



# Diffusion of systemic innovations in the construction sector

John Lindgren

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# Abstract

The amount of research dealing with innovation has increased dramatically, construction management research included. This thesis focuses on innovations with inter-organizational effects, systemic innovations, which may radically change and improve the construction process. The overall aim of the thesis is to contribute understanding of diffusion of systemic innovations in the construction sector through the study of two different types of systemic innovations, Building Information Management and Multi-Story Housing in Timber (MSHT). It explores what facilitates and hinders innovation diffusion, with a special focus on knowledge integration and mechanisms used in the diffusion process and their effects on knowledge development. The studies conducted were made in a Swedish context related to two separate companies work with diffusing the innovations, using a broad approach with different data collection methods.

The research departs in the interplay between the innovation content, context and process through which diffusion take place, displaying differences in how diffusion precedes and is affected. Where organizations are situated in the construction process and their ability to control the diffusion process is influential and diffusion is affected by established traditions and work procedures. For MSHT other structural materials form obstacles, while for BIM it is established work procedures and methods. Environmental pressure drives diffusion of MSHT and both innovations are supported by active clients. Diffusion also requires financial resources depending on the size of investment and associated risks. The cases show advantages with moving activities from projects into a continuous business that delivers to projects, where simplifying implementation is central. Mainly due to complexity, developing in steps enables simplifications and adjustments towards users in a controlled manner. MSHT to a higher degree depends on performing real projects for development and diffusion than BIM, which can be tested to a larger extent before diffusing into the real environment. MSHT in particular show a difference in relation to many traditional models of innovation and innovation diffusion where tests are assumed possible.

The research relates to and has emphasized interaction and dynamics in the diffusion process and has provided additional understanding for managing

complexity in the diffusion process. Projects are the most crucial knowledge integration mechanism with many underlying mechanisms, since they are a result of the development and show consequences of work performed. The applicability of codified knowledge in combination with more interaction-intensive mechanisms has been shown and the introduction of the knowledge type's domain-specific, procedural and general knowledge, complementing the current use of tacit and explicit knowledge, has provided additional understanding for diffusion and related knowledge flows. There are however differences in how knowledge types develop for the innovations. General knowledge is more influencing for BIM, while MSHT is about developing domain-specific knowledge. MSHT is about learning something new, while for BIM it is about re-learning. Findings show relevance in both using and developing the framework of innovation in organizations by Rogers (2003) for future diffusion studies in construction management research as well as the necessity of developing knowledge concerning implementation.

To my lovely daughters  
Wilma and Alice. You are the  
greatest ever!

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Finally, I hope that my aunt Marianne, who triggered my interest for construction especially as a boy, probably sits with a big smile “up there”. In addition, to my family and friends! Thank you for being there!

Falkenberg 7 December 2017

John Lindgren

# List of appended papers

This doctoral thesis is based on the five papers listed below and an introductory text consisting of 6 chapters.

The five appended papers are the following:

Lindgren, J. 2016. Diffusing systemic innovations: influencing factors, approaches and further research. *Architectural Engineering and Design Management* 12 no. 1: 19-28.

Lindgren, J. (2017) Exploring effects from the interplay of context, content and process for supplier innovation diffusion in construction  
Submitted to *Construction Innovation*

Lindgren, J., and Emmitt, S. (2017). Diffusion of a systemic innovation – A longitudinal case study of a Swedish multi-storey timber housebuilding system. *Construction Innovation* 17 no. 1: 25-44.

Lindgren, J., Widén, K. and Emmitt, S. (2017) Construction projects as mechanisms for knowledge integration: mechanisms and effects when diffusing a systemic innovation  
Accepted with minor revision to *Engineering, Construction and Architectural Management*.

Lindgren, J. & Widén, K. (2017): Diffusing building information management – knowledge integration, mechanisms and knowledge development, *Architectural Engineering and Design Management*, DOI: 10.1080/17452007.2017.1394260

Additional publications by the author, not included in the thesis:

Lindgren, J. and Widén, K. (2016) *Diffusing BIM – knowledge integration mechanisms and their effects*, CIB WBC 16 Congress.

Hjort, B., J. Lindgren, B. Larsson, and S. Emmitt. (2014). Success factors related to industrialized building in Sweden. In *CIB International Conference on Construction in a Changing World, 2014*. CIB.

Lindgren, J. (2003). Logistikens aktörer-Tankar inför ett ämnesområdes fortsatta utveckling. [The actors of Logistics - thoughts regarding the continued development of a subject] *Department of Industrial Economics and Management*. Royal Institute of Technology.

# Abbreviations

BIM = Building Information Modelling/Management, see section 3.2.2.1

CM = Construction Management

CSO = Case Study Organisation

ID = Innovation Diffusion

MSHT = Multi-Storey Housing in Timber

RS = Reinforcement Supplier



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# 1. Introduction

*Innovation and innovativeness are key concepts when it comes to the development of different sectors. In the innovation process, diffusion is vital to move the innovation into the hands of its users. The construction sector is no exception and the overall aim of this thesis is to contribute to the understanding of the diffusion of innovations with inter- and intra-organizational impact, in this thesis labelled systemic innovations, in the construction sector. In this introductory chapter a background, problem areas, purpose, research questions and a structure for the thesis is presented.*

## 1.1 Innovation diffusion challenges in the construction sector

Innovation diffusion concerns the communication of a new idea through certain channels in a social system (Rogers, 2003). This includes the adoption and use of new ideas, methods and products (Rogers, 2003, Howaldt et al, 2010, OECD, 2005), where Rogers also emphasizes the importance of the consequences of the innovation in innovation research. From a diffusion point of view, the construction sector is of interest since it is largely project-based which creates significant contextual differences from other sectors such as manufacturing with more fluent, non-disrupted processes (see for example Naar, Nikolova and Forsythe, 2016). Although different issues can be repeated between projects, the project-based setting may be considered as an unchangeable factor influencing diffusion. However, there are also changeable factors influencing innovation diffusion. Construction has frequently been described as dominated by a short term view (see for instance Barlow, 2000) with a lack of long-term planning (Miozzo and Ivory, 2000). Annan (2012) describes construction as fragmented, with intense conflicts and adversarial relationships between actors in the construction process. The

UK construction sector has been given as an example with its disjointed relationships and adversarial practices (Briscoe and Dainty, 2005) and continuous price pressure has led to construction being in a somewhat anorectic condition (Green et al., 2008), with limited possibilities to invest in development. Stress has also been emphasized as apparent in construction in general and for specific trades (see for example Cattell, Bowen and Edwards, 2016, Bowen et al. 2014 and Leung, Skitmore and Chan, 2007) as well as in specific countries such as Sweden (Styhre, 2011). Stress together with the characteristics of construction can influence innovation negatively since safe and approved solutions become more attractive (Emmitt, 1997, Larsson, 1992). As will be reviewed more thoroughly in chapter two, innovation diffusion is an ongoing process where it is essential to make an increasing number of users adopt and use an innovation, for which a steady information and communications flow is necessary, in order to present and introduce the innovation. However, working in projects complicates communication flows and there is a specific challenge in enabling continuous communication flows between projects. This issue is addressed both explicitly and implicitly in construction management research. Furthermore, the changeable factors emphasized above, also exert a negative impact on innovation diffusion within construction.

However, approaches or views of business in construction have been presented emphasizing a long-term approach, long-term relationships and a wider view of the construction process, for example supply chain integration and partnering (Eriksson, 2015) or Lean Construction (Gao and Low, 2013). Gains often mentioned from these approaches in other sectors (not project-based with continuous communication flows) are for example mentioned in relation with the concept Supply Chain Management (Christopher, 2011b). Stated benefits from this approach to business include unique products and services, faster research and development, faster cycle times, superior quality, cost competitiveness, shorter order cycles, flexible customer response, enhanced delivery performance, better asset management, increased cash-to-cash velocity and superior channel relationships (Fawcett, Magnan and McCarter, pp 37). Research in construction management has also shown the benefits of a changed and more overarching construction process approach, where total efficiency is in focus. According to Cain (2003) the involvement of suppliers in design and cost development, can provide improvements in costs and quality. Annan (2012) shows that a more effective management of the construction process leads to a better understanding of customer needs and supplier capabilities increased repeat business with key customers, less conflicts and disputes. Ekeskär and Rudberg

(2016) studies of the use of Third-party logistics providers in large construction projects as a supply chain management initiative showed that it facilitates an increase in productive work, reduction of costs and increased utilization. Havenvid et al. (2016) stress that long-term relationships between key actors across projects boundaries, especially between clients and contractors, appear crucial for renewal in construction. One key issue based on this is to adopt an inter-organizational focus and aim to make changes across several parts of the construction process.

Furthermore, within Innovation Diffusion research in Construction Management, an interplay from research on strategic change has been highlighted. Pettigrew and Whipp (1991) stress that in the strategic change process there is a continuous interplay between the content, context and the process that explains its outcome or result. Content refers to what the change is about. Context regards why change is taking place and process refers to how change takes place. This interplay has been useful in studies of operative change (Carlsson, 2000) and some authors also explicitly refer to the stated interplay in construction management and innovation diffusion studies in construction. Bresnen and Marshall (2000) explore the link between partnering and cultural change, and refer to this interplay and state that unsuccessful cultural change is caused by a “failure to match the attention paid to the content of change with that paid to the (internal) context and process of change” (pp 235). Shibeika and Harty (2015) studies of diffusion of digital innovation in construction show interaction between the dimensions, a range of activities and the dynamics in a non-linear diffusion process. Jacobsson and Linderoth (2010), also connects these dimensions in their studies of ICT adoption. The latter two studies also emphasized the emergent character of diffusion, events beyond control and effects on the diffusion context. Otherwise, several studies on innovation diffusion place great emphasis on the context and its influence on diffusion (see for example Green, Kao and Larsen, 2010, Widén 2006). Based on this, emphasizing and using the interplay as a point of departure, appears to provide additional understanding for the innovation diffusion process, since it can highlight both unique and general characteristics in diffusion processes.

The wider view of the construction process and the potential of studying the interplay between content, context and process, can be related to the innovations in focus in this thesis, systemic innovation. Systemic innovations is of interest to the construction industry since it has and is predicted to contribute with efficiency gains for the construction industry (Shabanesfahani and Tabrizi, 2012). In this thesis systemic innovation diffusion is treated in line

with Taylor (2006): interest is focused on the inter-organisational effects/consequences of innovations with possible effects on the whole construction process (including its actors and their resources). Emphasis is on the interaction between different parts of a system within a specific context, and on innovations not being isolated ideas, products, or practices in the construction process<sup>1</sup>. However, as concluded in Paper 3 appended, a systemic innovation may be labelled as different innovation types but may also include different types of innovations, however this research does not focus on how the systemic innovation is labelled.

