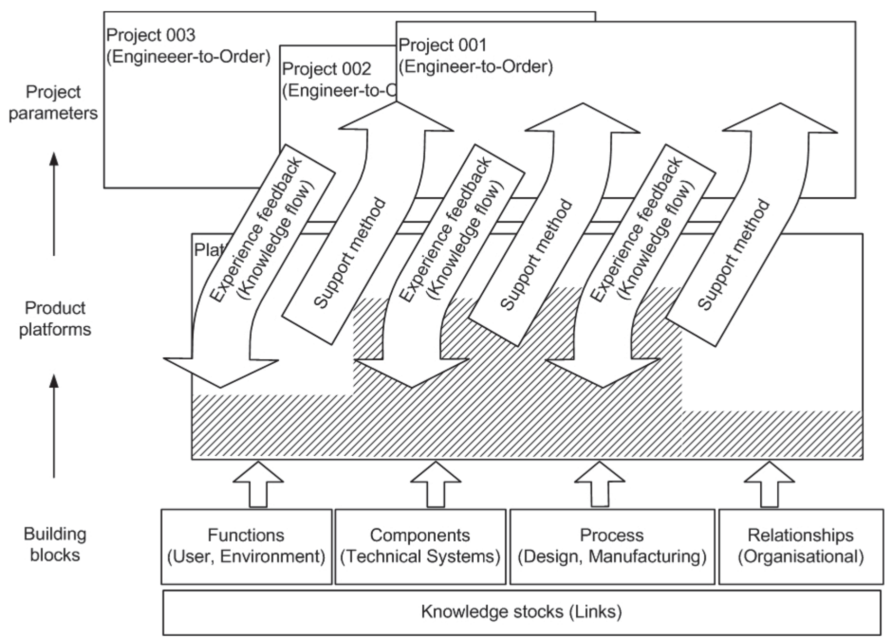


Figure 4. Knowledge stocks and flows relating to the company's house-building platform.

With a more dominant focus on knowledge pull toward components and commonalities, purchasing and outsourcing, benefits should increase. However, the risk of reducing the overall efficiency of the supply chain could inhibit the organisational certainty in platform investments (Karlsson and Sköld, 2007).

The results presented herein suggest that continuous platform development is based on small incremental steps driven by EF from projects. The strength of the project organisation is that it can manage variety together with repetitiveness.

Decentralisation, the short-term emphasis on project performance and distributed working practices limit the scope for improvement (Bresnen *et al.*, 2004). Individuals contribute varied experiences from different projects in the incremental innovation process. Different channels could therefore contribute to the development of different types of platform assets. However, it's difficult to evaluate the performance of individual incremental innovations.

This study has shown how a platform can work as a system for the support of incremental innovation. The four studied channels were shown to differ in terms of their knowledge push/pull mechanisms and their contributions to exploitation/exploration at the organisational, group and individual levels, as shown in Figure 3.

The feedback channels studied in this work are company-wide and are therefore also used in projects based on other platforms as well as several that do not use any platform. The platform developers of the house-building platform therefore have little control over the flows within channels. Experience is pushed from individuals to platform developers and only managed at the group level in the *Design optimisation* and *Client feedback meetings*. To gather feedback from the other channels, the developers are required to manually sift through all of the provided suggestions and decided which are of sufficient quality to justify implementation in the platform. As noted above, this creates data overload, i.e. noise that makes it difficult for platform developers to identify the most valuable feedback. The result is an inefficient innovation process. If the platform developers want to receive feedback concerning production process activities, other more (pull) controlled channels, incorporating a group learning level (similar to the *Design optimisation* meetings) would be more efficient.

Discussion

The knowledge creation processes and flows described in this study were used to support the incremental development of a house-building platform based on experience gained during its use. Feedback channels that relay information from projects to platform developers and designers are essential in this process. This study focused exclusively on EF from projects as a driver of platform development, but in reality there will be multiple knowledge creation processes within a firm that should be accounted for (Meiling, 2010). It is also important to consider other sources of innovation; EF is just one method for improving a platform based on operational work. Innovations can also be triggered by external factors such as changing markets or technological breakthroughs (Winch, 1998).

The house-building companies also need to communicate the trade-off between commonality and variety in the platform and establish procedures for managing any unique parts used in a given building project. In the case study, it was noted that a majority of the EF concerning component commonalities was pulled from group discussions by the platform developers. Over time, this may increase the commonality of the platform and narrow the product offer, but also cause organisational inertia arising from difficulties in satisfying stakeholder demands (Karlsson and Sköld, 2007).

The organisation is supposed to exploit the platform in its projects, i.e. organisational knowledge should be used by individuals in their work. In this respect, the platform developers also act as champions, controlling the incremental stream of innovation diffusion within the firm (Nam and Tatum, 1997).

The depth of this single case study illustrates how companies can incrementally develop a house-building platform from EF gathered during several projects. Gann and Salter (2000) describe the complexity of managing innovation in discontinuous project-based production via organisational learning and feedback loops. One effective way of creating knowledge flows from projects to platforms and from previous mistakes to successes (Henderson *et al.*, 2013) in order to promote the diffusion of innovation is to establish double-loop learning through feedback channels. However, the results presented herein suggest that the quality of the feedback supplied through these channels can profoundly affect the scope for using EF in the development of house building platforms. Quality here refers to how well platform developers can utilise EF in the development work and how effective channels are at feeding the experiences of individuals and groups associated with the project back into the platform and the organisational knowledge corpus. The adverse consequences of low quality feedback were demonstrated by the impact of the *Your point of view* channel, which allowed project members to directly push knowledge into a database with little or no quality control, leading to information overload.

Conclusions

In mass customisation industries, the development and improvement of product platforms usually occurs through processes that are separated from the platforms' uses in product customisation. This study shows that ETO house building platforms can be continuously developed while being used in ongoing projects. Platforms can also support double-loop learning, integrating the projects into the firm's business processes (Henderson *et al.*, 2013; Gann and Salter, 2000).

It is important to canalise the knowledge created during projects through EF channels to the organisation responsible for platform development, in order to facilitate the platform's incremental development. This requires the availability of different feedback channels that should be located in different organisational and process contexts to ensure a flow of EF relating to all of the platform's different building blocks and assets (Jiao *et al.,* 2007). The channels should also enable knowledge pull, e.g. by involving platform developers in the project at both the individual and group levels, thereby connecting the EF from the project with the incremental diffusion of innovation into the platform (Crossan *et al.,* 1999; Rogers, 2003).

Efficient innovation diffusion processes are created when the platform developers are involved with ongoing projects, both directly in collaboration with individuals working on those projects and through the routinisation of project improvements on the organisational level. By interacting with ongoing projects in these ways, the developers can serve as platform champions (Nam and Tatum, 1997). Group-level processing of EF seems to be essential for OL and efficient platform development because it allows for a preliminary filtering that increases the quality of the feedback received by the platform developers. Future studies should therefore examine the role of the group level as an intermediary between the platform and individual workers in house-building projects. In addition, the effects of knowledge pull and push on exploration and exploitation need to be studied more extensively.

Limitations of the study are both related to the context of the case and the theoretical perspective of analysis. A single case study limits the generalizability but gives a deeper understanding of the theoretical perspective of OL in platform development. In this study only four channels were examined were EF from the design phase dominated. More case studies could provide information of other types of EF channels, but also on EF information that focus on other phases and parts of the supply chain.

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Appended paper IV

Experience feedback in an adapt-to-order – make-to-order industrialized house builder

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Experience feedback in an adapt-to-order – make-to-order industrialized house builder

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Abstract
Although knowledge and knowledge transfer are central concepts of platform thinking, research on the use of platforms in construction has until recently largely overlooked the role of experience feedback (EF) in platform improvement and renewal. This paper presents a single case study on how EF is collected and utilized in a house-building organization that has adopted platform thinking and an adapt-to-order engineering strategy. The EF within the platform was dominated by informal and personal feedback channels. EF from projects fuelled continuous improvement and development of the existing products and the platform itself. EF from clients and other market-related channels was used for new product development. EF from consultants prompted changes due to revised building codes or demands from local authorities. The findings highlight the importance of having feedback channels for different stakeholders. Informal and personal channels are found to be inexpensive and flexible, and thus effective for smaller organizations.

Keywords Industrialized building, production strategies, product platform, experience feedback

Paper type Case study

Introduction

Companies in the construction industry experience quality, cost, and time saving problems similar to those found in other project-based industries, due to temporary organizations, loosely defined processes, and one-of-a-kind project attitudes (Koskela, 2000). Industrialized building (IB) offers strategies to combat these issues by adopting a more product- and process-oriented approach to the construction trade. Industrialization implies an increase in standardization and the use of manufacturing. As such, it offers opportunities to reduce costs, lead-times, and waste, while increasing quality, productivity, and predictability (Pan, *et al.*, 2012).

Several industrialized building companies have successfully implemented *platform thinking* in order to identify different customer segments and develop suitable product concepts (Jansson, 2013). These companies can pre-engineer their designs to different degrees, corresponding to different variations of the engineer-to-order strategy that include design-to-order, adapt-to-order, and engineer-to-stock. Similarly, the production process can be shortened by applying various degrees of pre-fabrication, in variations of make-to-order and assemble-to-order (Johnsson, 2013) .

Platform thinking assumes that the long-term success and survival of a firm requires continuing innovation and renewal (Meyer and Lehnerd, 1997). The organization must therefore collect and use experience from different channels in the supply chain to support this renewal process. However, while knowledge and knowledge transfer are central to platform thinking, research on the use of platforms in construction has until recently only focused on the design and implementation of platforms; there has been relatively little emphasis on the roles of platform renewal and collecting experience feedback (EF). Also, the general construction management literature contains relatively few case studies and those knowledge management studies that have been reported focus mainly on *what* is done rather than *how* it is done (Styhre and Gluch, 2010).

