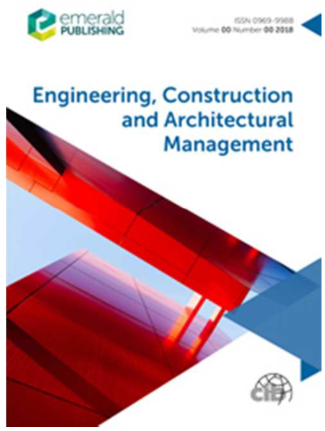

Construction projects as mechanisms for knowledge integration: mechanisms and effects when diffusing a systemic innovation

Journal:	*Engineering, Construction and Architectural Management*
Manuscript ID	ECAM-02-2017-0022.R2
Manuscript Type:	Original Article
Keywords:	Innovation, Knowledge Management, Case Study
Abstract:	

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Abstract

Purpose - The aim of this research is to study knowledge integration (KI) when diffusing a systemic innovation. The objectives are to understand what mechanisms are used, and when and what their effects are in terms of knowledge development.

Design/Methodology/Approach - The method comprised a longitudinal case study which followed a firm's attempts to develop and diffuse a timber multi-storey building system (the systemic innovation) over a number of projects.

Findings - The findings emphasize actual projects as the most crucial activity for KI and when and why soft personalization mechanisms and codified knowledge should be mixed. Furthermore, it shows how different types of knowledge is built up including construction process effects over a series of projects.

Research limitations/implications - The research contributes with knowledge about mechanisms for the diffusion of a specific systemic innovation type and provides input regarding mechanisms to use. The introduction of the concepts 'domain-specific', 'procedural' and 'general knowledge' into construction has increased understanding of innovation diffusion and knowledge flows and where and how they are integrated.

Practical Implications – The research shows how knowledge develops and through which mechanisms, and where problems occur. Construction organisations can learn from this to avoid mistakes and potentially better understand how to manage knowledge to diffuse a systemic innovation.

Originality/value - The research provides insight into systemic innovation diffusion over a series of projects and focuses on both projects and the construction process.

Keywords Innovation Diffusion, Systemic Innovation, Knowledge Integration, Mechanisms

Paper type Research paper

Systemic Innovation Diffusion and Knowledge Integration

Debate has been ongoing for several years about the need of a changed approach in the construction industry. Its short term view (for example Barlow, 2000) and stressful work environment (Cattell et al., 2016) are common motives stressing this need. Studies on innovation[1] in construction (Gadde and Dubois, 2010, Bygballe and Ingemansson, 2011, Håkansson and Ingemansson, 2012) using the ARA-model (Hakansson and Johanson,

[1] "an idea, practice or object that is perceived as new by an individual or other unit of adoption" ROGERS, E. M. 2003. *Diffusion of innovations (fifth edition)*, New York: Free Press.

1992), in which interaction between actors, resources and activities are focused, all highlight the negative influence of a short-term view and challenges with the project based setting of construction. Interaction is essential for innovation to occur and Gadde and Dubois (2010) have emphasised the usefulness of long-term relationships and mutual adaptations over time, but they have also stressed the challenge in construction. Bygballe and Ingemansson (2011) and Håkansson and Ingemansson (2012) also identified low interaction upstream in the construction process as significant, with a negative impact on innovation. Bygballe and Ingemansson (2011) focused on price as a barrier for increased interaction and innovation. They also claimed that innovation processes in construction are not fully understood and that more research is needed. However, Håkansson and Ingemansson (2012) conclude that significant levels of renewal and change has taken place downstream the construction process. Upstream interaction needs to be developed because subcontractors usually comprise about 60-70 % of construction companies' total volume, displaying significant potential for learning opportunities and innovation.

Despite a more integrated construction process bringing advantages, the project based work method and temporary nature of the construction context is highly influential for increased integration (Cheng et al, 2010, Eriksson, 2015). Since "*New ideas can either be adopted by firms and implemented on projects, or result from problem-solving on projects, and be learned by firms"* (Winch, 1998, p 273) diffusion over several projects are necessary (c.f. Senaratne and Sexton, 2008). Central to the innovation process is knowledge creation and exchange (OECD, 2005) and the ineffective flow of knowledge constitutes a barrier for innovation (Rundquist et al., 2013). Similarly, difficulties with systematic repetition (Gann and Salter, 2000) and accumulation of knowledge (Miozzo and Dewick, 2002) exist because of the project based nature of the work. Nevertheless, high innovators in construction ensure that what is learned from projects is transferred into continuous business processes (Manley et al., 2009).

Creating efficient knowledge flows become an even greater challenge for systemic innovation diffusion in construction. Different professions and trades are affected to varying degrees by systemic innovations. This variety implies simultaneous handling of different knowledge types and skills in projects. Previous (or current) knowledge can also be a barrier for the application of new knowledge in a new product (Henderson and Clark, 1990). Other influential factors are changes in population between projects (organizational variety), the amount of boundaries an innovation spans (and changes see Scarbrough et al, 2004) and the scope and complexity of the innovation (Taylor and Levitt, 2005). Furthermore, actors unaware of changes required to implement innovations in links to other components, processes, or systems or in the product itself, most likely meet resistance when diffusing their products (Slaughter, 2000) and systemic understanding instead fosters successful innovation diffusion (Widén and Hansson, 2007).