## 1.2 Examples of systemic innovation diffusion

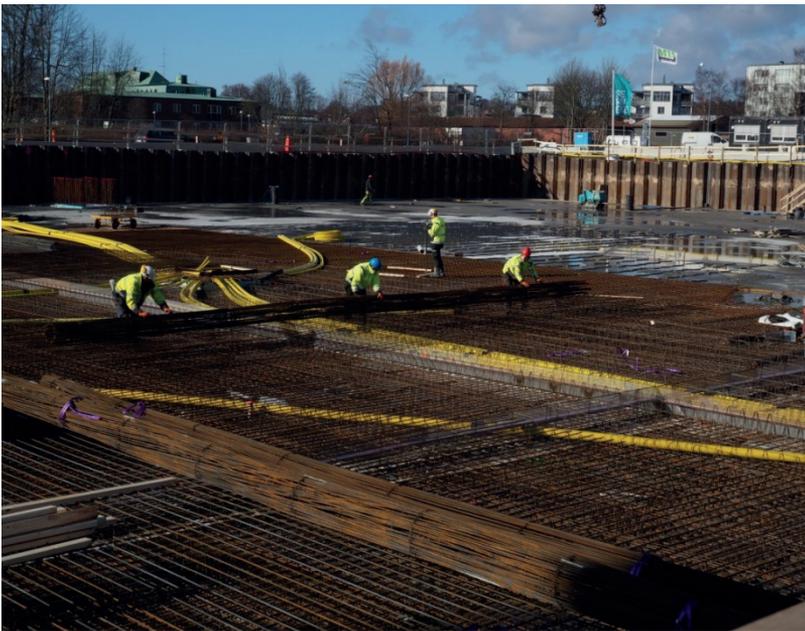
There are several examples of innovations whose advantages seem more or less obvious but when reviewing their impact on the construction process, challenges to diffusion become more apparent. One example is Rollout Bar Carpets, introduced on the Swedish market about 15 years ago. The pictures below display the difference between work with traditional reinforcement and work with roll-out bar carpets:

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<sup>1</sup> A more thorough discussion on what constitutes a systemic innovation and how it is defined is undertaken especially in Papers 1 and 3. For discussions on systemic innovations and related concepts see for example CHESBROUGH, H. W. & TEECE, D. J. 1996. When is virtual virtuous. *Harvard business review*, 74, 65-73., MAULA, M. V., KEIL, T. & SALMENKAITA, J.-P. 2006. Open innovation in systemic innovation contexts. *Open innovation: researching a new paradigm*, 241-257., SLAUGHTER, E. S. 1998. Models of construction innovation. *Journal of Construction Engineering and management*, 124, 226-231. or HENDERSON, R. M. & CLARK, K. B. 1990. Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms. *Administrative science quarterly*, 9-30..



Picture 1.1 Traditional tying of steel wire (picture: Bengt Hjort)



Picture 1.2 Roll-out bar carpets (picture: Bengt Hjort)

Tying together steel bars with steel wires in the traditional manor is time-consuming and negative ergonomically (Buchholz et al., 2003, Forde and Buchholz, 2004). With roll-out bar carpets, supports are positioned in the reinforcement area and the carpet is rolled out providing time savings and work environment benefits (Ålander, 2004, Simonsson and Rwamamara, 2007). It can also be used for walls, floors and other areas (Celsa, 2015). The adoption of the innovation has moved slowly and according to Hjort et al. (2015), implementation and adoption of the innovation is complex *due to the contextual delimitations of a project-based industry and the different roles in the construction process*. Furthermore, since design, manufacturing and assembly in the construction process are tied together through the use of advanced IT technology and production technology, changing the process might be difficult (Hjort et al., 2015). Viewing roll-out bar carpets as a systemic innovation, effects and consequences for the construction process become apparent and also explain the pace of the diffusion process.

Another example of a systemic innovation is the prefabricated wall which includes heating, ventilation and air conditioning (HVAC), plumbing and electrical components (Taylor, 2006). This type of wall replaced conventional stick-built timber housing. Compared with a traditional structure, the work structure changes, with reduced need for subcontractor work on site (carpenters, HVAC, plumbing and electrical components), since much of the work is done off site. Prefabrication also relates to industrialized house-building, another example of a systemic innovation, where it is of central importance to regard the construction process as a tightly connected integrated process, which requires restructuring to become reality. Lessing (2015) for example stresses systemic integration of twelve interrelated constructs to establish a production system that continuously produces buildings for certain markets and segments. Goulding et al. (2015) conclude (when addressing the need for new business models for offsite production) that a change process is necessary that includes new relationships, skills, technology, processes and new ways of working.

These examples affect several parts of the construction process and the scope of an innovation provides implications for innovation diffusion. Relating this to Taylor (2006), he states that innovations that affect few parts of the construction process diffuse faster than more extensive innovations. As can be seen from the examples above, the effect on the construction process is a significant factor explaining the diffusion pace, despite the obvious advantages of a specific innovation.

### 1.3 Knowledge integration and systemic innovation diffusion

There are a multitude of active occupations, professions and organizations in the construction process and the construction sector (Kanji and Wong, 1998, Milakovich, 1995, Sommerville, 1994). There is also evidence of poor interaction in the process for example between material suppliers and actors in the construction process (Sundqvist et al., 2012) resulting in insufficient information about customer needs for the materials supplier. In addition, there is a lack of knowledge integration in the construction process (Rundquist et al., 2013) and Love et al. (2014) stress interaction as a prerequisite to learning how to prevent errors and share experiences. Knowledge creation and exchange is central to the innovation process (OECD, 2005), and consequently also for the diffusion of innovations. Furthermore, the knowledge necessary to develop new products is becoming increasingly complex and distributed. Companies consequently need to develop their knowledge integration capabilities, which is motivated as a central factor for innovation success (Tell, 2011). In addition, knowledge integration is difficult to accomplish and constitutes a managerial challenge in innovation (Enberg et al., 2006, Hoopes and Postrel, 1999, Schmickl and Kieser, 2008). In reviewing research and research results it can be concluded that research regarding knowledge integration and similar concepts is increasing but that more research on knowledge integration in construction is necessary (Kivrak et al., 2008, Styhre and Gluch, 2010). However, Walker (2016) concludes that research in knowledge management and organizational learning, knowledge integration included, has matured over the time-period of 2005-2015.

Knowledge integration occurs through the use of knowledge integration mechanisms, and research has addressed models aimed at developing knowledge management from a strategic perspective (Kale and Karaman, 2011), Knowledge Management challenges and what mechanisms to use (Kale and Karaman, 2011, Robinson et al., 2005, Robinson et al., 2004). Kivrak et al. (2008) also highlight the need to develop effective mechanisms to capture and reuse knowledge. Research has also dealt with mechanisms that are used: Styhre and Gluch (2010) concluded that much knowledge remains personal or community-based and formalization and codification of operative knowledge is of small concern, but construction companies do show an interest in identifying and developing mechanisms that could be useful for codified knowledge. Bresnen et al. (2005) also stated that “personalization strategies” (p 236) dependent on social ties may be better for

knowledge transfer in a project-based environment than codification strategies, considering how construction currently works. According to Ruan et al. (2012), knowledge management problems in construction have dealt with a focus on managing knowledge within organizations so managing knowledge across organizational boundaries needs to be explored further, an issue for which mechanisms are of central importance.

## 1.4 Types of knowledge and knowledge development in construction management research

As highlighted, construction projects to a varying extent require different types of professions and knowledge types. Previous construction research has used tacit and explicit knowledge as knowledge types (Carrillo et al., 2006, Carrillo, 2004, Senaratne and Sexton, 2008, Robinson et al., 2004), where explicit knowledge can be codified but tacit cannot. Within the domain of engineering design Ullman (2010), suggests that engineering designers make use of three types of knowledge; 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 gained from previous or ongoing development projects (Court, 1997, Ramesh and Tiwana, 1999). Procedural knowledge relates to “knowledge of what to do next” (Ullman, 2010, pp 50) when working with development. This develops in the move from an ad hoc learning process to a systematic process that uses past experience. General knowledge concerns external conditions that influence product development (e.g., legal issues, social issues, or customer and supplier issues) (Andrews and Smith, 1996) or specialized expert knowledge in fields that may seem peripheral to current NPD projects. The use of these knowledge types is not only restricted to engineering design. Studies outside construction on new product development (NPD) and innovation have found this classification of knowledge into domain-specific, procedural and general as useful (see examples below), since it does not treat knowledge management as applied in phases but as types (Rundquist, 2012). According to Rundquist (2008) these types are possible to understand and relate to for people in the practical field in order to discuss the concept of knowledge and are thereby also of relevance to academia. Several sources have shown that these categories influence each other and can be related to innovation diffusion. According to Frishammar et al. (2012) integration of domain-specific and general knowledge was found to help matching technologies with new applications and markets, providing additional benefits from investments in innovation and technology. Integration of procedural knowledge has been found to be of less significance for commer-

cializing technology, but as vital in other studies (see for example Lichtenhaler and Ernst, 2009).<sup>2</sup>

## 1.5 Research problem

In this introduction, a number of research areas of interest that can add understanding to the area systemic innovation diffusion, have been identified:

- Systemic innovations, with their inter-organizational focus may exert a positive impact on the construction process and are of interest for further studies in order to contribute with increased understanding for diffusion.
- The interest in systemic innovation diffusion stated in the previous point is further underlined by the need to shift the approach to a more overarching and integrated focus on the construction process, with a long-term view which entails a lot of potential.
- The interplay between innovation content, the innovation diffusion process and the innovation context is seldom explicitly used in construction innovation diffusion research and potentially provides additional understanding of systemic innovation diffusion
- There is a stated need for more studies on knowledge integration in construction, specifically across organizational boundaries. In these studies mechanisms that are used are of specific interest, since mechanisms causes knowledge integration to take place. Since knowledge integration is central to innovation diffusion, mechanisms are highly interesting in order to understand innovation better.
- There is a potential for using the knowledge types domain-specific, procedural and general to increase understanding of knowledge development in systemic innovation diffusion.

When using the assumption that the diffusion process is affected by continuous interplay between the content, i.e. the type of innovation, the context in which the innovation diffuses and how it takes place i.e. the diffusion process, this implies a level of uniqueness in different cases of systemic innovation diffusion. Hence, there is a need for additional understanding regard-

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<sup>2</sup> This paragraph is a shortened and slightly rewritten version of material resented in paper four.

ing systemic innovation diffusion and also to explore different diffusion processes. In addition, studying different types of systemic innovations in different construction contexts improves the transferability of the results (Lincoln and Guba, 1985) and thereby also their general level (see chapter Methodology and Method, section on external validity/generalizability). Significant interest is focused on one key element in the diffusion process, knowledge integration. As stated in the introduction, many different competencies are pulled together in a construction process and many are temporary, adding to the complexity. An additional challenge also lies in knowledge development that must take place in this complex environment. Since previous innovation and innovation-related studies have shown that the categories domain-specific, procedural and general influence each other, these are introduced into this research and explored to increase understanding of knowledge development in the diffusion process. This also provides opportunities to explore how knowledge develops through the use of different mechanisms, relating to the stream of research that focuses on the types of mechanisms used.