(Gerth, *et al.*, 2013) described how production experience could be used during design in an ETO construction context, while (Jansson, *et al.*, 2015) claimed to be the first to explore *how* EF was used in the continuous development of a house-building platform within an ETO production strategy (more precisely, an adapt-to-order pre-engineering strategy and a make-to-order production strategy). Given this paucity of studies, more research is required to clarify how EF is organized and used in platforms that rely on other strategies to see if and how different strategies adopted within the building industry affect EF.

To address the knowledge gap mentioned above, we conducted a descriptive study motivated by the following research question: how is experience feedback being used in the development of products, processes, and platforms in an adapt-to-order – make-to-order strategy in industrialized house-building? This work expands the understanding of the role and use of EF in existing platform strategies, and should be helpful in ensuring the long-time survival of other industrialized house-builders using a similar strategy.

The next section presents the frame of reference used in the analysis of the case study, including a taxonomy of production strategies and a description of the uses of product platforms, in order to put the case into context. EF literature relevant to this context is then reviewed. This is followed by descriptions of the collection and analysis of empirical data in the case study, after which the findings of the study are presented and discussed in relation to the chosen frame of reference. The paper concludes with a brief discussion of the study's implications for researchers and practitioners.

Frame of reference

Production strategies

Companies may use different strategies to achieve success and meet customers' demands (Winch, 2003). Broadly speaking, these strategies can be classified as business strategies (which are based on the company's corporate vision) and production strategies (based on production technology and programs), both of which converge across a set of competitive dimensions such as quality, flexibility, time, cost, and environmental performance (Sackett *et al.*, 1997). In the literature, these production strategies have been further classified and categorized based on the stage in the supply chain at which customers enter, termed the customer order de-coupling point (CODP) (Haug, *et al.*, 2009). Rudberg and Wikner (2004) defined the CODP as the point at which decisions concerning customer demand go from being made without certainty or on the basis of speculation to being made on a certain basis supported by a commitment.

Several approaches for classifying companies' strategies have been presented in the literature. In their literature review, Wikner and Rudberg (2001) identified four common strategy types: engineer-to-order (ETO), make-to-order (MTO), assemble-to-order (ATO), and make-to-stock (MTS). However, many different terms have been used to describe these strategies in the literature because (i) these four categories represent regions within a strategic continuum rather than sharply delineated universal classes, and (ii) different authors have focused on different parts of the supply chain. For instance, Winch (2003) differentiated strategies on the basis of the point at which the client enters the *production information flow*, using the terms concept-to-order, design-to-order, make-to-order, and make-to-forecast. Conversely, Hansen (2003) adopted a *design and engineering perspective* and drew a distinction between specifications created before the CODP (norms and standards, generic product structures, standard parts and modules, standard products) and strategy types implemented after the CODP (engineer-to-order, modify-to-order, configure-to-order, select variant). Finally, Hvam *et al.* (2008) used a production view when defining the terms make-to-order, assemble-to-order, and make-to-stock.

Traditional construction companies typically use an ETO supply chain, like other companies that have large, complex project-based production systems and operate in capital goods sectors such as aerospace, shipbuilding, and machinery. ETO companies produce highly customized products in low volume. These high levels of customization increase costs, risks and lead-times.

The client enters the ETO decision process at some point during the design stage (Hicks and McGovern, 2009). ETO companies derive their competitive advantage from understanding clients' requirements and meeting them by using them as the basis for tenders, developing customized designs, and successfully completing contracts on time and to budget (Hicks, *et al.*, 2000).

Most scholars have adopted a sequential view of the supply chain in which the concept stage is followed by design, engineering, manufacturing, assembly, and then finally shipment. However, some production steps can be performed before certain design activities. This is acknowledged explicitly in the two-dimensional model developed by (Rudberg and Wikner, 2004), which has separate engineering (ED) and production (PD) dimensions, as shown in Table 1 and Figure 1.

Table 1. Rudberg and Wikner's (2004) two-dimensional CODPs.

	Traditional CODPs in terms of production and engineering strategies	
Traditional CODPs	Engineering strategy	Production strategy
ETO	DTO_{ED}	MTO_{PD}
-	ATO_{ED}	MTO_{PD}
MTO	ETS_{ED}	MTO_{PD}
-	ATO_{ED}	ATO_{PD}
ATO	ETS_{ED}	ATO_{PD}
MTS	ETS_{ED}	MTS_{PD}

The two dimensions are actually continuums, and a company can strategically position itself anywhere in the plane between the extremes of design-to-order (DTO_{ED}) and engineer-to-stock (ETS_{ED}) on the one hand, and MTO_{PD} to MTS_{PD} on the other. It should be noted that in their original publication Rudberg and Wikner (2004) used the term ETO_{ED} instead of DTO_{ED}; the latter term was proposed by (Johnsson, 2013). In the engineering dimension, a strategy that permits modification (at any level) of the product's design or engineering is described as an adapt-to-order (ATO_{ED}) strategy. A company can further systematize its product portfolio through *platform thinking*, in which the portfolio is divided into a set of *product families* whose members have some common parts based on a modular design together with some unique components.

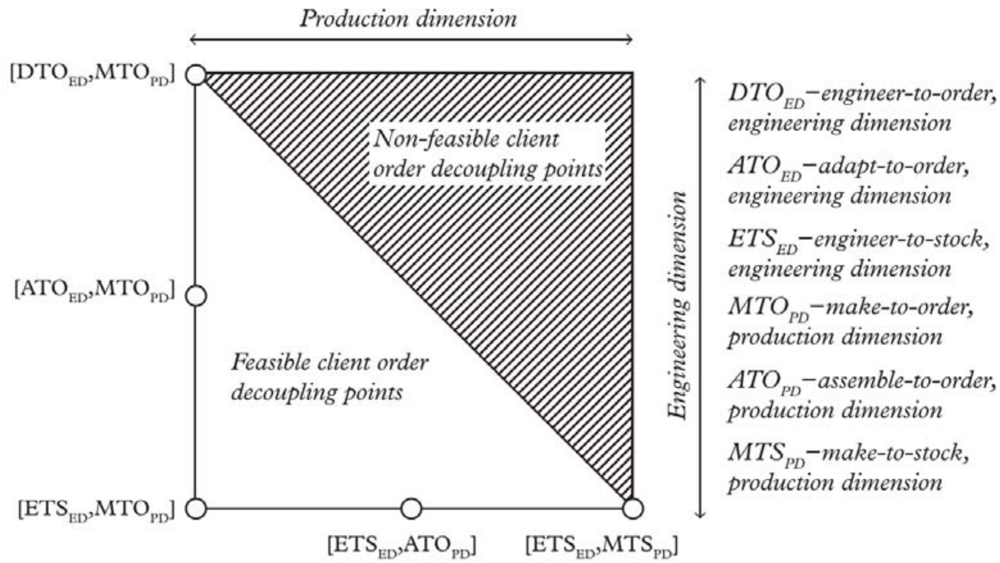

Figure 1. Customer order decoupling points for different production strategies. Reproduced from Johnsson (2013), revised from Sackett et al. (1997).

Strategies and platform thinking in house-building

Product platforms were first introduced in the manufacturing industries as strategies for managing customers' demand for greater product variety (Krishnan & Gupta, 2001), as product lifecycles shortened and technology started changing more rapidly (Ulrich, 1995; Pine, 1993). There are many different definitions of the platform concept (Halman, 2003; Jiao, *et al.*, 2007). For instance, Meyer and Lehnerd (1997) defined a product platform in terms of product architecture as a set of subsystems and interfaces that form a common structure from which a stream of derivate products can be efficiently developed and produced. Robertson and Ulrich (1998) simply defined a platform as a collection of assets that are shared by a set of products. Using platforms accelerates the development of new products and can increase product performance by enabling the reuse of standardized pretested components and the exploitation of the accumulated learning and experience garnered during earlier uses of those components (Halman, 2003). Product platforms can therefore also be described as repositories for organizational knowledge of components, processes and relationships that can be used to adapt a product for a specific customer (Meyer and Lehnerd, 1997; Robertson and Ulrich, 1998).

Jiao et al. (2007) presented a holistic "decision framework" for product family design and development based on the work of Suh (2001); see Figure 2. This framework is based on five design domains that are mapped together in sequence: the customer, functional, physical, process, and logistics domains. The customer attributes (CA) represent market segmentation and the demand for product families. The CAs are translated into functional requirements (FR) in the functional domain, and designers and engineers elaborate on how to meet these requirements. In the physical domain, product family design solutions are generated by mapping FRs to design parameters (DP), based on the assets of the product platform. The mapping of DPs to process variables (PV) determines the design of the production process, which encompasses production planning and is located within the logistics domain, which is in turn connected to the supplier platform.