This research addresses knowledge flows through the concept of knowledge integration (KI), i.e. combining new and previous knowledge (Rundquist, 2009, Rundquist, 2012). The focus is on how KI takes place, i.e. the mechanisms that are used. Mechanisms have been researched from a strategic perspective (Kale and Karaman, 2011), with a focus on mechanisms *to use* (Kale and Karaman, 2011, Robinson et al., 2005, Robinson et al., 2004) or used mechanisms (see for example Styhre and Glich, 2010) Previous studies have focused on models to use in general (for example Kanapeckiene et al, 2010, Forcada et al, 2013), or a specific focus, for example Yang et al. (2012) on capital facility managers and Bresnen et al. (2005) on a change event. Previous studies also collected empirical material from certain actors, for example managers (Robinson et al, 2006), highly educated people (Bakar et al, 2016), consulting engineers (Bröchner et al, 2004, Carrillo et al., 2006) or site personnel (Rooke and Clark, 2005). These studies do not focus on the construction process and the uniqueness of project based work *per se*.

The aim of the research is to study how KI takes place during the diffusion of a systemic innovation. It builds on a longitudinal case study following a firm's efforts to develop and diffuse a systemic innovation (a timber multi-storey housing system, hereafter denoted TMHS). The efforts are studied over a number of individual projects, enabling the identification of effects and consequences over several projects, different actors and professions/trades. The objectives are to understand what mechanisms are used, when, and what their effects in general and in terms of knowledge development. The research contributes with knowledge about what mechanisms *are used* for a specific innovation type and provides valuable input regarding what mechanisms *to use*.

Theoretical frame of reference for the study

Systemic innovation diffusion and Knowledge integration

Construction management (CM) research on innovation diffusion, communication of a new idea through certain channels in a social system (Rogers, 2003), has addressed different types of innovations, for example radical, incremental, modular, system or architectural innovations (Slaughter, 1998, often referred to in CM research, see for example (Lloyd-walker et al., 2014, Gambatese and Hallowell, 2011, Murphy et al., 2015). This research focuses on the development and diffusion of a timber multi-storey building system, considered to be a systemic innovation. Systemic innovations are holistic and relational (Colvin et al., 2014), may require change of processes in a coordinated fashion by multiple firms (Taylor & Levitt, 2005, 2007) and affect multiple relationships (Powell, 1998). Lindgren and Emmitt (2017) and Taylor (2006) reviewed the concept of systemic innovation and highlighted the inter-organizational effects/consequences from innovations with possible effects on the whole construction process (actors and resources included). This focus is continued in this research. The innovation types described above (incremental, modular, etc.) are not considered because the primary aim of the research is to understand inter-organizational impact, KI mechanisms and knowledge development.

Rundquist (2009) review of KI and similar concepts (knowledge transfer, knowledge sharing and knowledge application) concluded that KI covers the other concepts, hence the use of this concept for this research. KI contains processes of external knowledge identification, acquisition and internal utilisation of external knowledge (see also Kraaijenbrink, Wijnhoven and Groen, 2007). *Identification* can be done intentionally or unintentionally. *Acquisition* and *utilization* can take place through a variety of mechanisms (Kraaijenbrink et al., 2007). Knowledge processes interact and influence each other in practice (Kraaijenbrink, 2012) and this research stresses this interacting view. Furthermore, from an innovation perspective, the process of creating knowledge is an important part in KI (Berggren et al., 2011) and to make use of knowledge by combining new knowledge with the existing knowledge base is essential (Rundquist, 2009, Tell, 2011, Berggren et al., 2011). This is enabled by common knowledge (Grant, 1996), which permits people to integrate aspects of knowledge that are not common between them. This can be divided into subgroups:

- *Commonality of specialized knowledge* regards how common specialized knowledge is.
- *Language* is one of the most fundamental subgroups since many integration mechanisms are based on verbal communication.
- *Other forms of symbolic communication* relate to things that connect people to each other, for example computer software.
- *Shared meaning*, relates to knowledge that is tacit.
- *Recognition of individual knowledge domains,* regards the importance of knowing what other people know, enabling necessary adjustments between people.

Knowledge integration mechanisms

Research on KI mechanisms in CM often revolves around codification and formalization on one side and communicative and personal mechanisms on the other. Carrillo et al. (2006) for example, divides mechanisms into tools (using IT to share explicit knowledge) and techniques (using a human-centered approach to transfer tacit knowledge). Codification relates to low interaction and thereby efficiency, but previous research has viewed construction as quite hesitant to codify and formalize operative knowledge (Styhre, 2008, Bresnen et al., 2005, Scarbrough et al., 2004). The construction sector is characterised by much knowledge being personal or community-based. "Personalisation strategies", i.e. human centered and interactive approaches, dependent on social ties may therefore be more suitable for knowledge transfer than codification strategies (Bresnen et al., 2005).

Although formalization and codification of operative knowledge is of small concern (Styhre and Gluch, 2010) construction companies have shown interest in identifying and developing mechanisms to capture and reuse knowledge, and this is also of growing interest in construction research (Kivrak et al., 2008, Styhre and Gluch, 2010). According to Prencipe and Tell (2001) codified knowledge facilitates transfer of knowledge. Codification could be used more extensively to spread knowledge in construction organizations in balance with soft personalization strategies (Senaratne and Sexton, 2008). This is stressed by research findings from Bröchner et al. (2004): efficient knowledge transfer mechanisms in construction consist of combinations of rich (e.g. video conferences) and lean media (e.g. fax messages). However, research by Styhre and Gluch (2010) on use of platforms, standardized packages of prescribed components, routines and components contradicts the general picture and found platforms potentially useful for sharing and accumulation of (codified) knowledge. In specific, post-project reviews and discussion forums are the most popular knowledge transfer mechanisms (Carrillo et al., 2006): Together with face-to-face meetings they have been found as the most informative and useful (Carrillo et al., 2013). However, due to time constraints post-project reviews are done on demand from management (Carrillo, Ruikar and Fuller, 2013). Carrillo et al. (2011) also state that post-project review results are seldom distributed, resulting in lost knowledge exploitation.