## 1.6 Aim and research questions

The overall aim of the research presented here is to contribute to the understanding of the diffusion of systemic innovations in the construction sector. In addition to exploring what facilitates and hinders innovation diffusion, special focus is placed on knowledge integration and mechanisms used in the diffusion process and their effects on knowledge development.

The research questions that concern the diffusion process of systemic innovations in construction are<sup>3</sup>:

1. What facilitates and hinders the diffusion?
2. How does knowledge integration take place and what mechanisms are used?
3. How do domain-specific, procedural and general knowledge develop and what is their impact?
4. What are the effects of the knowledge integration process?

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<sup>3</sup> To see what research question that relates to what paper, see chapter four, Extended summary of appended papers.

## 1.7 Structure of the thesis

Having provided an introduction, background, research problem and aims and objectives, the rest of the thesis is structured as follows:

### **Chapter 2 Theoretical frame of reference**

This chapter provides a frame of reference for the thesis, with an overview, description of concepts, related research and clarifications of thesis-related issues. The overviews are given both in general and from a construction management perspective in order to provide a broad and context-specific overview.

### **Chapter 3 Methodology and method**

This chapter presents what has been done, why and aims to show awareness of methodology and method. It describes assumptions for the research as well as methods and approaches used, ending with a discussion on the quality of the conducted research.

### **Chapter 4 Extended summary of appended papers**

This chapter provides an extended summary of the appended papers. This includes author(s), publication status, research questions addressed and keywords. Furthermore, background & introduction, purpose, method, summary of main contents and results and contributions are provided.

### **Chapter 5 Analysis and discussion**

In this chapter the research questions are discussed. For each of the research questions a comparison is made regarding the studied cases. Following this, reflections and discussion are undertaken regarding conducted and previous research.

### **Chapter 6 Conclusions**

In this chapter, conclusions are presented regarding research questions. Then, theoretical contributions, research implications and practical implications are presented. The chapter ends with suggestions for future research.

## 2. Theoretical frame of reference

*In this chapter, a theoretical frame of reference for the thesis is provided; the innovation concept is reviewed. The interplay between content, context and process is dealt with in order to set a structure for the review of innovation content, the innovation and the innovation diffusion process, and the influence of context on innovation diffusion. Following this, the chapter moves into a review of knowledge and knowledge types, knowledge integration in an innovation context, knowledge integration mechanisms and effects of the knowledge integration process. In the frame of reference, both general and construction-specific research and sources are reviewed, to provide a broad and context-specific overview.*

### 2.1 The concept of innovation and research within innovation science

Innovation may be regarded as a key issue in today's society. It can, for example generate improved competitiveness for nations (Porter, 2011, Lundvall et al., 2002) as well as for companies and organizations (Tidd et al., 1998) and recently social values have been more strongly emphasized with regards to innovation by using the concept social innovation (Bhattacharya, 2013, Cajaiba-Santana, 2014). Research on innovation is conducted in many different subject areas, from different perspectives and using different approaches. There are various common concepts for the scholarly efforts in the areas of innovation studies or innovation sciences. These are umbrella concepts linking different research and business areas to policy and societal concerns (Rip and Voß, 2013). Since this research focuses on diffusion of systemic innovations with a focus on knowledge inte-

gration, mechanisms and effects in terms of knowledge development, it is situated in the area of innovation science. This research was conducted within innovation sciences at Halmstad University, here seen as a multi-scientific field of study that focuses on innovation, entrepreneurship, learning, corporate governance, management, business development and marketing.

The innovation concept relates to the word novelty: taking action to introduce or produce something new concerning the process of moving an invention to a widespread application (Godin, 2011, Goldsmith and Foxall, 2003). Regarding novelty, some authors are strict in the sense that it must be new (Godin, 2011 referring to Levitt, 1963; Schmookler, 1962) otherwise it is mere imitation, while others emphasize that it should be perceived as new<sup>4</sup>. Examples of the latter are Rogers (2003) and OECD (2005) who defines innovation as changes that will be of a significant degree of "novelty" for a company and excludes minor changes or changes lacking a sufficient degree of novelty. The concept novelty can also be problematized with reference to Crossan & Apaydin (2010, based on Hansen and Wakonen, 1997): something that can be replicated identically can be classified as innovation or not depending on how it is viewed and by whom, thereby including dimensions of individual interpretations. One example of how to assess the innovation concept according to Goldsmith and Foxall (2003) is to use three different attributes (relating to the word novelty); *recency*, meaning that "things are new when they are encountered or acquired recently" (p 323); *originality*, meaning that "things are judged as new when they are unfamiliar because they are so original" (p 323); *similarity*, meaning how different or similar "a thing is from an existing thing of the same type" (p 323).

Research on innovation in construction is often based on the same characteristics as in the previous paragraph, but frequently emphasizes the type of innovation (see also section Innovation Content). Several authors, for example Havenvid et al. (2016) refer to Slaughter (2000), who define innovation as "[...] a nontrivial improvement in a product, process, or system that is actually used and which is novel to the company developing or using it" (pp 2). Widén (2006) refers to innovation as the creation of something new (for example a product or a process) put to use, and uses the OECD/Eurostat definition which views innovations as a technological product innovation or

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<sup>4</sup> This appears to depend on the time-period in which the researchers were active.

a technological process innovation (OECD/Eurostat, 1997, paragraph 24)<sup>5</sup>. The standpoint in this thesis is what is stressed by Crossan and Apaydin (2010): Innovation can be seen as a result but also as a process. Furthermore, innovation is perceived by its user as new and the resulting change should be perceived as significant. Innovation is realized through a process through which the innovation is diffused and adopted, resulting in some type of value for its recipient. In line with previous construction management research (see for example Havens et al., 2016, Widén, 2006), this thesis also focuses on a specific type of innovation, systemic innovations but with a focus on the inter-organisational effects/consequences of the innovation and possible effects on the construction process (including its actors and their resources).

## 2.2 The interplay between content, process and context as a point of departure for diffusion studies

Before reviewing the innovation process and innovation diffusion process, the interplay between content, process and context was stressed in the introduction as potentially useful to provide additional understanding of systemic innovation diffusion. In Pettigrew and Whipp (1991) the process of assessment, formulation and implementation of strategic and operational change and the outcome regarding competitive performance was studied. These extensive studies covered four mature industry and service sectors and seven different firms (none in construction however). One result from these studies was that well-performing organizations managed five areas differently; environmental assessment, leading change, linking strategic and operational change, human resources as assets and liabilities, and coherence (the areas are described below). Furthermore, management of change is the result of emergent, uncertain and iterative processes which require constant attention. A company's competitive ability is the result of a set of abilities and ways to demonstrate action. The company's ability to identify and understand competitive forces in play and to mobilize and manage resources to respond to these forces over time is of central importance.

Moving into the areas above in detail, *Environmental assessment* concerns the necessity of an organization to understand its environment. This understanding comes from a combination of analysis, judgement and action

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<sup>5</sup> The definition has changed and the latest definition is: "An **innovation** is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations. (OECD, 2005, p 47, paragraph 146).

through a series of acts over time. The dominating logic within an industry and the internal characteristics of a company shape this process and its related actions. Furthermore, important issues must be presented so that they matter for everyone in an organization. Since this area is about understanding the surrounding environment, it requires openness between the organization in focus and consequently the environment, at not least the ability to act on what happens in the surrounding environment. Pettigrew & Whipp conclude this can be explained by four conditioning features:

- the extent to which there are key actors willing to challenge assessment techniques that increase the openness in the organization
- structural and cultural features
- the extent to which pressure from the surrounding world is identified and associated actions are performed
- the extent to which assessment takes place as an activity without an end and is linked to the central activities of an organization

These points can be summarized into having an organization and people that comprehend the surrounding context, is receptive and sets direction. At the same time, operative and strategic change should be linked and people must be managed in order for a long-term learning process to be created. A challenging part in this, according to Pettigrew and Whipp, is to manage the coherence between these features and carry out, in this case a strategy, in a realistic manner, an issue that is explained further by the content of the other areas.

Regarding the second factor, *leading change*, there is no ideal leadership style. Instead it is about having the right leadership in relation to the organizational context and leadership is about building up a climate receptive for change. This includes justifying why a change needs to take place thus building up the ability to carry out changes. However, Pettigrew and Whipp also stress that establishing an agenda that sets the direction for an organization and enables the necessary visions and values is not easy. This is a process in itself which may require many attempts before it is possible to carry out successfully. They also highlight that leadership can be centred round the ability to manage a number of dilemmas and dualities (twofold solutions). The third factor, *linking strategic and operational change*, can be carried out in many ways but implementation is not a linear process. It has both an intended and an emergent character. Overall, it is about the same issues as in leading change; a receptive context for the change, ability to

change and the necessary visions and values for the chosen direction. The fourth factor, *human assets as resources and liabilities*, is largely about integrating Human Resource Management and learning into the business. Of critical importance is that an organization's knowledge base matches changes in the competitive environment through learning. The last factor is *coherence*, which is a consequence of the first four but is also the most abstract, since it is about relating the factors to each other and keeping the organization together while reshaping it. All in all, there is a relation between strategic change and competitive ability. Competition and strategic change are mutual processes that operate on multiple levels over time. Taken altogether, this overview hopefully sheds a better light on the interaction between content, process and context, and that they interact to produce an outcome. The following sections will elaborate on these dimensions in an innovation and innovation diffusion context.

The approach by Pettigrew and Whipp (1991) is broad in the sense that in its basic form revolves around massive data collection over time. Carlsson (2000) is an example of using the framework on a minor scale, since he used it for studies on the operative level and with less massive data collection than Pettigrew and Whipp. As Carlsson states, it can be used with different theoretical perspectives. When reviewing the dimensions and using them, they might seem obvious, but as also noted in the introduction the dimensions have potential for further use in innovation diffusion research in construction. However, as highlighted by Dubois and Gadde (2002) when reviewing approaches in case studies and its research process, the boundaries that are set influences research findings. Different boundaries in time can provide different results. Consequently, the extent of data collection affects the results and thereby also how the framework by Pettigrew and Whipp is used. A summarizing conclusion is that this approach requires a high level of sensitiveness in the research process and an adaptable and perceptive approach is needed. The selection of suitable data to present may differ between different researchers' perspectives and all the information is not always available.