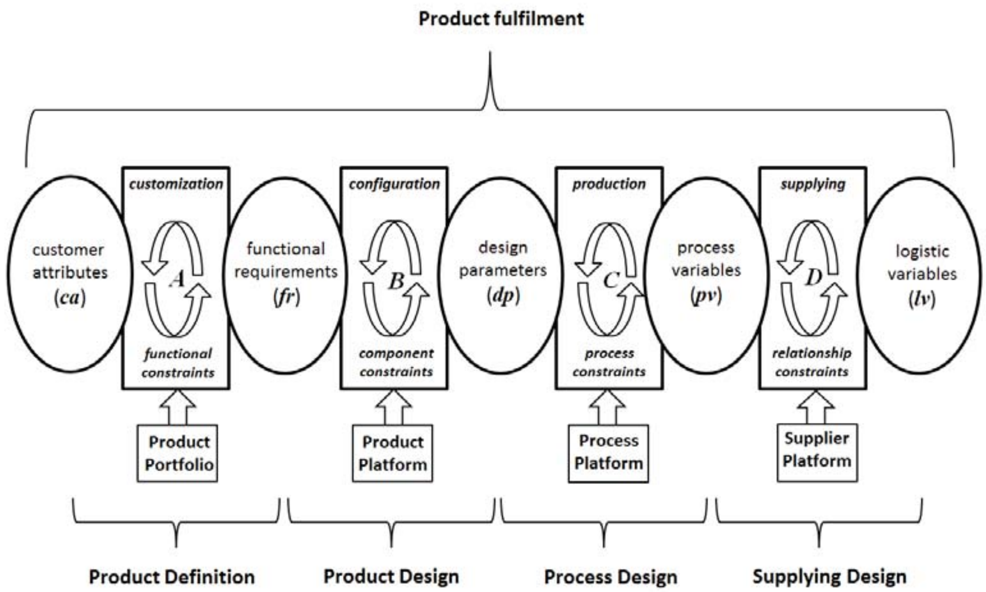

Figure 2. Decision framework of product family design and development along the spectrum of product realization (Jiao et al., 2007) based on the concept of design domains by Suh (2001).

There are two categories of components in the product platform – those representing commonality and those representing distinctiveness. Common components are those that are common to the entire product family whereas distinctive ones are only used by individual products or product subgroups. According to Meyer and Lehnerd (1997), finding the right balance between commonality and distinctiveness is a major challenge in platform design. To support this process, Bowman (2006) suggests that market positioning should be defined with respect to customer needs. In the product customization process, product platforms support the engineering work by reducing development costs, time, manufacturing costs, production investments and complexity (ibid).

The process domain is primarily related to production and cost commitment, which is why process design is the de facto enabler of mass production efficiency (Jiao *et al.*, 2007).

A number of successful uses of product platforms in industrialized house-building (IHB) have been reported in recent years. For instance, a German house-building platform managed to reduce construction costs by more than 30% over 14 years (Thuesen and Hvam, 2011). In this case, the adoption of on-site construction methods made it possible to achieve high efficiency without the need for off-site manufacturing. In this DTO context, platforms have been described as systems for storing knowledge and/or predefinitions of house-building components, related processes, as well as internal and external relationships (Jansson et *al.*, 2013). Another common factor in industrialized building is the need to make strategic decisions about the level of pre-production. (Gibb, 2001) distinguished four separate approaches to industrialized building differentiated by their level of pre-production: *Component Manufacture and Sub-Assembly*, *Non-Volumetric Pre-Assembly*, *Volumetric Pre-Assembly*, and *Modular building*.

Construction companies that have implemented platform thinking have moved *from* pure ETO *toward* a form of mass customization. By doing so they have achieved economies of scale while still meeting customers' expectations of design flexibility. In general, these strategies can be classified using the two-dimensional taxonomy of engineering and production strategies proposed by Rudberg and Wikner (2004) as shown in Figure 1. The applicability of this taxonomy was tested empirically in a multiple case study on house-building firms conducted by Johnsson (2013). All of the firms examined in the case studies had adopted a product platform strategy and used different levels of pre-engineering, although all of their strategies were classified as MTO_{PD} with respect to the production dimension.

Platforms should explicitly support the incorporation of experience acquired during the production process in order to support continuous improvement (Thuesen and Hvam, 2011). However, Styhre and Gluch (2010) showed that platforms can be difficult to implement in an ETO supply chain in the construction industry because there is a degree of institutional skepticism regarding the use of standardized solutions and pre-design of buildings. On the basis of their case study, they concluded that the ETO platform was a bit too general to effectively support knowledge sharing.

The customization of house-building products involves the same process of transformation between domains as outlined in Figure 1 but in an ETO supply chain (Gosling and Naim, 2009; Johnsson, 2013; Jensen, 2014), since some parts of the designs used in house-building projects are unique and not part of the platform (Jansson *et al.*, 2013). The customer order decoupling point is located at the design stage in the ETO supply chain, when the product becomes differentiated from its predecessors (Gosling and Naim, 2009). This variation is reflected in the level of standardization in house building platforms (Jensen *et al.*, 2012), which are developed incrementally on the basis of experience that flows into the organization from projects and is stored within the platform's predefinitions (Styhre and Gluch, 2010).

The platform can be continuously and incrementally further developed based on experience gathered in projects. Its success and development will depend on how efficiently experiences from projects are collected, interpreted and institutionalized (Meiling, 2010).

Experience feedback in house-building platforms

Learning from past experiences and using improvement ideas to enable continuous improvement have been recognized as fundamental components of effective quality management (Juran, *et al.*, 1999). Experience feedback (EF) is related to knowledge management (KM), which offers methods for capturing new knowledge gained from projects and reusing it in the organization (Anumba *et al.*, 2005). In the Organizational Learning literature, *experience* is seen as the basis for individual learning, which can be communicated to groups, interpreted, and ultimately integrated into routines, diagnostic systems, and rules and procedures that are adopted across the entire organization (Crossan, *et al.*, 1999).

In the literature, knowledge has been divided into two classes – *tacit* and *explicit* knowledge. Tacit knowledge is more skill-based, and therefore more prone to being transferred through people-centered techniques. Explicit knowledge, on the other hand, is more connected to information and is preferentially transferred via IT tools (Carrillo *et al.*, 2004).

In this paper, EF is defined as the transferring of ones experiences regarding a specific matter to a known receiver, with the purpose of improving factors relating to that matter. Feedback can be given through different feedback channels or knowledge transfer channels, where a channel is a function (a person, a group of people, or a technology) that relays a message from a sender to a receiver. Channels can be *informal* or *formal* and *personal* or *impersonal* (Kaye, 1995). Informal channels such as unscheduled meetings or coffee break conversations can be effective for promoting socialization but could hinder wide dissemination of knowledge (Holtham and Courtney, 1998). According to Fahey and Prusak (1998), such channels may be more effective in small organizations.

Even manufacturing companies with well-established EF systems do not generally realize the full potential of reusing past experiences (Alizon, *et al.*, 2006) even if they have methods for knowledge transfer such as those discussed by Boer et al. (2001). Regarding construction, Meiling (2010) stated that a major challenge is to manage the large number of experiences generated during each individual construction project and use them for improvement. One reason that this is so challenging is the absence of a central support system for making experiences available as they are acquired. Instead, construction managers seem to prefer the use of more “traditional” business communication technologies for knowledge sharing, such as face-to-face meetings, telephone, and e-mail (Bresnen, *et al.*, 2004)

In an analysis of industrialized house building research, (Lessing, *et al.*, 2015) found that only a few researchers had studied the reuse of experience whereas fields such as planning and technical systems had been studied much more extensively. There have been even fewer studies on product platforms and experience feedback in construction. However, there have been some notable contributions on product platforms and experience feedback outside the context of construction management research. For example, Chai *et al.* (2012) argued that knowledge sharing and having a product champion are the most important factors when building competences for platform-based product development.

(Jansson et al., 2015) were arguably the first construction management researchers to explore the use of EF in the continuous development of a house-building platform used with an ETO production strategy. Four different, formal channels for experience feedback from building projects were identified and analyzed, to see how they supported the incremental development and use of the platform and product. The channels were named *design optimization*, *your point of view*, *improvement meetings* and *client feedback meetings*. It was found that the vast majority of the gathered EF related to how to better use the platform in the design stage, and not so much about improving the production process.

While the studies mentioned above have provided important insights, there is still great scope for providing further detail on how experience feedback functions for product platform companies.

Research method

Based on the nature of the research question that this work seeks to answer ("How is experience feedback being applied for the development of products, processes, and platform under an ATO_{ED} – MTO_{PD} strategy?"), a case study was identified as a suitable research method. Case studies enable researchers to develop deep and detailed knowledge regarding the studied phenomena (Yin, 2009) and are also suitable for collecting and analyzing data about processes (Pratt, 2009) such as those involved in the development of a product platform and the associated products. In this work we chose to focus on a single case in order to conduct a detailed, in-depth investigation. The unit of analysis in this work is experience feedback activities in a firm that has adopted an ATO_{ED} – MTO_{PD} strategy.

Case selection

This case study is part of the first author's doctoral project, which aims to draw general conclusions about how strategies affect the use of EF in construction by examining a series of firms that have adopted strategies located at different points on the continuum represented in Figure 2. The case was selected in cooperation with one of Sweden's leading construction firms, with which the author cooperated during the project. The companies targeted during case selection were Swedish building firms that had developed an industrialized building concept using an adapt-to-order pre-engineering strategy close to engineer-to-stock and a make-to-order production strategy. Several candidate firms that met these criteria were considered; in the end, the decision was mainly made on the basis of the positive impression that we received from the chosen company's manager (i.e. the head of the relevant division) concerning access to data**.**

The studied case, hereafter also referred to as the *platform and product development division*, or just *the developers*, is a division within a large construction company that has local offices in many parts of Sweden. Because of this situation, they work together with several different local construction divisions to build houses; these local divisions are henceforth referred to as *local production teams*. The developers are responsible for market contacts, platform and product development, and supporting the building projects that build their products.