Overall, mechanisms vary with regard to social interaction (Van De Ven et al., 1976, Grant, 1996). Several factors influence the interaction level. Johnson (1992) for example stress that more advanced innovations, scientifically or technically, require more complicated communication processes. The level of insecurity, i.e. difficulty and variability in conducted work is also influential (Van De Ven et al., 1976): a high level of insecurity complicates coordination through programming (impersonal methods such as plans, schedules and formalized rules) making feedback, i.e. direct adjustments through communication in groups, or between groups or individuals preferable.

Grant (1996) ranks mechanisms for integration of specialized knowledge into four types. *Rules and directives* contain impersonal methods such as plans, schedules, forecasts, rules, policies and communication systems (Van De Ven et al, 1976). A set-up of rules and routines can be an alternative mechanism. *Sequencing* is about organizing production activities in sequence so that every specialist has time to do what he or she should. *Routines* are performed automatically and are conducted simultaneously when a person is well acquainted with them and sees them as natural activities without giving them much thought. These first three mechanisms are efficient from the point of view that they minimize costs for learning and communication. The need for the fourth mechanism, *Group problem solving and decision making,* increases with growing complexity and insecurity communication, interaction and adaptation is enabled. The four mechanisms complement each other and are used as a point of departure in this research since they build on the interaction level and thereby resource consumption.

Knowledge types

Construction projects require different knowledge types to a varying extent. In previous CM research, tacit and explicit knowledge are commonly used knowledge types (Abu Bakar et al., 2016, Senaratne and Sexton, 2008, Carrillo et al., 2006). Explicit knowledge can be codified and tacit cannot (see for example Grant, 1996, Mezher et al, 2005). Styhre (2008) makes a similar division and discusses personal knowledge of individuals in relation to an organization's formalized knowledge in procedures and systems. Their research uses knowledge types found useful in new product development (NPD) and innovation studies outside construction; domain-specific, procedural and general knowledge (see for example (Frishammar et al., 2012, Rundquist, 2012, Court, 1997, Ramesh and Tiwana, 1999, Ullman, 2010). According to Rundquist (2008) these types are possible to understand and relate to for people in practice, and are thereby also relevant for academia. By using these knowledge types we aim to better understand how knowledge develops during innovation diffusion.

Domain-specific knowledge relates to knowledge as "the form or function of an individual object or class of objects" (Ullman, 2010, pp 50) including knowledge acquired as a result from previous or ongoing development projects (Court, 1997, Ramesh and Tiwana, 1999), developed as a consequence of either intended or accidental results. Procedural knowledge refers to "the knowledge of what to do next" (Ullman, 2010, pp 50) and develops as it moves from an *ad hoc* learning process to a systematic process, using insights from past experience. General knowledge includes external conditions that influence product development (e.g., legal issues, social issues, or customer and supplier issues) (Andrews and Smith, 1996). In some circumstances this can be specialized expert knowledge, when it regards knowledge in fields that seem peripheral to current NPD projects. Previous studies have shown that these categories influence each other. Frishammar et al. (2012) found that integration of domain specific knowledge and general knowledge helps in matching technologies with new applications and markets, providing additional benefits from investments in innovation and technology. In the context of new product development, procedural knowledge is important to improve various stages, decisions and activities in a process, that can be an innovation process (Bartezzaghi et al., 1997), although Rundquist (2012) concludes that it has no significant effect on innovation performance. Since it has not previously been used in CM research, the interplay can be useful to increase understanding for knowledge flows in the construction context.

Method

This study is a part of a larger research project addressing KI in temporary projects and building component manufacturer's innovativeness. A systemic innovation developed by a case-study organization (CSO) was studied, including a series of projects and development work that took place between the projects. The CSO was participating in the larger research project. They were chosen for this study due to their work with the innovation being researched. The systemic innovation, a multi-storey building system, was considered a systemic innovation due to its inter- and intra-organisational effects in the construction process. A longitudinal case study using multiple data-collection (in line with Meredith, 1998) was used and reveals how different approaches to development and KI has been managed in the attempts to diffuse the systemic innovation. The researched KI process stretches from the early development phase that led to the system and includes a number of projects until the end of the research period; a period of twelve years. The KI mechanisms used, the role of common knowledge and effects were studied. Knowledge development was studied through the three knowledge types (domain-specific, procedural and general).

A two phase research strategy

Phase one - mapping the process

The first phase of data collection was done in parallel to a more overarching study on factors influencing the diffusion of systemic innovations (Lindgren and Emmitt, 2017). That study contributed with an overall understanding of the factors influencing the diffusion of the systemic innovation (the usefulness of broad approaches for systemic innovation studies is addressed in Lindgren, 2016) and contextual understanding for the research. The importance of contextual understanding has been emphasized in previous research on innovation in construction (Green et al., 2010, Larsen and Ballal, 2005, Widén, 2006). The first task was to map the process within the CSO and its projects, including the development steps for the TMHS. This provided insights into:

- *what* (knowledge types) and *how* (mechanisms) knowledge is developed and integrated

- effects and current development areas

- understanding of the whole process, the involved people and activities that take place

- understanding of the complexity of the system.