### 2.3 What is diffusing? - Innovation content

As previously stressed, research in construction has often focused on a specific innovation type. In general, technological or product innovation, changes in goods and services have received most research interest over the years (Birkinshaw et al, 2008; Howaldt & Schwarz, 2010). Process innovations, significant changes regarding production and delivery methods have

also been paid considerable attention in general (OECD, 2005). OECD (2005) also highlights organizational innovations, implementation of new organizational practices such as business practices, workplace organization or a company's external relations, and market innovations relating to the implementation of new marketing methods, changes in product design or packaging, product "promotion and placement" (pp 17) or approaches to pricing. Another type of innovation is Management Innovation related to organizational innovation, "the invention and implementation of a management practice, process, structure, or technique that is new to the state of the art and is intended to further organizational goals" (Birkinshaw et al, 2008, pp 825). All these different innovation types relate to business, but innovations can have impact on society (Smith, 2003). Although a technical innovation has consequences for society and social effects have been studied in relation to these types of innovations, in recent years social innovations have been addressed as a separate innovation type (Howaldt et al., 2010). Based on a review by Howaldt et al. (2010), social innovations can be viewed as a new combination or a new configuration of social activities within particular areas or social contexts under the influence of specific actors or constellations. As for this kind of innovation, it should be socially accepted and spread in the community or specific areas. Lindell (2012) also stresses that the lack of impact on society at large has been neglected when studying innovation, for instance reduction of jobs (examples to the contrary are also available), lead to stress and anxiety, increases risk of accidents, more waste and debris.

Other ways of classifying or dividing innovations are as technical versus administrative, which highlights a distinction between social structure and technology (Gopalakrishnan & Damanpour, 1997). Technical innovations include products, processes and technology used to produce products and services. Administrative innovations relate to organizational structure, administrative processes and "human resources". Another division that Gopalakrishnan & Damanpour makes is between radical versus incremental innovations. A radical innovation involves some kind of fundamental change and departs to a greater extent from that which exists today. Often these examples may be somewhat extreme and then a good complement is to observe the adoption curves showing how different customer groups embrace an innovation (Lindell, 2012). Another similar discussion about innovations is undertaken by Goldsmith & Foxall (2003), who view products on the basis of how continuous or discontinuous their effects are on established patterns of consumption:

- Continuous innovations disrupt established patterns of consumption the least.
- Dynamically continuous innovation has more disruptive effects, does not include new patterns of consumption, but a new product or the change of an existing product.
- A discontinuous innovation establishes new patterns of consumption

Construction Management research on innovation has in general focused on products and processes. The division of innovation into product or process provides clarity, for example in terms of the source and type of resources required for a contractors innovation strategy (Lim and Ofori, 2007). Several researchers use an innovation categorization by Slaughter (2000) (see for example Lloyd-Walker, Mills and Walker, 2014; Gambatese and Hallowell, 2011; Murphy, Perera and Heaney, 2015). Slaughters categorization relates to two dimensions, *the magnitude of change from current state-of-the-art* (pp 227) and *expected linkages of the innovation to other components and systems* (pp 227). Magnitude stretches from incremental to radical and this division has for example been used in construction by Larsson (1992) when studying the adoption of technological incremental innovations on Swedish building sites. Other examples are Widén (2006) and Lloyd-walker et al. (2014). Regarding linkages, innovations are categorized as modular, architectural or system innovations (Slaughter, 2000). *Modular innovations* relate to a significant change within a component and *architectural innovations* a small change in a component but with a major change in links to other components and systems. A *system innovation* implies the integration of multiple independent innovations that must work together to perform new functions or improve the facility performance as a whole. Slaughter captures impact in two dimensions both regarding current business (magnitude) as well as on the construction process (linkages). Harty (2005, 2008) also categorizes according to impact, but in relation to what is possible to influence as within (bounded) or outside (unbounded) a single sphere of influence. Unbounded innovations can result in effects beyond the expected, and are harder to manage than bounded. One additional example is Lim and Ofori (2007) who stress the inclusion of competitive advantage into their classification of construction innovation types. They take their point of departure in benefits and returns that emerge from innovations and classify them into innovations that consumers are willing to pay for, that reduce the contractors' construction costs or innovations that encompass intangible benefits but competitive advantage.

As stated in section 1.2, this research concerns systemic innovations with a focus on inter-organisational effects/consequences and possible effects on the construction process (including its actors and their resources). Interest is not focused on the innovation type as such (product, process etc.) and the systemic innovations studied might also be labelled the same as many of the innovations above. Since systemic innovation relates to a systems view from different levels, this is relevant to innovations that are not considered isolated ideas, products, or practices in the construction process; and was therefore suitable for the innovation type studied in this research<sup>6</sup>.

## 2.4 How does innovation and innovation diffusion take place?

Having reviewed different innovation types, this part addresses how an innovation, as defined in Section 2.1, moves from being a new idea, is developed, how it is diffused and used. Firstly, a review is made of the innovation process viewed as a linear process and as a more interactive process, followed by a review of innovation diffusion and systemic innovation diffusion in construction.

### *2.4.1 The innovation process*

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<sup>6</sup> For a more thorough review, see Paper 2.

The innovation process can be pictured in an orderly, sequential fashion or as different parts interacting to accomplish innovation i.e. a linear or an interactive model as Gopalakrishnan and Damanpour (1997) stresses: some researchers view the innovation process as sequential and linear, while others as convergent, parallel and divergent<sup>7</sup> (for a similar discussion, see Hadjimanolis (2003)). One explanation for this is that with an increasing amount of innovation studies complexity and actual progression become more evident (see for example Marinova and Phillimore (2003) or Rothwell (1994) reviews of generations of innovation models). In addition, models highlight activities that can be controlled or are outside an organization's control to different extents, depending on the level of analysis. When innovation is viewed as a linear process, it is divided into sequential sub-processes as can be seen in examples in the table below. These examples are similar in their steps although they have different names:

Author(s)	Innovation Process Steps
Gopalakrishnan and Damanpour (1997)	- Generation (idea generation, project definition, problem solving, design and development, marketing and commercialization) - Adoption (adoption, initiation and implementation)
Godin (2006)	research - applied research - development - production-diffusion
Marinova and Phillimore (2003)	basic science - applied science and engineering - manufacturing - marketing - sales
Lindell (2012)	Development; creation of test materials and components; prototype development and field testing, adaptation to production and market requirements and launch
Rothwell (1994)	Market need - development - manufacturing - sales

Table 2.1. Examples of linear models

<sup>7</sup> Marinova et al, divide into more models: linear, interactive, system, evolutionary and innovative milieu. The division into linear and interactive models has however been used since all models (with the exception of the linear) stress interaction, although under different conditions.

Rogers (2003), also describes the basic process as moving from recognizing a problem or need moving through research, development, commercialization, diffusion and over into consequences<sup>8</sup>. OECD (2005) defines the activities more broadly as all scientific, technological, organizational, financial and commercial steps that lead to or are intended to lead to the implementation of innovations. One criticism regarding these linear types of models is that they are too orderly and structured. Innovations often evolve and there is a lot of experimentation and learning throughout the process (Lindell, 2012, Marinova and Phillimore, 2003). Another criticism is that they are extreme examples of the innovation process that does not really show the interaction and feedback that takes place in the process (Rothwell, 1994, Kline and Rosenberg, 1986). Lindell (2012) also highlights that in the early "innovation phases" consequence analyses for the later stages should be made. Altogether, this criticism motivates the second view on the innovation process as presented in this thesis.

Several authors also see the innovation process as a complex process with multiple, clustered, linked steps of convergent, parallel and divergent activities. Another type of innovation model is system models, which view innovation as a system, emphasizing interaction, inter-connectedness and networks among companies (Marinova and Phillimore, 2003). Examples are given in the table below:

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<sup>8</sup> He however also raises that steps do not necessarily take place in a linear fashion, but can be iterative between the stages.

Author(s)	Model name	Description
Kline and Rosenberg (1986)	Chain linked model (interactive)	Building on interaction between elements research, potential knowledge, invent and/or produce analytic design, detailed design and test, redesign and produce and distribute and market. This continually builds up needed knowledge.
Birkinshaw et al (2008)	Management Innovation (interactive)	Internal and external change agents interacting with each other over a number of different areas also interact in the management innovation process.
Rothwell (1994)	Coupling model (interactive)	Logically sequential, not necessarily continuous process, in a series of functionally distinct but interacting and interdependent stages.
Etzkowitz and Leydesdorff (2000)	Triple Helix III (system)	Consisting of the three spheres state, industry and academia that aim to realize an innovative environment consisting of university spin-off firms, tri-lateral initiatives for knowledge based economic development, strategic alliances among firms, government laboratories and academic research groups.
Freeman (1995)	National Innovation systems (system)	A set of institutions that jointly and individually contribute to development and diffusion of providing a framework for the implementation of government policies influencing the innovation process (system model), most important feature its inter-connectedness, the way various elements interact.

Table 2.2. Examples of interactive and system models.

It can be noted that these models differ in their level of analysis. They can for example be viewed from a local, regional, national or international level (Hadjimanolis, 2003) or as in some examples above on a company level (Rothwell, 1994 and Birkinshaw et al., 2008). To conclude this section, the innovation process may be viewed differently concerning how it progresses, and the progression reflects how manageable it is. Furthermore, it can be viewed from different levels. This research focuses on the inter-organizational construction process level, i.e. the construction process, its actors, their resources and their interaction.

#### 2.4.2 Innovation diffusion and systemic Innovation diffusion in construction

One significant part of the innovation process is the diffusion process. Innovation diffusion, i.e. “the process by which an innovation is communicated through certain channels over time among the members of a social system” (Rogers, 2003, p35), relates to the adoption and diffusion of new ideas, methods and products within a social system (Howaldt et al., 2010, OECD, 2005). In the former review of the innovation process, the diffusion process is displayed, for example as a second phase according to Gopalakrishnan and Damanpour (1997) (adoption, initiation and implementation) or in production-diffusion (Godin, 2006). Both historically Godin (2011) and by reviewing innovation models (Godin, 2006), Godin claims that diffusion is a

central part of the innovation process. However, Tidd (2010) stresses the need for more understanding as to why and how innovations are adopted. Rogers (2003) describes diffusion from the perspective of both individuals and organizations. The diffusion process of individuals consists of five stages 'knowledge stage, persuasion stage, decision stage, implementation stage and confirmation stage'. Rogers (2003) also covers diffusion in organisations: this process being much more complex since it involves a number of individuals who play a role in different types of decision-making. These decisions relate to activities leading to the decision to adopt (agenda-setting and matching) and implementation (redefining/restructuring, clarifying and routinizing). Agenda-setting regards defining a problem and/or a need for an innovation and can be initiated by the knowledge of an innovation. Matching relates to matching needs or problems with an innovation. Redefining/restructuring concerns reinvention of the innovation to fit to the organization or adjustment of the organization to fit with the innovation. Clarifying is the stage when the innovation is more widely used and gradually becomes clearer for the organization. Routinizing regards when an innovation becomes incorporated into regular activities of an organization. A central part in this process is that the innovation is modified and reinvented in the implementation phase, displaying the process as more iterative. Rogers also discusses other important elements, for example the consequences of innovations. Rogers emphasizes a look beyond the diffusion and the inclusion of how innovations are used, which can show effects never intended.