Data collection

The data collection consisted mainly of interviews. Individual face-to-face interviews were conducted with key personnel in the central platform organization and a number of experienced representatives from local production teams (two of the interviews were conducted, and recorded, via video conference). From the former, we interviewed the *head of division*, the *head of development and production*, two (2) project managers, three (3) project engineers, and a material purchaser. From the latter, two (2) project managers and one (1) site manager were interviewed. The interviewees were selected by the head of development and production, after the author had requested to interview key personnel from the central organization and a number of project managers and site managers from local organizations.

Each interview took about 90 minutes. The interviews were semi-structured, with open-ended questions. The main questions used to support the analysis in this paper are found in Appendix 1. Based on the answers, follow-up questions were asked in order to obtain the most complete possible record from each interviewee. Each interview was audio-recorded and subsequently transcribed *verbatim*.

Additional archival data in the form of assembly instructions and public documentation available on the company's website, including product descriptions, were also collected.

Data analysis

The interview data were grouped into themes and coded based on the frame of reference. First, the type of engineering and production strategy used by the case organization was identified on the basis of interview responses relating to platform content and utilization. A key step in this process was to identify the customer order decoupling point and then to identify the aspects of engineering and production work that occur before and after this point. This information was used to classify the platform's balance of commonality and distinctiveness. Second, the platform's established EF channels were identified along with the kind of information relayed along these channels. These channels are described analytically in the following sections. Finally, we identified how this information was managed within the platform and product development division for the purpose of platform and product development, i.e. how this information influenced the development of the platform and its products and processes. The results of these steps together answer the research question. We then discuss how our results relate to previous publications in the field.

Results

Platform organization

The developers consists mainly of a number of *project engineers* (PE) and a few *project managers* (PM) who are led by a *head of development and production*, and a *division manager*. This organization is supposed to mirror that of the local production divisions. The group also has employees who work in the same open office landscape and serve key business support functions including market communication/sales, finances, purchasing, and after-market support. The group's duties include both platform and product development *and* project management.

For instance, the PEs are supposed to spend approximately 20% of their working time on product development and improvement and 80% of their time "on projects". The PMs, on the other hand, might spend only 20% on projects and 80% on product development – or somewhere in between. They take on the responsibility for larger development projects such as the development of new products.

A new recruit usually starts out running projects. The current PMs all have experience of running projects as either a PE or a site manager. According to the *head of development and production*, it's important for PMs to have know-how and personal experience of how the company's products perform in a project environment before starting work on product development.

Pre-engineering strategy and product development

The studied division had begun as a development project that was led by the current *head of development and production*. Its mission was to develop an innovative building concept that could reduce production costs by 30%. The conceptual ideas resulting from this project developed into a technical platform for a product family of multi-family dwellings.

The products were defined from the foundation up, i.e. earthworks were project-specific and engineered to order in each project, on sub-contract. Each building element – floor slab, external wall, internal wall, etc. – existed in one variant only. This standardization of building blocks was expected to enable the exploitation of economies of scale by purchasing large quantities of few components from few suppliers. During the platform's development, buildability, i.e. the capacity for rational production on site, was the most important criterion for the selection of building elements. The different products that were differentiated from one another by design elements such as the floor layout, and the associated building information models, were re-used in every project conducted using the products.

At the time this study was conducted, the division had released two products, here named *Two* (2-storey) and *Four* (4-storey). *Two* was the first to be developed. An architect and a few other internal consultants from within the company helped with the design and development process, which was required to respect the restrictions of the platform. The development of *Four* started after *Two* had undergone considerable work and improvement, to the point that the developers were satisfied with its state.

Both products were first tested in pilot projects before being offered to clients. During these pilots, people from the development team acted as site managers and chief foremen, using workers from their own local construction division. The building information model (BIM) manager – one of the interviewed PEs – was also located on site during both pilots. This enabled the developers to find and resolve many of the errors in the initial BIM, drawings, *work descriptions*, and other supporting documents.

A few variants enabling customer choice were also developed to enable some degree of mass customization. Some of these were connected to the building level, such as the type and color of the façade; others were on the apartment level. Usually each choice was between one default and one alternative. All of the alternatives were pre-designed, pre-engineered, and detailed in the BIM models, cost estimates and other documentation associated with the platform.

The products are continuously improved, which is a key priority of the developers. They have released major updates to the products on a biannual basis. Releasing new products in the product family is of lower priority; these are instead released when the developers feel that they are ready. The same people work on new product development, continuous improvement, and project management, which makes it natural for the team to prioritize improvement to ensure that their time is used as effectively as possible.

All ideas for new products or suggestions for improvements to the current ones are recorded on a common *gross list*. Each suggestion and idea is then investigated to clarify its benefits, costs, and likely effects on construction. The list is constantly prioritized; once a change has been adequately evaluated and selected for adoption it is moved to a *development list*, and becomes scheduled. A *development* is here characterized as an improvement that improves the product and necessitates a design/model revision. Some representative developments include a total redesign of a roof, a change to the ceiling solution on floor 2, or a change of bathroom supplier. In contrast, *continuous improvements* are smaller changes that can be implemented with less effort, for example by adjusting the tact times in a work instruction or by changing the geometry of a slab by a few mm.

Production strategy

During the initial platform development, the developers made the unusual (in IB) strategic decision to limit the number of prefabricated sub-assemblies (building elements) and subcontractors in each project in order to minimize their dependence on external resources and the problems they felt most traditional building projects encountered because of their out-sourced production organization.

Another ‘unorthodox’ decision was to not invest in any in-house manufacturing facilities. This decision was partially founded in the previous personal experience of the head of development and production with problems achieving return of investment for such facilities. Instead they decided to perform as much of the construction work on-site as possible. They also wanted to utilize the advantage of being part of a large company by making use of local resources around the country rather than employing their own dedicated production teams.

The interviewees reported that the developers mainly support their projects through a PE, whose function during a project combines the traditional role of a PE in a Swedish construction firm (which involves site management support including operational micro management of schedules, deliveries, site layouts, and so on) with the role traditionally served by the client’s project manager. In the latter respect, they act as the developers’ representative, providing guidance and control over the project.

Market communication was handled by sales personnel situated within the division. The business offer includes a locked schedule and price (lump sum). After the contract is signed, the head of the division contacts the local production office in the city or region where the estate is located and requests that a production organization be set up. The interviewees expressed that it is preferable for the site managers to have little (ideally no) prior experience of site management; failing that, they must be willing to adopt an entirely new philosophy and new ways of doing things. As one PE explained:

> “In the three projects that I currently run, I have ‘green’ SMs in two of them, and a more experienced one in the third. I can really notice a difference. The ‘green’ ones I’m in contact with almost every day, addressing different questions and concerns. The experienced one is more “easy going”. They have made some deviations from the system without consulting us, which they should not do. So there’s a difference.”

The client often has a finalized building permit plan for the site. The PM offers help in drawing up the finalized production documents, specifying the number of units of each product to be requested with the assistance of an associated architect (typically, the same architect who designed the products). This is also the point at which the client can choose the customer-selectable options for the houses, such as the design of the façade. The *head of development and production* explained the preference for using the firm's architect by saying

> "it will cost [the customer] much less to have our architect make the production documents than for them to employ someone local who is less familiar with our products."

At this time, a PE is assigned and starts to work together with the site management, ordering the first batches of materials and sub-assemblies. One of the interviewed PEs described this stage of the work as follows:

> "It's not so much traditional project planning as pre-production planning. We have a preset schedule for each house type, we only need to change the number of workers that we have available in the local team."

The cost estimates for the project are structured around specific building elements or work results/packages/moments. Each such work unit has a work description including a list of the needed material articles (and the required quantity of each one) as well as the necessary tools and equipment, and the time expected for the work. These are all connected. The unit time and the quantities in the estimate are exported to the scheduling software, which is used to draw up a timetable for the project including buffers, details of the number of workers that will be available, and optimized allocations of their time on site.

In addition, each activity or "work moment" in the construction phase is preceded by a pre-production planning meeting involving all members of the production team, which draws on very detailed *work descriptions* supplied by the PE. These descriptions are key knowledge assets in the platform, describing the construction process in detail.

The initial idea proposed by the *head of development and production* was that these documents would be so detailed that they could be used to support construction teams consisting of multi-skilled workers, who would rotate through all of the activities involved in the construction of a house.

The PE is responsible for introducing local organizations to the products, the production methods, support systems (documents and templates), and residents' apartment choices (which are handled by the client). This is achieved by holding a start-up meeting attended by everyone in the local organization who is to be involved with the project.

The interviewees reported that their local teams were now starting to be re-used as their first projects reached completion. This re-use of established teams should accelerate subsequent project start-ups and the introduction of new products within the product family. One PE suggested that this may increase the power of site managers by making them more secure with the new system, and that it might reduce their likelihood of asking questions of the SMs.

The adoption of the new production strategy was accompanied by a new cooperation agreement that changed the balance of power between the developers and local organizations. Initially, the central team, in their role as product owner, acted as both supplier and client to the local organization. Therefore, local production teams had little incentive to feed back their experiences and help develop the products and work methods. At the same time the local organizations found it difficult to make profits from the projects in which they participated. The contractual agreement with the local production team was subsequently replaced with a cooperation-based agreement similar to the partnership agreements found in client-contractor situations. In the new agreement, the development division and the local teams share both costs and earnings. Interviewees from both the developers and the local organizations agreed that the new arrangement has improved the incentive to provide experience feedback because any improvements that result now directly increase the local team’s profit and also improve the overall working climate of the projects.

Experience feedback

We identified several communication channels by which different senders feed back their experiences with the products to a receiver (typically the developers, i.e. the platform). These channels are summarized in **Error! Reference source not found.**.