Data were collected through interviews with people working in the process, supported by a review of relevant documents, including meeting notes, construction schedules and technical drawings. The factory producing the prefabricated elements was also visited. In addition to the *what* and *how* questions regarding knowledge the interviews also addressed the interviewees' function and responsibilities, interaction patterns, current performance in the process, development areas, changes from a historical perspective and barriers and success factors. Interviews were semi-structured providing flexibility and structure for meaningful interviews (Merriam, 1994, Andersen, 1994) and enabling points of interest to emerge and be discussed. The initial round of interviews was set up in collaboration with the main contact person at the CSO, who also selected suitable interviewees, active in different parts of the construction process thereby helping to ensure a representative view. Nine interviews were conducted with individuals lasting between 40 and 65 minutes.

An ongoing project was monitored and observed for 16.5 months providing data that may be neglected in a historical review, and reducing the risk of retrospective explanations (c.f. Voss, Tsikriktsis and Frohlich, 2002). Observation was considered useful to grasp tacit knowledge (which can be difficult to capture, see Kivrak et al, 2008). On-site observations were conducted by one of the authors during six one-day visits, supported with extensive photographing, note taking and audio-recording. The visits were conducted according to the timeline in Figure 1.

Figure 1. Timeline for on-site observations (placed here)

The choice of making observations at different stages of progression provided the possibility to study the knowledge integration process over time, including the potential to identify the mechanisms used and effects. The majority of the visits took place in the first part of the monitoring period, where the highest amount of "new" activities took place. The latter parts of the monitoring were more related to repeating the activities conducted. Hence, the need for knowledge integration seemed greatest in the first part of the monitoring. The final visit at the end of the period allowed for an overview and follow-up of the project. During the first visits general questions were asked to better understand the process. Over time more precise questions were raised regarding KI and related mechanisms, providing 39 unstructured interviews in total with project and site personnel. The interviewees represented different roles on site, providing an overall view of the progress of the monitored project. Project documents (drawings, time-schedules, meeting notes etc.) were also reviewed to enhance understanding for the project and provide input for additional interview questions.

Validation of data comprised presenting the findings to key actors at three points in time:

1. After four months with the project manager responsible for the manufacturing of the timber structure, the prefabrication factory production manager and the contact person for the research project. Data was presented and discussed individually.
2. After five months, a draft of the research results was presented and discussed with senior research colleagues participating in the project. The academic critique helped to further focus the research.
3. After six months with two central people in the case study organization (CSO)'s work group for the TMHS. Experiences and other data from the erection of the first building in the monitored project were reviewed and discussed.

Validation activities, including those mentioned in phase 2, have provided additional confidence in the research results and confirmed the findings being in line with interviewed actors' experiences.

Phase two – validation and additional questions

Validation of results from the overarching study and this study was made in the end phase of the monitored project. Additional questions regarding reported research and performance of the monitored project were raised. At these occasions the project manager, the assistant site manager, the head designer, the development manager for housing and a project manager who had managed other multi-storey projects participated. The validation sessions were done individually except with the head designer and the development manager for housing, who participated in the same session. Each occasion lasted approximately one to one and a half hours. After this, as new data were added to the results, specific follow-up questions were addressed to the mentioned people and other people able to answer certain specific questions. A discussion was also held with the project managers' manager, regarding results and overall project management issues related to the study.

Results and analysis

The case study organization (CSO) is a Swedish corporation active in timber-processing in different business areas. It is active throughout the construction process including management of rental apartments. Timber products not related to the construction process are also a part of the business. The case study organization (CSO) is a Swedish corporation active in timber processing in different business areas. It is active throughout the construction process including management of rental apartments. The timber-based multi-storey building system that was researched is one system among others on the Swedish market. At the time of the study four companies in Sweden had well-developed systems. Three of these were three-dimensional volumetric elements that were complete with plumbing, electrical installations and finishes (Mahapatra *et al.*, 2012), and one was built-up by prefabricated surface elements, similar to the system developed by the CSO. Systems with prefabricated surface elements may allow more architectural freedom. Overall, research conducted on multi-storey housing in timber relates to industrial building, due to the material's suitability for this (Tykkä *et al.*, 2010). For an extended review see Lindgren and Emmitt (2017). According to the technical manager at the CSO, an openness to other timber system manufacturers existed, where they openly reviewed each other's systems and solutions. Furthermore, the system builds on the method for building prefabricated small domestic houses in timber, and has many similarities to this way of building. Therefore, both similarities and differences existed among the different systems available.

Regarding the research results and analysis, at first conducted projects and their progress are described, followed by findings specifically related to the perspective of the study.

Development of the system

At the time of the study the CSO had completed five projects, had three ongoing and three in the start-up phase. The main features of the completed projects are described in table 1:

Table 1. Overview of the projects (placed here)

The first two projects used almost the same building system, were seen as quite successful by the CSO and contributed with basic knowledge about erecting multi-story buildings in timber. Project no. 3 started with development of what was called a prefabricated lean-inspired building system. Actors from different organizations participated with different perspectives to enable a well-functioning system. However, lean based thinking collided with many aspects of the construction process, resulting in many small modifications (see table). The redesign for project no. 4 provided better results and this system worked well from a sound, fire and assembly perspective. Project no. 5 contained some errors and was an important test for the monitored, sixth project.