Rogers is frequently referred to in innovation diffusion research in construction management (see for example Emmitt, 1997; Larsen, 2011; Shibeika and Harty, 2015). Emmitt (1997) studied whether Rogers's paradigm could be applied to the UK building industry. Emmitt pictures the building industry as complex especially in terms of relationships affecting each other. The need for a product initiates a search for a new product, not awareness of it. After his enquiries, he extended Rogers model by adding tender action as a sub-stage of decision making and extended implementation with specification substitution. Larsen (2005), influenced by sociology, divided the process into six stages<sup>9</sup> to reduce the positivist language, and placed emphasis on the early stages of the process: awareness, interest, opinion forming, decision making, use and promote/impede. Larsen has made several studies on diffusion (see for instance (Larsen and Ballal, 2005, Larsen, 2005, Larsen, 2015, Larsen, 2011) and has contributed with a better understanding

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<sup>9</sup> Rogers (2003) originally uses the five stages the knowledge stage, the persuasion stage, the decision stage, the implementation stage and the confirmation stage (pp 171-194).

of the innovation diffusion process in construction regarding how actors beliefs, attitudes and behaviour change through the diffusion process, how they are influenced in their networks and shaped by their contextual setting and broader institutional forces. Larsson (1992) focused specifically on adoption decisions and concluded that the site manager is a key actor taking many individual decisions in the stressful construction context. Trusted and established methods and solutions were preferred to reduce risk taking and explains the rejection of new ideas, a finding also shown by Emmitt (1997). Samuelson and Björk (2013) researched what levels decisions are made regarding project documents on web servers (EDM), electronic handling of orders and invoices between companies (EDI) and BIM, and concluded that they originate from where decisions are made and refers to the innovation process of an organisation, as defined by Rogers (2003). Shibeika and Harty (2015) also describes the diffusion of digital innovation as “multiple and partial... showing a range of activities and dynamics of a non-linear diffusion process” (p 1). They also refer to the innovation process in organizations, since it places more emphasis on the interactive elements in the process, such as reinvention to match the context in which it is diffusing. Overall there are, of course, researchers who manage diffusion and related issues under other themes with findings that resemble those of Shibeika and Harty (2015). One example is Vass and Gustavsson (2017), who show inter- and intra-organizational challenges in BIM-implementation and the process as being non-linear and with issues to resolve during implementation. However, regarding Rogers (2003) view of diffusion in organizations, as far as the author is aware, it is quite seldom mentioned in construction diffusion research thereby showing research potential.

According to Rogers, diffusion is a type of social change, “defined as the process in which alteration occurs in the structure and function of a social system” (p 6). A social system consists of interrelated units engaged to solve a problem and accomplish a common goal. The members or units may be individuals, informal groups, organizations and/or subsystems (p 23). Hence every diffusion study has some kind of social system to investigate. One reflection is that many researchers seem to follow a linear picture of the diffusion process when discussing it, although many pinpoint that the process is not always conducted in an orderly fashion. As shown in the section on the innovation process and by studying (Rogers, 2003), processes may be iterative and complex, not straightforward. Rogers (2003) also states that diffusion must be understood in the context of time, communication channels and its impact on all participants. One of his essential contributions regards the categorization of people into adopter categories and how they

respond to change: Innovators, Early Adopters, Early Majority, Late Majority and Laggards. At the centre are people's attitudes and beliefs which are affected by different factors throughout the diffusion process and they form one part that explains the diffusion process.

Since diffusion is about social change, it also has a natural relationship to change management. The influence from people's perceptions on the change process is also evident in, for example Carlsson (2000). Carlsson has also used the interplay between content, context and process as a point of departure in his research on operative changes but places a special emphasis in the change process itself (with the influence of the interplay as a factor). He defines a change model as fundamental assumptions about how changes are carried out and the mechanisms at play in the change process. He uses theory from the research areas strategic change and learning organization as he presents three different types of approaches: linear, processual and circular. The linear model is most suitable for less extensive changes and assumes that the change is formulated, decided and then implemented. Changes are considered to be a process of rational decision-making, where changes take place in a stepwise model. One example in construction research is the Price and Chahal (2006) strategic framework for change management. This model consists of six steps; preparing the organization, developing the vision and implementation plan, checking, communications and workforce engagement, implementation and evaluation.

When the scope of change increases, the process approach which regards changes as social processes and considers political processes is more suitable. The process model does not assume rationality but that a critical mass of actors is necessary to carry out a change process. A social process leads to the development of structures. Actors act according to different views of reality. The model assumes a clear relation between formation of the change process and its implementation. Hence, how formation is carried out exerts effects on implementation. For more extensive changes where new mental models are developed, a circular model which regards changes as circular learning processes is more appropriate. Changes take place in the interaction between learning and doing and the model focuses on the interaction between action, observation and reflection. Actors develop new mental models through their own actions.

To summarize, this review has described how there is a potential dynamic in a diffusion process that adds additional understanding. Depending on the type of innovation and its impact, this influences the progress of the diffu-

sion process and how it influences people in the diffusion process is a central influencing factor. Following this, diffusion processes are different depending on the interplay between their content, context and process. Not least is it important to assess the individuals that take part in the diffusion and their knowledge levels. This addresses the importance of working with the second focus area of the thesis, knowledge integration. However, before moving into this area, contributions from previous research regarding the influence of context, content and process on innovation diffusion and systemic innovation diffusion in particular are reviewed.

## 2.5 Influence of context on innovation, innovation diffusion and systemic innovation diffusion

Several researchers emphasize the influence of context on innovation and thereby innovation diffusion, for example Rip (2012) who stresses that innovation depends on the context but can analytically be handled separately when the context is institutionalized: general structures, patterns and layers of context influences innovation. One part in Rips (2012) analysis is that new technology usually fights alongside the old and "everyone" knows that a replacement will take place (compare with path-dependency, see for example Mahapatra et al., 2012) but actors and activities may become dependent on each other and not "move" independently. Brown and Duguid (1991) connects learning with innovation and stress that what is learned is deeply connected to the conditions (context) in which it takes place. Hemlin et al. (2008) also stress that creative knowledge environments are crucial for innovation. In creative knowledge environments how individuals, groups and their environment interact to create positive influences is central. There are specific environmental factors that interact to create creative potential; active participation, lively and supportive internal and external communication, necessary resources, high levels of motivation and job satisfaction, good selection of staff, good individual competencies and traits, outstanding leadership, quality management and an institutional base with good reputation and visibility. Studies of innovation environments have found that although these have integrative structures, they seem to emphasize diversity, exhibit multiple structural links internally and externally, show flexible or permeable boundaries, a sense of collective pride and belief in the individual's ability, believe in collaboration and teamwork, which is similar to research on research environments (Hemlin et al., 2008).

Regarding these characteristics several sources imply that managing the dynamics of the innovation process is a challenge. Hemlin et al. (2008),

referring to Kanter (1996), stresses that different stages of the innovation process have different requirements for its context, implying a need for a dynamic and alert approach throughout the innovation process. Moreover, behaviour, attitude and feelings in the organization exert an impact on creativity. According to Rip (2012) leaders with the ability to handle context are most likely to be more successful. Based on work-team environment studies, there are many contextual factors that influence creativity and innovation. However, there is no optimal working structure, size or leadership style for creativity; it appears to depend on the phase of a specific process. Innovation is also linked to the turnover of people in the group as social interaction is important for creativity in different forms of groups. It is also important to encourage informal contacts between people. Rip (2012) also highlights that innovators are often creative mavericks with a limited interest in building relationships. One conclusion in Rip is that there are no simple formulas to support creativity, but it is possible to draw some conclusions as to the fact that individuals are central. Successful creative environments require a special leadership and work/style in which the leader supports creativity, where the team has significant autonomy, and where "self-leadership" and social interaction are prominent. Workgroups reward diversity and adaptation should not be over-emphasized. It is also important to distinguish between the different stages of the creative process. To conclude, the overall impact of context is substantial and constitutes many challenges.

The importance of context has also been stressed in innovation diffusion research in construction, both as criticism regarding research conducted and as included in research. Several researchers have criticized research for not including the context correctly, providing inadequate results and conclusions. Larsen (2011) for example sees the connection and importance of contextual settings as over-simplified in innovation diffusion research. Widén (2006) points out that existing theory should be assessed critically and contextualized for the sector. Innovation diffusion research in construction and contextual factors research has focused both on the inner and outer context, but they are not always easily separated. A summarizing view on innovation in construction is that much research focuses on the outer context when dealing with the construction environment on an overarching level. The Egan Report (Egan, 1998) for example focused on the construction sector as a whole and gave several examples of changes that are necessary in construction as a whole and the report is often referred to in construction management research (see for example (Dainty et al., 2001, Ness, 2010), but has been criticized for not considering the construction context

and conditions (see for example Bygballe et al., 2013, Green, 1999). Winch (1998), addressed the construction innovation problem at the institutional and company level, consisting of the innovation superstructure on one side (clients, regulators and professional institutions) and the innovation infrastructure on the other (trade contractors, specialist consultants and component suppliers). In between are systems integrators (principal architect/engineers). Winch concludes that the innovation superstructure and infrastructure must change to enable a better dynamic between the parts in the construction system, a dynamic that may be different depending on the total situation. What can be concluded from Winch is that many factors interact and influence innovation diffusion, which can differ depending on the actual situation. In this case, where the research has an inter-organizational focus, inner context is interesting from the point of view of how it interacts with outer context.

Winch emphasizes that for construction, innovations have to be implemented in projects and the role of an individual firm within construction influences the innovativeness level. The project-based setting is also the most influential factor for innovation diffusion in construction, often accompanied by a short-term relationship and financial perspective (Widén and Hansson, 2007, Winch, 1998, Barlow, 2000, Forman, 2013). Each new project can bring new features and conditions (Sullivan et al., 2010), which in turn influences diffusion. Taking a traditional manufacturing company as an example, manufacturing takes place at specific locations, distribution channels are set up and preceding development can take place through different tests before a product is sent into production. During the period of manufacturing, stepwise improvements can take place under conditions that can be regarded as fairly static. Construction on the other hand, takes place in projects, at different locations with different conditions and this altogether creates a special context with consequences on a number of innovation and innovation diffusion related areas. Other issues can also be raised. A building is a system of many interacting components that work together with its environment. Since changes in one part can lead to changes in other parts, this implies complexity (Winch, 1998, Slaughter, 1998, Widén and Hansson, 2007, Barrett and Sexton, 2006). Buildings can most often only be tested in full scale and have to last for many years (Slaughter, 1998).