Project engineers

In keeping with the importance of their role in providing project support and control within the platform, the PEs were also the most important feedback channels (for the purposes of this discussion, we disregard the PEs’ roles outside of individual projects). Project managers communicated their feedback to PEs via face-to-face conversation, phone calls, e-mail, written comments on drawings and work descriptions, and post-project experience meetings. The first three methods of communication were reported to be most important for EF. Feedback acquired through these pathways has been used both to initiate larger product development steps and to drive smaller adjustments that enable continuous improvement.

The PEs visit their projects every other week. During the visits, they meet with the site management and may also walk around the site to chat with the workers. In addition to the site visits, the PEs are in near-daily contact with the SMs via e-mail or phone.

Table 2. Summary of experience feedback channels in the case organization.

Channel	**Sender**	**Receiver**	**Type of feedback**
Project engineers	Local production team	Platform	Production descriptions
	Suppliers		Manufacturing capability
Progress meetings	Local production team	PE, central PM	Project progress, prognosis
Project managers	Consultants	Platform	Changed code of practice
Purchaser	Suppliers	Platform	Manufacturing capability
	Purchaser	Suppliers	Supplier's quality
After-market	Tenants	Platform	Complaints
	Inspectors	Platform, project	Defects (remarks)
Sales/market	Current and potential clients, municipalities	Platform	End-customer needs, local constraints
Experience meetings	Local production team Clients	Platform	Project outcomes, product performance

The PEs ask the SM's and chief foremen about specific or general ideas for improvement or change. Some of these people prefer verbal communication while others prefer to write, so the interviewed PEs considered it important to be flexible in their methods of communication. As the *head of development and production* put it:

> "You can't force people to do things in one way or the other. The most important thing is that they DO report [their experience]".

All of this communication is supposed to go through the PE because they are responsible for the operational improvement work on the products. One PE explained the benefits of this approach as follows:

"It allows me to resolve the matter by myself, or else to take the issue to the [developers], or contact some expert outside of the group".

However, more experienced SMs had a tendency to forget to report problems to the developers. As one PE noted:

> "Sometimes you get to a site and notice they have come up with some unique solution, and you ask 'what's that?', and they tell you that 'well, we had this problem…', and I'm like 'well, I'd have appreciated it if

> you'd given me feedback and let me know about that because then I could have…'".

The expected tact times for specific work moments were derived from theoretical piece rates, and are mean values based on significant levels of repetition and associated learning curve effects.

One PE described problems with coping with the ever-growing size and complexity of the platform and its products, in terms of improving the products consequently, and suggested that it might be better if the PEs were given functional responsibility for the platform's common elements and subsystems rather than the product as a whole.

EF on the production documents and work descriptions from local teams that were inexperienced with the products was effective for reducing the documents' ambiguity and increasing their clarity.

Prognosis meetings

In addition to the start-up meeting mentioned in the section above, there are also *prognosis meetings* every 3rd month, where the PE and the PM from the platform meet with the SM and project manager of the local organization. However, the focus here is more on project progress and economic forecasting.

Project managers

Because PMs spend most of their time on product development, they have considerable contact with consultants, who are hired by developers to help with the design and engineering of their products. The consultants are well informed about imminent changes in building codes and codes of practice, and share this information with the developers. For instance, the developers communicate to the market that their houses perform a certain rating better than the regulations in energy performance, so when regulations become more stringent, the developers need to improve even further.

Purchaser

The central purchaser represents a two-way channel whose most important function (in terms of EF) is to allow developers to send feedback to their centrally tendered suppliers. In this way they can request changes in the products or raise awareness of issues with quality or deliverability. Because communication through this channel is an ongoing process, the suppliers can also report issues with manufacturing capability arising from increased demand.

After-market

The developers recently started to study how they could improve the management of the information contained in inspection reports. Their remarks in these reports mainly relate to surface damage visible once a project has been completed, and the developers wanted to maintain a record of recurring remarks so that they could be connected to specific subcontractors. For such connections to be reliable, it is important for the inspections to be as objective as possible and for all of the work to be judged using the same criteria. A problem identified by the developers is that many of the inspectors employed by the small inspection companies in the industry apply different criteria even though an inspection is supposed to be neutral, and the same criteria *should* be used in all cases. However, the developers had had good experiences with a leading building inspection firm in Sweden, which has introduced a digitalized tablet-based inspection system in their projects. The developers felt that that the combination of a digital system and a larger company should increase the likelihood that a consistent set of criteria would be used in all of their projects, and had therefore started recommending the inspection firm in question to their clients.

Sales/market

The interviewees reported that several variants of *Four* were in development. These variants were defined as distinct products (rather than a single product with multiple customer-selectable options) due to differences in their floor layout. These variants had been introduced in response to divergent requests from the market. One was introduced to increase the scope for building within city centers, where more closed blocks are desired. Another was developed to comply with the Norwegian building code. A third was developed in response to customer demand for more and smaller apartments per floor. A few customer choices have also been developed after receiving feedback from the urban planning offices of some municipalities that have architectural requirements for facades, balconies, etc.

Experience meetings

The experience meeting with the client – in literature often referred to as *post-project review* – is a formal experience feedback meeting that is held at the end of every project in the company, not just the division examined in this work. It is attended by representatives of the local team as well as the PE and PM from the developers. The company has templates for the agenda and the minutes of the meeting, although it is quite general because it is designed to be applicable to all projects. The interviewees reported that this generality makes it difficult to obtain useful information from these meetings.

During the course of the pilot projects, the developers held weekly review meetings each Monday morning (with the entire production team) and each Friday afternoon (attended by developers only). During the weeks, the PE spent much of his time documenting every production moment for the work description, which was continuously revised.

Improvement process

Every improvement suggestion that is received is put on the gross list and investigated. The platform and product developers then use the results of the investigation to decide whether or not to implement the change. If they choose to implement it, the associated EF will be codified into the relevant revised documents.

Analysis and discussion

Pre-engineering and product strategy

The pre-engineering strategy of the studied division was classified as an ATO_{ED} strategy. The product is fully predesigned, but the location of the CODP permits customers to customize certain aspects of their order such as the nature of the façade and the balconies. Each apartment can also be customized with a few end-customer choices between a base alternative and a more exclusive option (Rudberg and Wikner, 2004). A problem with the classification system of Rudberg and Wikner (ibid) is that the ATO_{ED} umbrella can potentially cover a very wide range of customization levels, from a situation where almost every part or sub-system can be exchanged or configured with a wide range of options or varieties, to one such as that considered here, where the products are highly standardized with only a few exchangeable parts and customer-selectable options.

Each new product design uses a large proportion of common parts. However, many different layout designs (and thus products) can be constructed from a limited set of basic building blocks. In most cases there is only one available design solution for each element type (e.g. one type of external wall), except the where the client can customize the design. The prefabricated bathroom pods and staircases are also entirely standardized.

This stands in contrast to DTO house-building platforms, which have no finished product design to modify. Platforms of this kind consist of a vast library of components and have a low degree of commonality but a high degree of distinctiveness. They are used by the architects and engineer consultants that design the buildings (Jansson, *et al.*, 2015).

The decision to have a high proportion of common components with limited distinctiveness was based on an initial market screening exercise, which identified a low-to-medium income segment of the population for which the company did not produce any houses at the time. In order to offer more affordable apartments, they designed a highly standardized platform with heavily standardized products so that they could achieve economies of scale. Future feedback from the market will show the developers if this level of standardization is attractive enough, or if more customization is desired. As the developers become increasingly confident about their production performance and their capacity to manage customization, they will be able to add further customization choices to the platform.

The developers had used platform thinking to create a house-building platform. From the beginning, the intention was to develop an entire product family from the platform, and they chose to start with the product they considered least likely to be economically successful – the *Two* – to demonstrate the platform's effectiveness. This approach echoes that adopted in the Skanska-Ikea joint venture *BoKlok*, which also released a small, two-story, apartment building as its first product, mainly as a proof of concept (Lessing and Brege, 2015). However, at the same time this house type represented a “blind spot” in the market segmentation of both companies and their competitors.

Production strategy

The developers decided early on to use an on-site construction-based production system, using local resources in the company rather than investing in any in-house, off-site manufacturing plants. Industrialization was instead achieved through the products’ high level of standardization, and through the production process with its easy-to-follow work descriptions. The biggest investments were instead made in the design of the platform and the detailed design of the first product.

Many similar industrialized production systems that have been described in the literature relied on investment in off-site facilities, where a well-planned plant layout and a high amount of automation can push unit costs down; this was the approach adopted in the development of the *BoKlok* and *Kärnhem* systems (Lessing and Brege, 2015). However, as was the case with the *NCC Komplett* system (Segerstedt and Olofsson, 2010), this approach carries the risk that underestimation of the costs of plant investment or overestimation of market demand and production volumes can kill the platform before it reaches break-even and gives the expected return on investment. Because they had not made such big investments, the developers in the studied division were able to start on a small scale and grow their market organically.

The production strategy adopted by the studied division was classified as an MTO_{PD} strategy because no prefabrication takes place before the CODP. However, on-site construction is based on a number of volumetric sub-assemblies (VSA) in the form of bathroom and staircase pods (Gibb, 2001), which are delivered intact by suppliers. The bathroom pods could have been made to forecast, but were in fact made to order due to a backlog of orders of a few weeks at the supplier. Thus, the suppliers were a bottleneck for the moment. One reason for minimizing prefabrication initially was to be less dependent on suppliers, which appears to have been wise in this case.