The monitored project

Project no. 6 consisted of one six-storey building with 50 apartments and two five-storey buildings with 20 apartments, varying from one to three-room apartments. It was seen as an indicator if the CSO could handle large projects. Virtually the same system as in project no. 5 was used. The buildings (see Figure 1) were quite traditional in design, besides irregularly placed bay windows and façade sheets in different shades of red on the larger building (the most complicated building ever according to the project manager). The other buildings have balconies and rendered façades.

Figure 2. The largest building near outside completion (placed here).

The CSO managed the project from start to sales of the apartments. A weather protection system was used and the CSO fabricated the main elements for assembly (floors, walls etc.). The erection work involved 30 different subcontractors, from assembly to cleaning of the building. The project was seen as a logistical challenge with a physically restricted site and many buildings erected at the same time, but afterwards no problems were reported related to this. Designers from different technical areas participated in the project design phase. Other subcontractors, without previous experience of the TMHS, were contracted during the latter part of the process.

Some mistakes stemming from the design phase led to additional work on site; incorrect measurements for the bay windows resulted in considerable extra work on site; some beams had incorrect measurements but this was quickly corrected. During the project the first site manager left the project due to burn out and the subcontractor handling electrical installations went bankrupt resulting in considerable additional costs. Furthermore, missed material deliveries due to missed ordering and wrong specified amounts from the design phase caused delays. Major problems also occurred since the CSO business area managing material deliveries did not deliver to site as agreed, reportedly due to internal lack of respect, prioritizing external customers before internal customers. In the validation sessions it became clear that a better-developed system and better site organisation might have made the project more successful. Since many problems relate to administrative processes, some interviewees stressed that the CSO needs to specify (and improve) their administrative processes, for example individual responsibilities not clearly defined at the outset of the project.

KI - findings from the perspective of the framework

This section nuances the findings relating the empirical data to the framework. Used KI-mechanisms and effects are described first followed by knowledge development and its effects. Finally, common knowledge in the KI process is discussed.

Used KI Mechanisms and their Effects

KI in design development in the case has at large a character of trial and error. Different mechanisms were used in combination to integrate and create knowledge:

- The main designer reflected on improvements from an erection and design perspective, based on his knowledge in structural mechanics.
- The market was scanned for possible solutions. Viable options were reduced since the CSO´s own products must be used. Regarding fire-demands existing knowledge about materials was used and tests certified that demands were met.
- The company occasionally used knowledge outside the CSO to get a second opinion or validate design: for example, external consultants have been used and the technical Research Institute of Sweden have conducted tests with one party wall.

These different used mechanisms however only provide partial data. Finalized projects are a central mechanism to validate the design and after completion. Buildings are evaluated and tested regarding sound and energy-effectiveness and test-results are used as input for redesign.

The use of field factories in the first projects enabled changes on site with group problem solving and decision making as a natural starting mechanism. In the later, more defined stages with the increased use of prefabrication low-interaction mechanisms were used more extensively; although in certain cases in combination with more interaction-intensive mechanisms. The use of different project managers in "later" projects can be viewed as a form of 'work rotation' mechanism. However, formal project evaluation was not always conducted, and a structure for it was lacking. The project managers' line-manager also emphasized problems retrieving feedback from the erection phase (a focus on finishing projects made feedback low-prioritized). The CSO has also used the same people in different projects, enabling transfer of experiences between projects, since individuals often learn from mistakes and try to avoid these in future projects. Codified knowledge in the form of drawings was extensively used to show design changes and communicate the defined system to its participants (supported by oral communication). Uncertainties have resulted in errors occurring on site. According to the main designer, 3D-visualisation could have reduced the number of mistakes, minimizing room for individual interpretation and visualizing possible mistakes prior to construction.

A problem regarding KI was the sequential contracting of subcontractors. A late entrance into the process decreased possibilities to find and correct problems. However, since manufacturing of units was done very close to the delivery date it enabled changes to be made before they were manufactured and delivered to site. In the monitored project the carpenters asked for dowel pins to simplify assembly when erecting the first building. For the following building this was fixed, emphasising the integration of knowledge. In project 4, before starting erection, site modules were built and tested by the assembly crew for two days, including sound tests. These activities led to adjusted details for better workplace functionality and constructability.

The findings also display different views on how to integrate knowledge about the system. CSO interviewees stressed the importance of previous project studies and supervision of subcontractors. For the monitored project visits to ongoing or finished projects, project reviews with participating actors and actors from previous projects were used as site educators. However, according to the primary subcontractor, the carpenters, the most important mechanism was learning by doing. Since they had built prefabricated family houses for the CSO they recognized parts of the system. After erecting one floor, the 'new' system was learned and they were up to speed. They furthermore stressed that each craft should provide feedback about the system but spontaneous visits and monitoring work on site has detected mistakes, which suggests this is not happening all the time. In several projects, screwing was not made according to instructions compromising the acoustic isolation between units, caused by uninformed craftsmen. The only suggested way to handle this is to inform/educate and monitor projects in the erection phase. This shows the heavy influence from current practice in combination with low interaction mechanisms and codified knowledge. People often neglect instructions and act 'on routine', as witnessed in this research.

To summarize, when reviewing the KI-processes, different stakeholders come in at different stages of the construction process. Changes are mainly made in the design phase based on ideas from the market or self-reflection, or based on feedback from the projects previously conducted (see Figure 2 below). When reviewing how different stakeholders are introduced into projects, this takes place at different stages depending on their significance for the projects.