### *2.5.1 Contextual factors influencing systemic innovation diffusion*

Taylor (2006) presented constructs influencing diffusion of systemic innovations that can be viewed as contextual, with their major focus on structure

and organisation in the construction process (i.e. covering dimensions in both the inner and outer context). These constructs identified by Taylor were; organisational variety, the change in the population of contractors from project to project, how many different boundaries an innovation spans; and scope. High levels of organisational variety and a large span are negative for the diffusion of innovations (Taylor and Levitt, 2005). When the *scope* moves from incremental innovations to systemic innovations, diffusion is affected negatively. One conclusion that can be drawn from Taylor is that diffusion relates to the scope of the innovation and its fit in the current structure, but also how it affects the flow of inter-organizational knowledge, since the more parties, processes and products that are affected, additional knowledge flows and exchanges come into play (Taylor and Levitt, 2005). With higher complexity, multiple companies are required to change their processes and/or routines in a coordinated fashion. This can result in change and redistribution of work between design and construction companies (Taylor, 2006).

Other research has also described dimensions in both the inner and outer context as influential on diffusion. As an example, Miozzo and Dewick (2002) presented three contextual factors related to corporate governance influential on diffusion 1) the structure of ownership and management of contractors 2) institutions within the firm that facilitate diffusion of new processes and practices across different divisions and 3) long term relations between companies and collaborations with external sources of knowledge (pp 1005). Where there are opportunities to invest in research and development but also an organizational structure that facilitates implementation of innovations, this is positive from an innovation diffusion point of view, in combination with the factors stated by Miozzo and Dewick. Research has also focused on clients and contractors, since they control the construction process through the design of contractual arrangements, which sets the pre-conditions for the innovation climate and other actors behaviour (see for example Miozzo and Ivory (2000). Other studies also emphasize the behaviour of end-part actors in the construction process (see for example (Loosemore and Richard, 2015, Winch, 2003)), i.e. involvement of and by the client. This dependence on end-part actors in the construction supply chain is also shown in Larsson et al. (2006)) in their studies on building component manufacturers role in the innovation process. Innovative suppliers interact and communicate with their customers to a greater degree. One consequence from these sources regarding systemic innovation diffusion, is that actors downstream the construction process, often control the construc-

tion process, but interaction is anyhow needed across the construction process.

## 2.6 Knowledge integration in an innovation context

Having covered the overarching theme in this thesis, innovation and innovation diffusion, the thesis now moves into another focus area, Knowledge Integration (KI). According to a review by Tell (2011) of 46 publications on KI, this is about division, integration and coordination of knowledge (however it lacks a general definition). It involves economic agents such as individuals, groups and organizations. Tells (2011) review distinguishes between three interpretations of knowledge integration (a) knowledge sharing, (b) knowledge relatedness, and (c) knowledge combination (p 21). In addition, three approaches on knowledge integration were identified;

- (i) as sharing or transferring knowledge,
- (ii) as use of similar/related knowledge
- (iii) as the combination of specialized, differentiated but complementary knowledge.

Of these approaches (i) and (iii) are the most common. A point in (i) in addition to that it emphasizes transfer (which from one point of view is inefficient) is that some kind of sameness is necessary for integration to occur and innovation requires both breadth and width in terms of knowledge. In (ii) it is stated that individuals specialized in certain areas more easily integrate knowledge and the focus here is on depth. Approach number (iii), does not emphasize sharing and states that combining is preferable from an economic perspective.

Tells literature-review emphasizes that knowledge integration focuses on how differentiated knowledge can be effectively integrated when economic activities are undertaken, where classification of knowledge into specialist capability and ability to generalize, i.e. trans-specialist understanding, is at the centre. These types of knowledge are necessary to solve problems in an overall efficient manner, but a challenge lies in deciding how much trans-specialist understanding should be developed since it does incur costs (Postrel, 2002). To exemplify this, a design might meet functional demands regarding physical strength, but be difficult to manufacture i.e. the design meets one type of requirement but not another. Visible in this example, is that specialist understanding works to solve specific issues, but trans-specialist understanding regarding manufacturing is missing, a type of

knowledge that is necessary in the development of a product, however its' lack also adds costs for KI. This type of reasoning is also evident in Grant (1996, 2013), who emphasizes the division into specialist and general knowledge when dealing with how knowledge integration can take place, what results are achieved and that one type of knowledge requires the other. As can be noted, efficiency in integration is a central concept, and Grant (1996) places a lot of emphasis on coordinating knowledge as efficiently as possible. The key is to create efficient mechanisms that economize on learning, not always leading to individuals developing knowledge but different individuals, or professions, executing tasks that require different types of knowledge as efficiently as possible. One key issue, however, regarding innovation and KI, is knowledge development or creation. Tell (2011) concludes that absorption, recombination and integration of external or unfamiliar knowledge is essential for innovation, or as Berggren et al. (2011) puts it "different knowledge bases – well established as well as newly generated – have to be combined and integrated in order to achieve new, functional products or solutions (p 4)". From an innovation point of view, knowledge integration is also a process of creating new knowledge (Berggren et al. 2011) and this is another view than the one described by for example Grant, emphasizing efficient KI. Furthermore, application of existing and creation of new knowledge are intertwined (Berggren et al. 2011). Primarily due to the innovation perspective in this thesis, this is the view that this work is focused on.

Paper 4 and 5 highlighted Rundquist (2009) in relation to KI, who stresses the importance of combining new knowledge with an existing knowledge base, where common knowledge plays a key role (Grant, 1996). Another source used in the appended papers stressing the usefulness dimension was Jetter et al. (2006), who defined knowledge integration as processes of external knowledge identification, acquisition and internal utilization of external knowledge (p 1) (see also Kraaijenbrink et al., 2007). As stated in the papers, external knowledge was viewed as knowledge outside the specific context, and not outside company boundaries as the references. An interacting view of the parts of the Knowledge Integration Process, was also emphasized, since knowledge processes in practice interact and influence each other (Kraaijenbrink, 2012). The research presented in this thesis, mostly relates to the area denoted (i) above but uses influences in some ways from all areas.

## 2.7 Knowledge and knowledge types

As shown, KI can concern different types of knowledge that should be integrated. Two other classic, but opposing views are the qualitative and quantitative perspective of knowledge (Svedberg, 2007, Gustavsson, 2000). The quantitative perspective views knowledge as something to study and memorize, i.e. a measurable product. The opposing qualitative perspective views knowledge as a process in which people are active and seek knowledge, which is not always measurable. This has effects on how peoples learning are viewed and takes place. This research relates to a qualitative perspective with its interest in the knowledge integration process and how it takes place. It also takes its point of departure in viewing people as active in the KI-process in search of knowledge that is useful.

As can be seen, the view of knowledge related to the research approach. Polanyi (1962) state that knowledge created in research is dependent on the context in which it takes place and its (research) traditions. However, there is always an element of personal knowledge in every individual that is not possible to express or as Polanyi (1966) puts it “one can know more than one can tell” (p 8). This relates to the concepts tacit and explicit knowledge, introduced by Polanyi (1962, 1966). Explicit knowledge relates to knowing what (Grant, 1996) and the ability to articulate, i.e. the opportunity to express and present knowledge (Polanyi, 1962). Tacit knowledge relates to knowing how (Grant, 1996), which Nonaka and Takeuchi (1995) divides into a technical dimension (related to knowing how) and a cognitive dimension. The cognitive dimension relates to “schemata, mental models, beliefs and perceptions so ingrained that we take for granted” (pp 8). This also complicates the transfer of tacit knowledge or as Nonaka (1994) states:

“People do not just passively receive new knowledge; they actively interpret it to fit their own situation and perspectives. Thus, what makes sense in one context can change or even lose its meaning when communicated to people in a different context.” (p 30)

The interest in tacit and explicit knowledge has also received attention in CM research to characterize knowledge and how it is managed in the construction sector (see for example (Carrillo et al., 2006, Carrillo, 2004, Senaratne and Sexton, 2008, Robinson et al., 2004). A similar division has also been used by Styhre (2008), who discusses personal knowledge of individuals in relation to an organization’s formalized knowledge in procedures and systems. Construction, as will be shown in this section, can be

characterized as a “social” sector, where knowledge is very much tied to people and communities (see for example Bresnen et al., 2005) and as a sector with a large amount of tacit knowledge that cannot be fully codified (Addis, 2016). However, as Addis (2016) points out, the dominating objectivist knowledge management approach in construction management research provides certain contributions for the field, but it neglects knowledge as a part of a social practice, consequently another approach is useful for studying the tacit dimension of knowledge.

Although for example Bresnen et al. (2005) has stated that codified knowledge and codification strategies might be less suited to the construction sector, as highlighted in the introduction (section 1.3) there is an interest among construction companies in using explicit knowledge to a greater extent, relating to the concept codified knowledge. Explicit knowledge can be codified and tacit cannot (see for example (Grant, 1996, Mezher et al., 2005)). Codified knowledge, is a result of a process converging knowledge into messages processed as information (Cowan et al., 2000). The main motive here is to increase efficiency. In general, knowledge that is codified and commodified is suggested as simplifying knowledge transfer and its associated transfer costs (Cowan et al., 2000), thereby addressing an efficiency perspective. Prencipe and Tell (2001), who uses Zollo and Winter (2002), views the codification process as consisting of experience accumulation, knowledge articulation and knowledge codification. The process of converting tacit knowledge to explicit has also been studied and emphasized by Nonaka and Takeuchi (in different sources and with different co-authors) with a focus on knowledge creation, which is in line with the innovation-perspective in this thesis (see section 2.6). Tacit and explicit knowledge interplay in making knowledge explicit and in creating organizational knowledge (Nonaka, 1994). In their various writings (together, alone or when writing with others) they emphasize management of this knowledge process as essential to stay competitive. Making tacit knowledge explicit is of importance in their so-called SECI-model. The model relates to steps that must be taken in order to achieve this; Socialization, Externalization, Combination and Internalization (Nonaka, 1994, Nonaka & Konno, 1998):

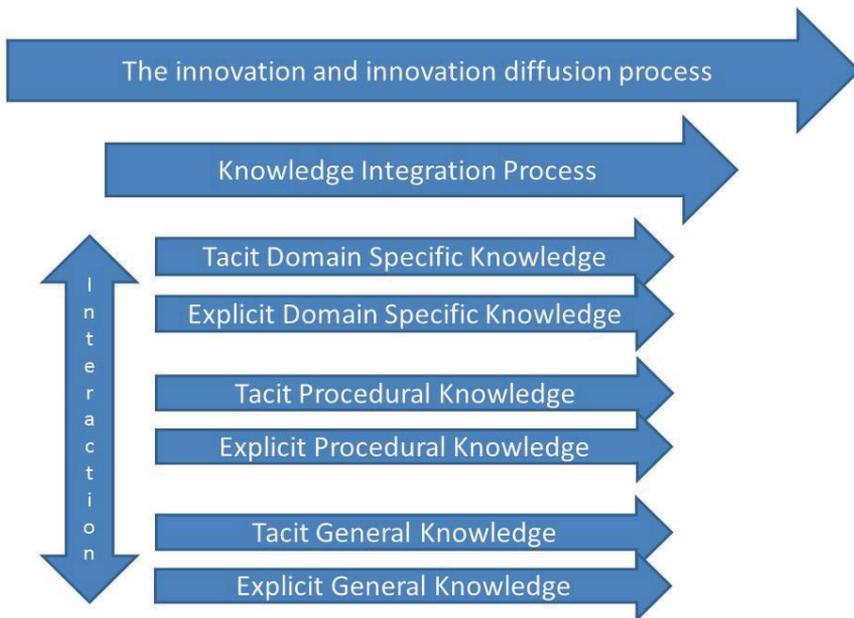
- Socialization refers to sharing tacit knowledge between individuals (for example the learning system between master and apprentice or on-the-job-training). For this to take place, shared experience of some kind is necessary.