The product design decision process can be described using the model of Jiao et al. (2007), which is outlined in Figure 1. The market communication in the customer domain forms CAs, which represent the basis for customer demand (Bowman, 2006). This includes the available customization. In the functional domain the CAs are mapped against FRs, which must correspond to the possibilities offered by the product platform and to the product design. The components together form a BIM library, from which each new product BIM may be derived. The resulting design is then communicated to the market. In the physical domain, the components and their interfaces in the product platform are mapped to the production methods in the process platform. The work descriptions can be found here, together with production drawings, estimates, schedules, and other documents. In the logistics domain, the different suppliers and their products are mapped to the production system and the components that are used.

Collection and use of experience feedback

Informal and personal feedback channels (Holtham and Courtney 1998), and so-called traditional ways of communication (Bresnen et al., 2005), dominated the EF to the platform. This is usually appropriate for a relatively small organization (Fahey and Prusak, 1998) because on a small scale, reliance on informal channels does not hinder the wide dissemination of knowledge across the organization (Holtham and Courtney 1998).

The organization seems to have done rather well without any dedicated IT systems for EF. This could be due to the limited size of the product family and its platform, and the relatively low production volumes. However, there is still a continuous trial and error process of developing routines and structures for improvement and development. As the developer group grows and matures, and personnel come and go, a need for more systemized forms of knowledge transfer may arise. There is also a need to keep good track of the motivations that led to certain design solutions.

EF from projects fuelled continuous improvement and further development of the existing products and platform. EF from clients and other market-related channels was used for new product development. EF from consultants affected changes due to changes in building code or demands from local authorities. Such larger changes to the platform and the product family were released twice a year.

Through the PEs, information traveled in both directions, to and from the platform. The information transferred to the platform related to project support and management, and included material call-offs, schedules, delivery plans, introductions to the products and the production process, and meetings. Information transferred in the latter direction included questions, reports of problems, and other experience feedback.

In this ATO_{ED} – MTO_{PD} system, process-related EF concerned only the production phase. In a DTO system (Jansson, Lundkvist, and Olofsson, 2014), much of the EF is instead focused on the design process, during which consultant architects design new products for each new project. In such cases it is less straight-forward to get meaningful feedback from the production phase because it is less well-defined than that considered here, in which the standardization of the products enables standardized production.

The PEs actively sought feedback from both site management and workers. This commitment, together with the cooperation agreement, has fostered a culture of knowledge transfer through experience feedback, since both the developers and the local teams benefit economically from continuous improvement of the products and platform. One problem found in traditional construction projects is that experts such as site managers or experienced engineers tend to hold on to and not share their knowledge (Egbu and Robinson, 2007). This precludes knowledge transfer.

In this case study, the developers own most of the knowledge jointly. This gives them more power over the projects and makes them more independent from experienced site managers.

The case division had adopted many of the titles associated with traditional, project-based construction management, such as PE and PM, but in reality their roles were largely those of product developers. One of the PEs was not working in project management at all – his responsibility was for BIMs and derived production documents. The PMs more closely resembled Product Managers in that they were responsible for larger development projects and the development of new products. Even the local SMs in the projects have a somewhat different role to that of SMs in traditional building projects; they are not so much "kings of the site" as "fire fighter". This makes the business model disruptive.

The PE's have acted as product champions in the projects, supporting the use of the platform assets. The different PEs were experts in different products, and had only worked with experience feedback (as well as the associated improvement and development efforts) relating to "their" product. However, since projects increasingly contain multiple different products, each PE must have sufficient knowledge of all of the products to make their improvement work efficient. As the number of product variations and customer choices increases, the PEs' work will become progressively more complex and difficult.

It may therefore be better for PMs to take on product responsibilities instead of the PEs. This would allow the PEs to become functionally responsible for different platform subsystems, allowing integration of the two roles into a matrix organization. This should also increase the platform's consistency, ensuring that the best solutions are used throughout the product family and distinctiveness is kept to a minimum.

Conclusion

The goal of this case study was to determine how experience feedback is being applied for the development of products, processes, and platform under an ATO_{ED} – MTO_{PD} strategy.

The study contributes to academia in that it presents an interesting view on industrialized building. Instead of investing in costly in-house manufacturing plants, which most previous studies have identified as being typical in this style of construction management, the developers took on board their experiences with failed investments and their access to local construction teams across the country. Production efficiencies were instead achieved by careful identification and selection of their end-customers, standardization, platform thinking, continuous improvement, and on-site construction.

In the ATO_{ED} strategy, the organization has a product focus. Since these products are developed from a platform and belong to a product family, it is important that the platform (and subsequent product) development is well-founded in a thorough analysis of the market; that is to say, the developers must listen to end-customers and clients. For the sake of the platform's long-term success, it's important that the platform developers maintain EF channels that are accessible to different stake-holders including clients, engineering and architectural consultants, and potential future customers.

The results obtained in this work showed that informal and personal feedback channels (Holtham and Courtney 1998) dominated the EF to the platform, which is suitable given the developers' relatively small organization (Fahey and Prusak, 1998) and should not hinder the wide dissemination of knowledge (Holtham and Courtney, 1998) within the development team or more generally across the local organizations. Informal and personal channels are inexpensive and flexible, which makes them effective for smaller organizations and well-suited for use with a strategy based on investment in product development instead of production systems

It is important to note that this case study only describes one example of the real-world development of EF in an industrialized building organization, in the context of one set of pre-engineering and production strategies. In order to determine how different pre-engineering and production strategies in construction affect the organization of experience feedback activities in general, it will be necessary to combine these findings with the results of studies on other companies using other combinations of strategies.

Appendix 1. Main interview questions.

Platform system
How would you describe the house-building concept of your division? (boundaries, difference from rest of company)
What was the background to it, what were its parts, who participated in the development, and what type of knowledge was collected?
Tell me about the development of the platform over the years, in terms of organisation, structure, and content.
Which components are defined in the platform? How are they defined/documented?
How do you deal with the local conditions of the site in your projects?
Platform development
How has the platform evolved since its beginning?
Tell me about how you have worked with development of new products in the past and how you work with it currently?
Describe the continuing work with smaller improvements to platform parts.
Describe the work with larger development work of platform parts.
Platform utilization
How does the platform support early stages of a project using your platform?
How does the platform support tendering of subcontractors and purchasing of material?
How does the platform support project planning and work coordination on site?
How does the platform support project logistics?
How does the platform support pre-production planning?
How does the platform support the production phase?
Describe the use of work descriptions, and the role they play, in your projects?
How does the platform support project hand-over?
How does the platform support the process post hand-over?
Communication and experience feedback
Describe the different ways of communication between the platform organisation and the local organisations.
Describe the channels for experience feedback that you have toward the platform. Which are common for the entire company and which are specific to your platform? Have the channels changed over time?
What is your opinion about the experience feedback in your organisation?
Does your division have any expressed strategy for experience feedback?
Do you feel that your platform is **lacking feedback** from any particular stakeholder or other **division**?

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Appendix 1

Extended results from survey

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EXTENDED RESULTS FROM SURVEY

This appendix presents new results from the survey also used in Paper I, and brings broader picture of experience feedback practices in the Swedish construction industry.

1.1 Introduction

The construction sector has been considered to perform poorly in terms of learning and improvement, and feedback and learning loops are often broken in project-based organisations. Off-site construction has often in literature been promoted as performing better than on-site construction in terms of learning and improvement (Gann, 1996; J. Meiling, 2010b). However, there is a lack of studies actually comparing the practices of EF in on-site and off-site construction. The objective of this chapter is to compare the practices of experience feedback in *on-site and off-site* building in the Swedish construction industry.

1.2 What was done

The results presented here were derived from basically the same survey data material as Paper I, but after conducting an additional analysis. Seven additional replies to the questionnaire, not present at the time of the analysis for Paper I, were also included.

However, in this chapter comparison between the on-site and of-site companies were needed. All of the off-site companies addressed a national market. It would therefore not be suitable to include the regional and local companies, as we wanted to control the factors of company size and addressed market. Additionally, these groups also provided a small amount of replies (a total of 13), in comparison. It was therefore decided to filter out the local and regional companies in the new analysis; left in the analysis were 37 respondents – 21 on-site builders and 16 off-site builders.

1.3 Results

Use of Quality Systems

The use of quality systems could have an affect on how a company works with EF and improvement. The quality system of the respondents' companies are shown in Table 1. For the national on-site builder, we see a clear dominance for ISO 9000 certification, whereas the opposite is the case with the off-site builders. This survey did not seek to find the reasons for this difference, but it is plausible that ISO 9000 certification is a common requirement in procurements of the on-site builders' clients, whereas the off-site builders clients prioritise other factors.

Table 1. Type of quality system used in respondent's company.

	ISO 9000 certified	ISO 9000 compliant (not certified)	Proprietary quality system (non-ISO 9000 compliant)	Have no quality system	Don't know	Response rate
On-site builders	85.71% (18)	9.52% (2)	4.76% (1)	0%	0%	100% (21)
Off-site builders	25.00% (4)	6.25% (1)	62.50% (10)	0%	6.25% (1)	100% (16)

Improvement programs or -projects

Both on-site (90.5%) and off-site (93.8%) builders have improvement programs or projects. Free-text answers revealed that for the off-site builders these improvement programs/projects concerned lean production, value stream, continuous improvement, EF, standardisation, building information management, and prefabrication. For the on-site builders, the programs/projects concerned standardisation, technical platforms, EF, project planning routines, prefabrication and supply chain.