Figure 3. Introduction of stakeholders in the projects (placed here)

Knowledge development and its effects

Overviewing knowledge development, domain-specific *product* knowledge is prominent. It gradually increased as more projects were constructed, specifically for design where knowledge is accumulated. In the erection phase, where new actors frequently came into the project, accumulating knowledge appeared to be more challenging. The design level had become more advanced to fulfil higher demands on construction strength, acoustics and fire. The increased prefabrication level also implies developed domain specific *process* knowledge. Development of product design seemed to precede process development. However, process development may require product changes, showing interplay between product and process. An effect of knowledge development was improved efficiency and a lowered KI need in the erection phase. The lowered need can be exemplified by a carpenter used to timber stick-building (as used in domestic houses). He stated that the work was boring and not challenging because of the high level of prefabrication. Procedural knowledge is continuously increasing as the system develops and a systematic approach is continuously refined.

Regarding integration of general knowledge several interviewees' perceived construction as a closed sector. An example is the "lean-based" system, developed from thoughts and ideas from the automotive sector. It was considered hard to understand and apply and was effectively abandoned after one project, despite its aim to be used in several projects (i.e. a system). The development manager and head designer felt that the current state of the system was now more suitable for lean thinking, showing the need for several projects to realize a system solution. Furthermore, regarding integration of general knowledge, web-based services aim to be used to simplify information access. ICT usage has development potential (for example electronic ordering) and BIM-solutions and developments are scheduled for use in future projects. In total, this shows potential for integration of general knowledge for the future. To conclude, overviewing knowledge development and its effects also entails differences in knowledge integration across projects. The focus of the development has at first been on the first part of the construction process (design) but as development of the MSHT has progressed, focus has changed towards subsequent parts of the construction process (manufacturing, erection), as these have needed development.

Common knowledge in the KI process

The knowledge leap among the actors varied from none to more extensive. Over time the design and the construction methods have developed from prefabricated small family houses, but with the lean-inspired building system the leap was obviously too large, highlighting the role of common knowledge. When the leap is too large, new knowledge is harder to integrate. The monitored project showed an overall well-functioning system but project managers stressed the complexity in controlling all parts of the system. The project manager needs a common knowledge base that intersects the different professions' knowledge base. A highlighted alternative solution is to simplify the system with standardized solutions and simplify the control of the process. It was also stated that the amount of needed common knowledge can be too much for one person to handle, and thereby be an obstacle in the development of MSHT.

Discussion

The aim of the research was to study how KI takes place during the diffusion of a systemic innovation. In the study projects are the central mechanism in the KI process, surrounded by different mechanisms. The built projects validate development and show what works (and what does not). The importance of projects as a central activity in the innovation projects has been stressed by, for example, Winch (1998), however not explicitly as a mechanism. Furthermore, many different mechanisms are used depending on the trade and process step in question and balance is needed between codification and "soft" personalization strategies, for example when screwing was not made according to instructions compromising acoustics. The impact from current practice is also an example how previous knowledge can be a barrier for KI (c.f. Henderson and Clark, 1990). On a general level, a conclusion is that balance is needed in line with Senaratne and Sexton (2008); since there are many different trades with different competencies throughout the process, requiring different types of mechanisms to handle different types of tacit and explicit knowledge. However, the dominant use of drawings, i.e. codified knowledge, contradicts the current picture of construction and sheds light on the need to nuance codified knowledge types (c.f. Kivrak et al. 2008). A pattern in the study is that interaction needs and knowledge demands in projects decreases, while the level of prefabrication and definition steadily increases. The choice of mechanisms initially can be related to the innovation initially being a technological change demanding more social interaction (c.f. Johnsson, 1992) and insecurity requiring interaction (Van De Ven et al., 1976). A result from development is that diffusion is simplified due to a decrease in the amount of knowledge required to integrate into the system. It also seems logical to introduce new project managers and increase the number of projects when the system reaches a certain level, since the amount of knowledge required to integrate is lower.

The system has become more defined and has moved towards being a standardized package of prescribed components, routines and components, i.e. a platform approach. Similarities with the research by Styhre and Gluch (2010) are also visible: knowledge is integrated into the product, which acts as a boundary object linking different needed stocks of knowledge to erect the building. In line with Styhre and Gluch (2010) it becomes a vehicle for sharing and accumulating knowledge. The CSO also manages the whole chain and are able to work on a long-term basis with the system, enabling better possibilities to mobilize social capital (see Styhre, 2008) and enable KI since the 'ownership' of resources enables improved control (Taylor, 2006). The transfer of activities from projects into the organization by the CSO also simplifies KI by having continuous knowledge flows.

When reviewing knowledge development, domain-specific knowledge comes into focus due to the application of an established material in a new setting and integration of general knowledge seems to require developed domain-specific knowledge. Domain-specific issues needs to be set before implementing fine-tuning solutions, which at large are about integration of general knowledge. Regarding the introduced knowledge types, they have been useful to understand knowledge development and different knowledge flows for systemic innovation diffusion in construction. The division into domain specific *product* knowledge and domain specific *process* knowledge has further nuanced domain specific knowledge development. In the case study, no existing general knowledge existed for product development but for developing the process. The case study also displays possible development and innovation potential for general KI.