- Externalization refers to the process of making tacit knowledge explicit. This requires the ability to make tacit knowledge understandable to others, i.e. a good level of ability in making it comprehensible. This includes different ways of expressing ideas and thoughts such as words, concepts, metaphors, narratives etc.
- Combination regards the conversion of explicit knowledge into more complex sets of knowledge revolving around communication, diffusion and systemization of knowledge. Three processes are key; capturing and integrating new explicit knowledge, dissemination of explicit knowledge by direct transfer through meetings and presentation and finally making (editing) explicit knowledge more usable.
- Internalization regards the process of making newly-created explicit knowledge into an organization's tacit knowledge and rests on the ability of individuals to identify useful knowledge. It is important to embody explicit knowledge into action and practice. This stage often results in an end product, for example a product or a system.

Although this process might seem rather straightforward it involves a considerable amount of interaction and iteration. For construction, with the SECI-model in focus, learning and codification needs to take place over several projects (Sexton and Barrett, 2003). When studying this model in a construction context, Senaratne and Sexton (2008) found that knowledge is transferred through the project participants heads and a primary conclusion was that there are difficulties with reaching the final stage of the SECI-model in construction. Although there are many techniques that could be used to transfer knowledge, construction mainly uses social interaction. Therefore, emphasis must be placed on the inter-project social system and not the inter-project technical system. One main argument is that codification strategies ("hard-strategies") must be balanced with "soft-personalization" strategies. This would enhance creation, dissemination and shared understanding of tacit project experience. It also contains a lot of nuances and sub-contexts, depending on the individuals involved. Similar points are also made by Addis (2016) i.e. due to the substantial amount of tacit knowledge in construction, codification needs to be balanced with "softer" methods of a more social character.

Although the division into tacit and explicit knowledge is useful concerning how knowledge is and can be transferred, this research complements the current use of tacit and explicit knowledge with the additional knowledge

types domain-specific, procedural and general knowledge, due to their significance in previous new product development (NPD) and innovation studies outside construction (see for example (Frishammar et al., 2012, Rundquist, 2012, Court, 1997, Ramesh and Tiwana, 1999, Ullman, 2010). Defined in the introduction, these interacting knowledge types show relevance for knowledge necessary throughout the innovation and innovation diffusion process. As previously shown the knowledge types can be of importance to contextualize knowledge (integration of domain-specific and general knowledge, Frishammar et al., 2012, see introduction), or as procedural knowledge has shown to be necessary for the development process (Lichtenthaler and Ernst, 2009). By complementing the current use of tacit and explicit knowledge with these knowledge types, the argument in this research is that this can nuance the understanding of knowledge integration in the construction innovation context. As shown in figure 2.1, domain-specific, procedural and general knowledge may be tacit or explicit, and they interact through the innovation, innovation diffusion and knowledge integration processes:



*Figure 2.1. The interaction between different knowledge types in the studied processes.*

## 2.8 Knowledge Integration mechanisms

Mechanisms for knowledge integration deal with how knowledge is integrated. According to Almeida et al. (2002) it is essential to consider the objective of a process for the design and choice of mechanisms, for example whether it is about replicating, combining or applying knowledge in a new setting. With the efficiency perspective that Grant (2013) rests on, the challenge for coordination lies in the efficient use of mechanisms that exploit different individuals' knowledge in the production of a particular product. However, since this thesis combines the efficiency and innovation view, mechanisms should integrate the knowledge generated as efficiently as possible. It is inevitable that different types of interactions and interdependencies need to be mastered through different types of mechanisms and this changes over time (Berggren et al., 2011), but from an innovation perspective the aim should be to use mechanisms to generate and integrate knowledge.

When specifically viewing mechanisms, interaction is a key concept and the level differs depending on the type (Van De Ven et al., 1976, Grant, 1996). Johnson (1992) states that innovations that are more advanced, scientifically or technically, require more complicated communication processes. One example is technological change, which demands social interaction, for example dialogue and conversation, between the parties involved and affected. Examples of mechanisms with different amounts and ways of social interaction are learning-by-doing, learning-by-using and learning-by-interacting (Johnson, 1992, referring to Arrow, 1962, Rosenberg, 1982, Lundvall, 1985). Some authors, for example Sarv, 1997, also pinpoint the fact that the capability of learning is developed gradually and learning needs to be organized. In addition, increased knowledge has been stated as stimulating innovation i.e. knowledge is essential for innovation capacity (Berggren et al., 2011). To summarize there are different ways of integrating knowledge which influences the stock of knowledge. Since innovation depends on knowledge, mechanisms and their effects exert a direct influence on knowledge, which in turn affects our capacity to innovate. Based on knowledge integration literature and from an innovation point of view it is central to focus on knowledge generation and how knowledge is spread and integrated.

Prencipe and Tell (2001) studied codification in project-based companies. One point is that for functionally based companies their departments act as knowledge silos, and this natural type of organizational mechanism is not

evident in the same ways as for project-based companies that need to transfer knowledge acquired in one project to other projects. The temporary and unique nature of projects furthermore undermines organization-wide learning in project based companies (Brusoni et al., 1998). In the studies of project-based firms, Prencipe and Tell (2001) show the use of different mechanisms (in their case denoted typologies) with a special interest in the use of codified knowledge. It is quite evident that companies work with different mechanisms simultaneously. Construction is no exception and mechanisms, drawing on the review made in Paper 4, are characterized by combinations of rich (high interaction intensive media, for instance meetings) and lean media (low interaction intensive media, for instance written messages) (Bröchner et al., 2004). The use of combination of mechanisms is also emphasized by Senaratne and Sexton (2008). In studies of mechanisms, Carrillo et al. (2006) found post-project reviews as most useful to facilitate the application of best practices. According to Rooke and Clark (2005) construction workers in general learn in three ways: (1) by *'watching more experienced co-workers'*; (2) by *'trying things out'*; or (3) by *'direct instructions'* (p. 566). Styhre and Gluch (2010) research on the use of platforms, standardized packages of prescribed components, routines and components, found platforms potentially useful for sharing and accumulating knowledge. These examples add further to the notion different mechanisms are used depending on the characteristics of tasks, knowledge and relationships (Tell, 2011).

Although it is of interest both academically and practically to know the methods that are used and where they are used, in this thesis a main focus regarding mechanisms is on efficiently integrating knowledge created, with the stated interactive view of the KI-process in this research as a basis. The level of interaction is a central point of interest due to its direct relationship with efficiency. However, the primary focus is on innovation and knowledge generation. According to Van De Ven et al. (1976) the level of interaction depends on coordination type and level of insecurity, i.e. difficulty and variability in work performed. With higher levels of insecurity it is more complicated to coordinate with programming (impersonal methods such as plans, schedules and formalized rules), which may require coordination and decision making in groups. Another influential criterion on the interaction level is *dependence*, i.e. the need for an activity to be executed by several people. As previously stressed, innovation diffusion can be highly influenced by insecurity, and this might lead to the use of more interaction intensive mechanisms. The need for coordination in groups also increases with increasing dependence. Grant (1996) classifies complementary

mechanisms according to their interaction level. Following their interaction level, the first is impersonal methods under the heading *Rules and directives* (plans, schedules, forecasts, rules, policies and communication systems). *Sequencing* regards organizing production activities in sequence giving specialists time to do what they need to. *Routines* are performed automatically and are conducted automatically and simultaneously, when implemented. *Group problem solving and decision making* differs from the first three since it adds costs for learning and communication. With growing complexity and insecurity the need for the final mechanism increases. The research presented uses these four mechanisms as its foundation.

To conclude, reviewing the construction process a number of trades participate in the creation of a construction object, for example a building or a bridge. For systemic innovation diffusion, different types of knowledge are used, which requires different types of mechanisms depending on the knowledge in focus. In addition, depending on how disruptive the knowledge integration process becomes due to the project-based work method, this constitutes a challenge. Hence to manage this challenge, knowing the mechanisms to use, when and why is of central importance. Choosing the level of interaction as a point of departure relates to an efficiency perspective and in this thesis this means effective integration of created knowledge, which is especially interesting in construction with its disrupted knowledge flows which complicates KI and place even higher pressure on being effective.

## 2.9 Effects from the knowledge integration process

One important overarching parameter regarding innovation is to contribute to companies competitive advantage, i.e. a unique position in relation to competitors and customers (Christopher, 2011a). From an innovation point of view generation, creation and integration of knowledge is a primary point of interest and thereby its assessment is natural. Since systemic innovation diffusion is in focus, how the mechanisms contribute to the diffusion of innovations is also a central concern as well as possible effects on the construction process.

Value parameters that specifically address knowledge integration according to Grant (1996) (pp 111-112) are transferability, capacity for aggregation, appropriability, specialization in knowledge acquisition and that knowledge requirements for production are met. The transferability of knowledge was stated as being of critical importance, as well as a prerequisite for the ability

to add knowledge to an existing knowledge base, i.e. capacity for aggregation. The usefulness of knowledge and whether it contributes to return on investments is addressed in its *appropriability*. It is, as emphasized above, having people with diverse skills performing different tasks is an important part of an organization and this places emphasis on *specialization in knowledge acquisition*. A main point here is that if knowledge is too general it does not add value. A final parameter is that *Knowledge requirements of production* are met, in producing goods and services of value to a company. Setting these parameters in relation to the research presented here, the value in created knowledge and its use for the systemic innovation is at the centre, and due to the focus of this research, it is central for the construction process in total. However, this adds complexity to the assessment, due to the scope of the assessment and the limits that are set for it.

## 2.10 Summary

This chapter has reviewed the innovation concept, innovation types and levels of analysis in innovation research. This research focuses on the inter-organizational effects/consequences of systemic innovations and its diffusion on a construction process level. Innovations are regarded both as a process and a result that is perceived as a significant change for its users. The research rests on the assumption that the innovation content, the innovation diffusion process and the innovation diffusion context interact and explains the outcome of the innovation diffusion process. The influence of these dimensions in previous research has been reviewed. Managing the interaction between content, process and context requires coherence between different factors. When setting this in relation to construction and the stated research problem, construction is a challenging sector, due to its decentralized business environment with work taking place in projects. Diffusion of systemic innovations requires implementation over several projects, affecting several parties from different organizations in the construction process. Actors in the end part of the construction process, such as clients and contractors are seen as those who have to manage and control innovation, but this is challenging due to the disruptive nature of the construction sector and diffusion into different project contexts, where different individuals take part. These characteristics form a primary difference compared to the main reference regarding the interplay between content, context and process, Pettigrew and Whipp (1991). Their research focuses on organizations that more or less controlled the strategic change process. Adding to the complexity, according to Rogers view on innovation in organizations, the innovation process is non-linear and characterized by re-invention. Hence,

as Taylor and other researchers has found, systemic innovation diffusion is largely dependent on the impact it exerts on the construction process.