Both groups find their company’s own employees and clients to be most valuable sources of new experience and knowledge. In the on-site group, these are then followed by sub-contractors and after-market (end-customer complaints/issues). For the off-site builders, the third and fourth most important sources were after-market and inspections. Other sources that individual respondents emphasized were: internal experts, monitoring of the industry and other industries, and cooperation with universities. A minority in both groups (37.5%-40%) responded that their company used an IT system for the management of end-customer complaints.

Storing of new knowledge and experience

Table 2 presents to what extent the respondents believed new knowledge and experience from projects was stored in different containers within the company.

The on-site builders seemed to rely more on individual workers, closing meetings, experience feedback meetings, and binders, than the off-site builders did. The off-site builders were showed more variation, and thus it was difficult to draw any clear conclusions about the different containers. For instance – just as many of them reported that they didn’t use a central database at all, as those who reported that they did so to great extent. Another example is the use of minutes from different meetings, where some reported use to little extent, and some to great extent.

Appendix 1

Table 2. To what extent is new knowledge and experience from your company's production stored in the following places?

	Not at all	To little extent	To some extent	To great extent	Don't know	Response rate
Personal experience within workers						
On-site builder	0.00%	14.29%	23.81%	61.90%	0.00%	100.0%
Off-site builder	0.00%	0.00%	56.25%	43.75%	0.00%	100.0%
Minutes from project-closing meetings						
On-site builder	0.00%	0.00%	66.67%	33.33%	0.00%	100.0%
Off-site builder	6.25%	31.25%	37.50%	18.75%	6.25%	100.0%
Minutes from experience feedback meetings						
On-site builder	4.76%	9.52%	66.67%	19.05%	0.00%	100.0%
Off-site builder	0.00%	43.75%	37.50%	18.75%	0.00%	100.0%
In a company-central database						
On-site builder	0.00%	47.62%	47.62%	0.00%	4.76%	100.0%
Off-site builder	25.00%	37.50%	12.50%	25.00%	0.00%	100.0%
In an network-attached computer, e.g. at the local office						
On-site builder	23.81%	38.10%	9.52%	19.05%	9.52%	100.0%
Off-site builder	25.00%	18.75%	31.25%	18.75%	6.25%	100.0%
In archives/binders						
On-site builder	4.76%	14.29%	66.67%	14.29%	0.00%	100.0%
Off-site builder	6.25%	31.25%	50.00%	6.25%	6.25%	100.0%
In other places						
On-site builder	0.00%	4.76%	4.76%	0.00%	28,57%	38.10%
Off-site builder*	0.00%	6.25%	6.25%	0.00%	25.00%	37.50%

*One respondent here added a free-text commentary that “knowledge that is implemented in our building system is documented on our type drawings”.

Sources of new knowledge and experience from projects

Table 7 presents to what extent the respondents acquire new knowledge and experience from different sources.

The on-site builders reported greater use than what the off-site builders did of personal channels such as colleagues, sub-contractors, consultants, and clients, but also of the use of project-dedicated servers, which therefore seem to be the most important IT-based EF channel for on-site building projects.

The off-site builders used to look in binders/archives to greater extent, but just as with Table 6 they showed greater variation than the on-site builders in the use of several sources, such as compilations of experience from previous projects.

Table 3. To what extent do you acquire experiences from other projects in the company from the following places?

	Not at all	To little extent	To some extent	To large extent	Don't know	Response rate
From colleagues during meetings and coffee breaks						
On-site builder	0,0%	0,0%	28,6%	71,4%	0,0%	100,0%
Off-site builder	0,0%	12,5%	62,5%	25,0%	0,0%	100,0%
From compilations of experiences at the end of completed projects						
On-site builder	0,0%	19,0%	66,7%	9,5%	0,0%	95,2%
Off-site builder	6,3%	18,8%	43,8%	31,3%	0,0%	100,0%
From searching trough a project-dedicated server						
On-site builder	4,8%	28,6%	38,1%	23,8%	0,0%	95,2%
Off-site builder	37,5%	25,0%	31,3%	6,3%	0,0%	100,0%
From searching trough archives/binders						
On-site builder	28,6%	42,9%	28,6%	0,0%	0,0%	100,0%
Off-site builder	12,5%	18,8%	43,8%	12,5%	0,0%	87,5%
From subcontractors						
On-site builder	4,8%	23,8%	66,7%	4,8%	0,0%	100,0%
Off-site builder	6,3%	62,5%	25,0%	0,0%	6,3%	100,0%
From engineering consultants						
On-site builder	4,8%	19,0%	66,7%	9,5%	0,0%	100,0%
Off-site builder	31,3%	43,8%	18,8%	0,0%	6,3%	100,0%
From clients						
On-site builder	0,0%	33,3%	52,4%	14,3%	0,0%	100,0%
Off-site builder	18,8%	25,0%	31,3%	18,8%	6,3%	100,0%
*From other places**						
On-site builder	0,0%	4,8%	9,5%	0,0%	14,3%	28,6%
Off-site builder	12,5%	0,0%	6,3%	0,0%	25,0%	43,8%

* One off-site builder provided a free-text answer: "Site visits to where solutions from previous development projects have been used"

Appendix 1

Systems for experience feedback

Table 8 shows the respondents' level of agreement to claims regarding how their company works systematically with EF.

The off-site builders were a bit more confident about their company's system for storing EF than the on-site builders were. They were also more confident about errors not reappearing than the on-site respondents did, as they worked more actively with following up reported errors, compared to the on-site builders. The on-site builders, on the other hand, saw greater potential for improvement of their experience feedback process.

Table 4. Respondents' level of agreement to claims on systematic EF.

	Absolutely do not agree	Do not agree	Agree	Absolutely agree	Don't know	Response rate
It's easy to aquire experiences within the company.						
On-site builder	0,00%	23,81%	61,90%	14,29%	0,00%	100,0%
Off-site builder	0,00%	37,50%	43,75%	18,75%	0,00%	100,0%
The company has a functioning system for regerinsting/save experiences.						
On-site builder	0,00%	66,67%	28,57%	0,00%	4,76%	100,0%
Off-site builder	6,25%	50,00%	31,25%	12,50%	0,00%	100,0%
The company is actively working with the following-up of reported errors and nonconformities.						
On-site builder	0,00%	42,86%	52,38%	4,76%	0,00%	100,0%
Off-site builder	0,00%	31,25%	31,25%	37,50%	0,00%	100,0%
The company wants to improve it's process for experience feedback.						
On-site builder	0,00%	0,00%	57,14%	42,86%	0,00%	100,0%
Off-site builder	0,00%	0,00%	50,00%	50,00%	0,00%	100,0%
I see a clear potential for improvement regarding the handling of experiences within the company.						
On-site builder	0,00%	4,76%	23,81%	71,43%	0,00%	100,0%
Off-site builder	0,00%	6,25%	37,50%	56,25%	0,00%	100,0%
I feel comfortable that errors and nonconformities are not repeted in future projects.						
On-site builder	0,00%	66,67%	28,57%	4,76%	0,00%	100,0%
Off-site builder	6,25%	37,50%	56,25%	0,00%	0,00%	100,0%
The company is continuously doing improvement work.						
On-site builder	0,00%	0,00%	71,43%	28,57%	0,00%	100,0%
Off-site builder	0,00%	12,50%	50,00%	37,50%	0,00%	100,0%

The use of inspection data

The results in this section add, with the comparison between on-site and off-site builders, a new dimension to Paper I. Table 9 show respondents' level of agreement to claims regarding inspection data for them and their company.

Table 5. Respondents' level of agreement to claims on inspection data.

	Absolutely do not agree	Do not agree	Agree	Absolutely agree	Don't know	Response rate
The company has a system for compiling inspection defects between projects.						
On-site builder	0,00%	57,14%	19,05%	9,52%	9,52%	95,24%
Off-site builder	6,25%	43,75%	37,50%	6,25%	6,25%	100.00%
The company is actively working to follow up root causes to registered inspection defects.						
On-site builder	0,00%	47,62%	28,57%	9,52%	9,52%	95,24%
Off-site builder	0,00%	37,50%	43,75%	18,75%	0,00%	100.00%
The company regards registered inspection defects as valuable information.						
On-site builder	0,00%	42,86%	42,86%	9,52%	0,00%	95,24%
Off-site builder	0,00%	6,25%	43,75%	43,75%	6,25%	100.00%
The company is systematically using inspection defects in its improvement work.						
On-site builder	0,00%	66,67%	9,52%	9,52%	9,52%	95,24%
Off-site builder	0,00%	31,25%	50,00%	18,75%	0,00%	100.00%
The company compiles statistics on errors and defects between projects, in order to identify important areas for improvement.						
On-site builder	4,76%	57,14%	19,05%	4,76%	9,52%	95,24%
Off-site builder	12,50%	25,00%	43,75%	12,50%	6,25%	100.00%
The company is in need of an IT system, in order to support better handling of information from inspections.						
On-site builder	0,00%	19,05%	47,62%	23,81%	4,76%	95,24%
Off-site builder	0,00%	25,00%	37,50%	18,75%	18,75%	100.00%
I regard inspection defect remarks as valuable information.						
On-site builder	0,00%	14,29%	52,38%	28,57%	0,00%	95,24%
Off-site builder	0,00%	0,00%	37,50%	62,50%	0,00%	100.00%
I believe that the use of inspection defect data in my company could be further developed.						
On-site builder	0,00%	9,52%	57,14%	28,57%	0,00%	95,24%
Off-site builder	0,00%	0,00%	37,50%	62,50%	0,00%	100.00%
My company has stated a goal to decrease the number of inspection defect remarks.						
On-site builder	0,00%	19,05%	28,57%	42,86%	4,76%	95,24%
Off-site builder	0,00%	6,25%	18,75%	75,00%	0,00%	100.00%

The off-site builders had introduced systems for compiling and using *inspection data* in-between projects to greater extent than the on-site builders, and their company also regarded inspection remarks as more valuable information than the on-site builders.