Finally, by working over a series of projects, a learning cycle is established and managed. The approach in developing the system can be considered systematic and the performance of the buildings control actions and activities, but it is not structured on a higher level as in models by, for example, Robinson et al. (2004). Furthermore, a standardized structure for the evaluation of projects in the study is missing. As suggested in Chinowsky and Carrillo (2007) more overall systematic work in the CSO may be needed to improve the overall learning capabilities for the CSO and to become more proactive.

Conclusions and further research

This research emphasizes the importance of actual projects as the most crucial activity for KI. Projects serve as a result of the development, as a checkpoint and as a mechanism to integrate knowledge, including many underlying mechanisms. Knowledge areas to integrate become evident through mistakes and experiences from the projects adding understanding to why development preferably is made in small steps and over a series of projects. The research shows that a major challenge relates to the innovation's level of complexity, extent and how it affects different types of knowledge and groups. Furthermore, the research shows the necessity of integrating knowledge from a diversity of participants *to and from* the systemic innovation to improve its efficiency. The systemic innovation acts as a platform that serves as a boundary object bonding and bridging different stocks of knowledge, supporting the research by Styhre and Gluch (2010).

The introduction of domain-specific, procedural and general knowledge into construction management research complements the division into tacit and explicit knowledge. Dividing domain-specific knowledge into product and process knowledge provided additional understanding regarding different flows of knowledge and provides guidance in the implementation of a new material. The study also reveals that procedural knowledge is gradually built up and becomes increasingly systematic through development. In addition domain-specific knowledge mostly regards knowledge generation, general knowledge typically regards knowledge application and procedural knowledge how to develop knowledge. Common knowledge enables KI but could be studied more in depth to investigate how different knowledge bases connect and what types that are used when, where and why. Furthermore, architects were included to a minimal extent in this study. Given that they have considerable impact on the final product they should be included in future research. In addition, studies on product development outside construction highlight positive effects by integrating various types of knowledge, especially general knowledge. This could be explored further, since it seems to be a major concern for development steps to come for this systemic innovation.

Continuous KI is improved by moving activities upstream into a continuous organization enabled by an increasingly defined setting, decreasing the need for specialized knowledge, reducing complexity on site and simplifying diffusion. The study confirms studies emphasizing a balance between the use of soft personalization and codified knowledge and contributes to when and why these could be mixed. As the definition level increases, the need for more interaction intensive mechanisms decreases and a more systematic approach with KI can probably take place. Interaction intensive mechanisms are especially needed when methods and solutions deviate from current practice, implying technological change and insecurity as highly influential. Contrary to previous results, drawings, i.e. codified knowledge are extensively used in the study pointing towards the need for a more nuanced discussion on what types of codified knowledge to use when and where.

Having shown in the research how knowledge develops, the mechanisms used, and where problems occur, this provides potential learning opportunities for construction actors. The possibility of avoiding mistakes is increased and, potentially, a better understanding of how to manage knowledge to diffuse a systemic innovation within construction organisations is now available. Due to the many parts that interact and develop, it is likely that the diffusion process has the character of an iterative learning process in similar cases. However, it needs to be contextualised for different cases due to the potentially unique influencing factors. Since there are both similarities and differences between different building systems, this also needs to be taken into consideration. Furthermore, the research presented here may be most relevant for those producers who use prefabricated surface elements and for actors who, like the case study company, have the possibility to manage and hence control many parts of the construction process. These points are also relevant when it comes to generalisation of the findings, for example the findings should have general relevance for situations with similar characteristics.

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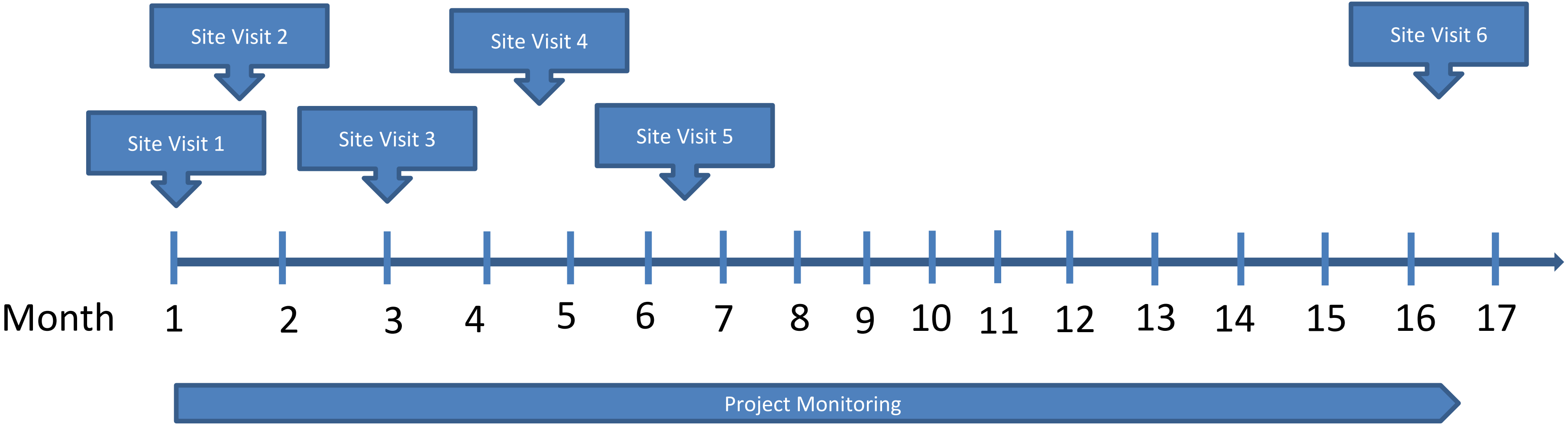
Site Visit 2
Site Visit 4
Site Visit 6
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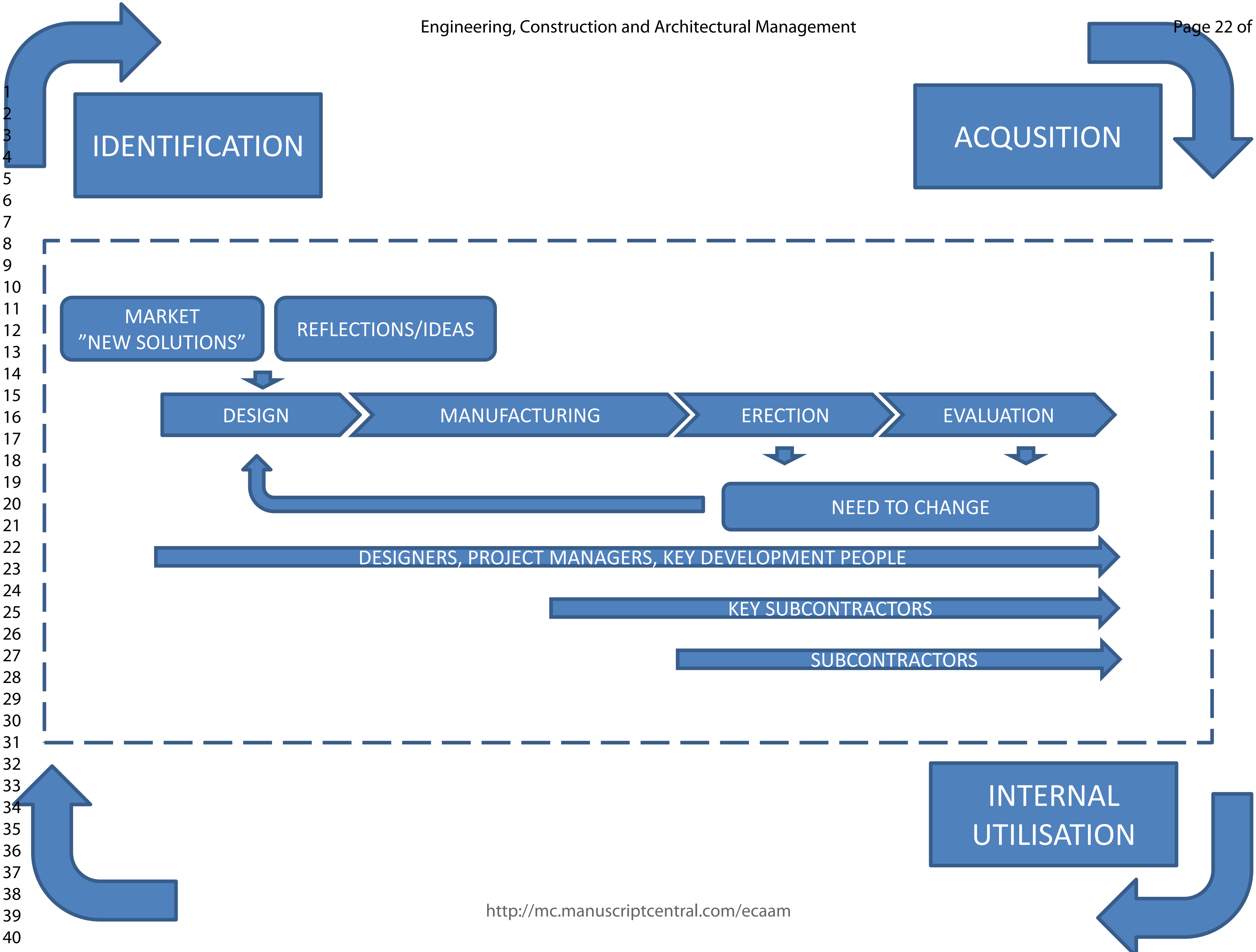
Project Monitoring

Project No	Time	No of buildings/stories/ apartments	Main Characteristics	Mistakes/problems
1	2003-2005	3/4/24	- prefabricated floors - other production in a field factory	- rain damaging parts of the last house
2	2006-2008	1/5/29	- CSO delivered base material - all manufacturing in a field factory	- none reported
3	2010-2012	4/5/6	- development of a prefabricated lean based system - internally fabricated elements	- too low prefabrication level - much added on site - deliveries made through floors and windows - forces from weather protection system causing redesign
4	2011-2012	3/4/36	- design of floors and some details changed - bearing walls and floor prefabricated - façade set on site	- none reported
5	2013-2014	2/4/24	- stabilizing wall modified further	- tough weather (rain and wind) handled with plastic foil complicating assembly for the last house - façade sheets mounted incorrect - on-site inventories showed

				improvement potential - Scaffolds raised during erection caused stress - holes not prefabricated, made on site, not included in the quotes.

Table 1.

Figure 1


IDENTIFICATION
ACQUSITION
MARKET
”NEW SOLUTIONS”
REFLECTIONS/IDEAS
DESIGN
MANUFACTURING
ERECTION
EVALUATION
NEED TO CHANGE
DESIGNERS, PROJECT MANAGERS, KEY DEVELOPMENT PEOPLE
KEY SUBCONTRACTORS
SUBCONTRACTORS
INTERNAL
UTILISATION