However, voluntary free-text commentaries suggested that often the inspection reports were stored as scanned PDF documents on project-dedicated servers (project management systems), or paper-based archives. One on-site builder implied that it was difficult to measure quality by inspections, as inspectors were subjective and that no inspection report therefore was entirely comparable to one conducted by another inspector. He mentioned that their effort to analyse inspection remarks had not improved anything, only increased their administrative burden.

One free-text commentary from an off-site builder reported that one problem with inspection data is the amount of noise in the data, due to the sheer amount of it, and that mining this data for knowledge was an entirely manual process.

Despite this, the off-site builders analysed the reports, to identify reoccurring defects. They also tried to connect these to the cost of rework after the final inspection and during the following two-year warranty period, as the managers wanted to decrease these costs. The outcome of this tracking of cost-related problems could then result in relevant parts of the building system being re-engineered.

Improvement suggestion systems

Table 10 show the respondents’ level of agreement to claims regarding suggestion systems.

The use of *improvement suggestion systems* was strikingly similar between the two groups, although the off-site respondents were in general more positive to improvement suggestions than the on-site respondents.

Table 6. Respondents' level of agreement to claims regarding suggestion systems.

	Absolutely do not agree	Do not agree	Agree	Absolutely agree	Don't know	Response rate
The company has a functioning system to handle improvement suggestions.						
On-site builder	0,00%	33,33%	52,38%	9,52%	0,00%	95,24%
Off-site builder	6,25%	31,25%	50,00%	6,25%	0,00%	93,75%
The company values improvement suggestions from the employees.						
On-site builder	0,00%	0,00%	66,67%	28,57%	0,00%	95,24%
Off-site builder	0,00%	6,25%	62,50%	25,00%	0,00%	93,75%
The company is continuously implementing good improvement suggestions.						
On-site builder	0,00%	9,52%	66,67%	14,29%	4,76%	95,24%
Off-site builder	0,00%	25,00%	56,25%	12,50%	0,00%	93,75%
The employees think it is meaningful to hand in improvement suggestions.						
On-site builder	0,00%	28,57%	57,14%	4,76%	4,76%	95,24%
Off-site builder	0,00%	37,50%	43,75%	0,00%	12,50%	93,75%
The employees feel that they get sufficient feedback on their improvement suggestions						
On-site builder	0,00%	38,10%	28,57%	4,76%	23,81%	95,24%
Off-site builder	6,25%	37,50%	43,75%	0,00%	6,25%	93,75%
The employees believe that the company is handling their improvement suggestions without unnecessary holdback						
On-site builder	0,00%	28,57%	42,86%	9,52%	14,29%	95,24%
Off-site builder	6,25%	50,00%	25,00%	0,00%	12,50%	93,75%
The improvement suggestions that are handed in are generally relevant.						
On-site builder	0,00%	9,52%	57,14%	19,05%	9,52%	95,24%
Off-site builder	0,00%	6,25%	75,00%	6,25%	6,25%	93,75%
I see a value in getting improvement suggestions from other co-workers						
On-site builder	0,00%	0,00%	42,86%	52,38%	0,00%	95,24%
Off-site builder	0,00%	0,00%	12,50%	75,00%	0,00%	87,50%
I believe that the company should be able to receive more relevant improvement suggestions than they are today.						
On-site builder	0,00%	0,00%	38,10%	52,38%	4,76%	95,24%
Off-site builder	0,00%	6,25%	43,75%	43,75%	0,00%	93,75%
I believe that improvement suggestions can be further encouraged.						
On-site builder	0,00%	0,00%	38,10%	47,62%	0,00%	85,71%
Off-site builder	0,00%	12,50%	50,00%	31,25%	0,00%	93,75%

The on-site respondents believed that their workers thought it was meaningful to hand in suggestions to greater extent than the off-site respondents did. However, due to the speculative nature of these questions, these results should be taken with a fair pinch of salt.

Table 11 presents how the respondents' companies gather improvement suggestions from employees. In the off-site companies, they did not promote suggestions for improvements with any extra incentives, whereas this was quite common in the on-site companies. Some of the off-site respondents provided free-text commentary; saying that they didn't need (or want) to provide any extra incentives to their employees, as the amount of suggestions they already got gave them plentiful of development work already. Such incentives would therefore not result in more improvements implemented.

Table 7. How improvement suggestions are gathered.

	Not at all	To little extent	To some extent	To large extent	Don't know	Response rate
They can be handed in through some kind of suggestion box.						
On-site builder	14,29%	19,05%	19,05%	23,81%	14,29%	90,48%
Off-site builder	25,00%	18,75%	12,50%	31,25%	12,50%	100,00%
They can be handed in anonymously.						
On-site builder	14,29%	9,52%	38,10%	14,29%	14,29%	90,48%
Off-site builder	37,50%	31,25%	18,75%	12,50%	0,00%	100,00%
They can be handed in to ones closest manager.						
On-site builder	0,00%	0,00%	33,33%	52,38%	4,76%	90,48%
Off-site builder	6,25%	12,50%	37,50%	43,75%	0,00%	100,00%
They are encouraged by some kind of incentive.						
On-site builder	4,76%	28,57%	33,33%	19,05%	4,76%	90,48%
Off-site builder	68,75%	12,50%	12,50%	0,00%	0,00%	93,75%

Experience feedback meetings

Table 12 show the respondents' level of agreement to claims regarding experience feedback and project-closing meetings. The on-site companies seemed to have EF meetings to larger extent than what the off-site companies did, although the off-site respondent group were actually a bit more positive to these meetings as a good way to collect experiences from projects.

A few of the respondents from both groups also provided free-text commentaries. The on-site respondents reported that problems with their current practice was that there was no central receiver of the experience data, and that many important project participants have left the project before the meetings are conducted. One respondent mentioned that it's important to hold separate EF and project-closing meetings, in order to focus fully on EF on that meeting.

Table 8. The respondents' level of agreement to claims regarding on experience feedback meetings.

	Absolutely do not agree	**Do not agree**	**Agree**	**Absolutely agree**	**Don't know**	**Response rate**
The company does conduct experience feedback meetings at the end of its building projects.						
On-site builder	0,00%	14,29%	47,62%	33,33%	0,00%	95,24%
Off-site builder	12,50%	25,00%	43,75%	18,75%	0,00%	100,00%
The experience feedback meetings of the company follow a standardised agenda.						
On-site builder	0,00%	14,29%	57,14%	23,81%	0,00%	95,24%
Off-site builder	6,25%	37,50%	25,00%	18,75%	0,00%	87,50%
I believe that post-project experience feedback meetings are a good way to collect experiences.						
On-site builder	0,00%	0,00%	38,10%	57,14%	0,00%	95,24%
Off-site builder	0,00%	0,00%	25,00%	62,50%	0,00%	87,50%
I see a significant potential for improvement regarding experience feedback meetings.						
On-site builder	0,00%	0,00%	33,33%	57,14%	4,76%	95,24%
Off-site builder	0,00%	6,25%	25,00%	62,50%	0,00%	93,75%
The company utilises the project-closing meeting for experience feedback in some way.						
On-site builder	0,00%	19,05%	57,14%	19,05%	0,00%	95,24%
Off-site builder	0,00%	25,00%	37,50%	18,75%	6,25%	87,50%
The company utilises the project-closing meeting to find improvement possibilities.						
On-site builder	0,00%	19,05%	52,38%	23,81%	0,00%	95,24%
Off-site builder	0,00%	25,00%	31,25%	25,00%	6,25%	87,50%

One off-site respondent reported that dedicated EF meetings are only held in projects with a lot of problems, and that successful projects instead generate photos that are posted in the lunch room at the office. Another reported that they have reoccurring EF meetings every 6th week, and that they use these to go through the improvement suggestions that every station along the production line have handed in since last meeting. A third noted that EF meetings are a good way to collect EF, but that it is not sufficient, if they are only held at the end of the projects, due to the long lead times.

1.4 Conclusions

In this extended analysis the survey data used in *Paper I* was re-examined. This time the full spectrum of EF methods and/or channels was considered, and the two groups – on-site and off-site builders – were compared. The analysis showed that there were both similarities and differences between the groups.

Off-site builders preferred to develop proprietary Quality systems, whereas on-site builders were ISO 9000 certified. Although EF is important for continuous improvement in the ISO 9000 system, the off-site builders seem to do a better job with EF and CI without the standard. If their clients look for other factors than ISO certification as a quality measure, a proprietary system should be more effective, as it could be “tailor-made” for the production system and its needs.

Both off-site and on-site builders used increased standardisation as a tool for improvement, but with different focus and by different means. Off-site builders had implemented lean production to improve their line-based production in factories, much similar to other manufacturing and assembly companies in other industries. The on-site builders instead developed product concepts, and turned toward technical platforms and increased use of prefabrication.

On-site builders preferred traditional channels for storing and acquiring new knowledge and experience, such as formal meetings, and informal, personal communication. Off-site builders instead preferred the use of *project binders* and *post-project compilations*.

The off-site builders had systems for storing experiences, and were also more dedicated to the following up of reported errors, than the on-site builders. They had also introduced systems for compiling and using inspection data in-between projects to greater extent than the on-site builders. Therefore, they also were more comfortable that errors would not reappear, than the on-site respondents did.

Limitations

Due to the limited number of respondents in the survey, statistical analysis could not be conducted.

Contributions

This is the first study to compare the different practices of EF in on-site and off-site construction.