The influence of the project-based, decentralized business setting is also apparent in the second major area of the theoretical frame of reference that reviewed knowledge in an innovation context, knowledge and knowledge types, mechanisms and effects. In this part of the frame of reference, the concept Knowledge Integration was reviewed and its meaning in an innovation context was explored. Knowledge creation is essential and new knowledge needs to be integrated, altogether in an interactive process. In this research, KI is seen as a process of knowledge identification, acquisition, and internal utilization of external knowledge (knowledge outside the specific context) in line with Jetter et al (2006), where the different parts interact in the KI-process. Knowledge and knowledge types per se have also been reviewed. Tacit and explicit knowledge is commonly used in research about how knowledge and KI should be managed. The main interest lies in transferring knowledge from tacit to explicit, but this is challenging for the construction sector due to its project based and decentralized business setting, in this case due to disruptive knowledge flows. In order to provide nuances in the KI-process from an innovation perspective, the knowledge types domain-specific, procedural and general have been defined and are used as a complementary division of knowledge in this research, due to their usefulness in previous innovation studies outside construction. These are regarded as complementary to tacit and explicit knowledge and are used to nuance knowledge development in an innovation context. How knowledge is created and integrated, i.e. the mechanisms that are used, is finally reviewed, where the interaction level is a point of departure due to its relationship to efficiency and finally effects were reviewed and presented. Based on previous studies, the use of explicit knowledge is regarded as essential to manage KI and innovation, but there is a challenge in construction due to its extensive use of tacit knowledge, and furthermore, some knowledge always remain tacit and is also interpreted to fit peoples own situation and perspectives.

The final section reviewed different types of effects from the knowledge integration process in order to provide factors to assess for the last research question. The value in created knowledge and its use for the systemic innovation is the primary interest. However, major complexity lies in the scope of the assessment, i.e. the limits that are set, and the conclusions drawn from this.

## 3. Methodology and method

*This chapter presents and reflects on what has been done and why. It aims to show awareness of methodology and method. It starts with the basic assumptions of the research since this affects the research process. Then the research process, its activities and the systemic innovations studied are described. This includes methods and approaches used and how collected data has been compiled, as well as how the appended papers are connected. The chapter ends with a discussion of the quality of the research conducted.*

### 3.1 Critical realism and qualitative research as points of departure

One point of departure, and a central part in research, explicitly or implicitly, is the researcher's view of the world (or methodological view) since this affects the entire research process (Arbnor and Bjerke, 2009). This stretches from the most established positivist position, where reality exists and can be objectively assessed (Arbnor and Bjerke, 2009)<sup>10</sup>, over to the interpretative position where reality is socially constructed and people define and interpret reality (Andersen, 1994). Positivist research normally relates to research in natural sciences and interpretative positions often relate to social sciences (Andersen and Gamdrup, 1994, Arbnor and Bjerke, 2009). This research takes the position of a critical realist, a position used in at least two dissertations in Construction Management (Pemsel, 2012, Hooper, 2015) and located midway between the positions mentioned (Pemsel, 2012) as Maxwell (2012) p vii, puts it:

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<sup>10</sup> They denote it analytical view, although positivist position is the most established term.

“The first, and most central characteristic of critical realism, relates to the distinction between ontology and epistemology. Ontology refers to what actually exists – the nature of reality. Epistemology, in contrast, refers to how we gain knowledge of what exists – how we can know anything. Critical realism combines a realist ontology (the belief that there is a real world that exists independently of our beliefs and constructions) with a constructivist epistemology (the belief that our knowledge of this world is inevitably our own construction, created from a specific vantage point, and that there is no position of our achieving a purely “objective” account that is independent of all particular perspectives). All knowledge is thus theory-laden, but this does not contradict the existence of a real world to which knowledge refers.”

Critical realism recognizes the existence of an objective world, but the view of it is an interpretation and thereby subjective. Bhaskar (2008) states, that for a critical realist the real world is an open system consisting of natural mechanisms, social structures and events. A critical realist interacts with the world and aims to understand underlying structures and mechanisms that produce events. According to Bhaskar, critical realism consists of the *empirical* domain made up of experiences, obtained by direct or indirect observations, the *actual* domain made up of events, whether or not they are observed and the *real* domain made up of the processes, the structures and mechanisms, that produce these events. Furthermore, Bhaskar divides knowledge into transitive and intransitive. Transitive knowledge, socially created knowledge, is represented by the empirical domain. Intransitive knowledge is represented by the actual and real domains, independent of the human mind. Intransitive knowledge is the goal of research, but transitive knowledge is necessary to produce it.

In order to improve the understanding of the diffusion of systemic innovations, conditions affecting diffusion were studied and a deepened focus was placed on knowledge integration, mechanisms, knowledge development and effects through studies of events that took and had taken place. Emphasis was placed on how people interpret things in their context. However, everything is not socially constructed. This research aims to understand mechanisms, social structures and events that influence systemic innovation diffusion and this view is in line with the research conducted and the research process. However, in some of the papers an interpretative position was taken. This is a result of the research process and it is not uncommon for researchers to change their view. For example, Maxwell (2012) and (Bhaskar, 2008) describe how they changed their view over time. Furthermore, the

interpretative position is of use since a critical realist and the people studied produce different interpretations. Hence, the interpretivist position is one useful perspective, among others, for increased understanding.

As stated in the introduction, the interplay between content, context and process implies a level of uniqueness in different diffusion processes. This research aims for an understanding of the diffusion processes and influences from the context regarding systemic innovations. It focuses on a specific phenomenon, systemic innovation diffusion, and aims to provide thick descriptions<sup>11</sup> of the phenomenon that can improve a readers understanding of the phenomenon<sup>12</sup>. Hence, this research can be classified as qualitative, i.e. focusing on meaning and context (Merriam, 1994). Maxwell (2012) also argues for the usefulness of critical realism for qualitative methodology, if taken seriously with its implications systematically developed. The opposing quantitative studies often relate to a positivist position, quantity and measurability (Andersen and Gamdrup, 1994) although quantitative techniques can be used in qualitative studies (Trost and Hultåker, 2007). One central issue is to separate the quantitative and qualitative on a theoretical level since they focus on different issues (Guba, 1987). Conducting research from other traditions than the positivist has also been called for to improve understanding of innovation diffusion in construction (Green et al., 2010, Larsen, 2005, Larsen, 2011, Larsen and Ballal, 2005). As an example, (Larsen, 2011) stresses that a positivist perspective emphasizes structure, an interpretative perspective emphasizes the actor and both positions contribute with understanding but the positions also interact. Different positions are useful in the development of research and this can be related to the critical realist of using different perspectives to increase understanding. Arbnor and Bjerke (2009) and Maxwell (2012) also stresses that there is no best methodological view: it all depends on what is actually studied.

### 3.2 Initial aims, research questions and studied systemic innovations

Having clarified the points of departure on which the research is based, the background to the aims and research questions is described, followed by descriptions of the systemic innovations studied.

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<sup>11</sup> The term originally comes from Geertz (1973), and originally addresses that a thick description explains behaviour and its context so behaviour becomes meaningful for an outsider. The descriptions in this research should therefore be considered from what it aims to describe.

<sup>12</sup> Description influenced by Merriam, 1994.

### *3.2.1 Initial aims and research questions within a research project*

The research presented in this thesis has been conducted within a larger, funded research project that lasted for a time-period of three years involving 5 senior researchers and a PhD-student. Based on a research overview, the overall goal of the research project were to:

- i) Study knowledge integration between projects in temporary coalitions and organizations with industrial manufacturing<sup>13</sup>
- ii) Improve building component manufacturers' innovation capacity.

The overall goals were based on the assumption that there was a lack of knowledge integration between building component manufacturers and the project-oriented construction companies. Improvement of knowledge integration between these actors was seen as a key for improved innovativeness. These goals form a point of departure for the research presented in this thesis. The final aim and research questions presented in this thesis are a result of the research process itself, which is described in section 3.3. Three companies participated in the research project and this thesis regards two of these, a reinforcement supplier (RS) and a corporation consisting of different business areas providing products based on timber. Two of these companies were chosen since they were diffusing innovations that fall under the heading systemic innovations and were assessed as suitable for extensive studies. In addition, the innovations were considered of great interest within construction management research on innovation diffusion.

### *3.2.2 Systemic innovations studied*

In this research, two different types of systemic innovations have been studied. These relate to two of the companies (the RS and the timber-based organization) who participated in the research project in which the research took place.

#### **3.2.2.1 Building Information Management**

The first systemic innovation studied is Building Information Management (BIM)<sup>14</sup>. According to Eastman et al. (2011) BIM regards a move from pa-

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<sup>13</sup> This is emphasized in the introduction. Since the construction sector is project-based, it has significant contextual differences from sectors with more fluent and non-disrupted processes.

<sup>14</sup> BIM is often referred to as Building Information Modelling.

per based modes of communication to electronic modes. It relates to a modelling technology with associated sets of processes to produce, communicate and analyse building models (Eastman et al., 2011). Viewing this in detail, it is quickly realized that BIM is an extensive concept with effects on many parts of the construction process. Shibeika and Harty (2015) discuss ‘fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic, p 453) and the need to diffuse digital technologies and practices to realize this challenge. They place it under the heading diffusion of digital innovation. Hooper (2015) makes a review of different concepts, which he concludes are rather disparate, but based on a number of different definitions his position is that BIM constitutes “a combination of process, technology and people who endeavour to create, enable and manage construction information” (p 26). The standpoint taken in this research is at the centre of the Eastman approach, BIM is about transfer to a digital construction process and about managing information effectively. The 3d-model visualized or the building model is one type of central information in this process. In order to digitalize the process and manage information, the research aligns with the position taken by Hooper, that it requires a combination of process, technology and people, not merely working with different types of software, to move development and diffusion forward. Hence, based on this, the term used, Building Information Management, is a suitable definition for the research. In addition, the potential impact on the construction process is considerable, clearly making this a systemic innovation.

As far as BIM is concerned, improvements and efficiency gains can be found throughout the entire construction process. Eastman et al. (2011) provides an extensive list of advantages that revolve around efficiency gains through efficient management of information throughout the construction process, for example by connecting the work performed towards the same information source, using the automation, control and follow-up opportunities from digital solutions and using visualization in the construction process to improve understanding and avoid mistakes in later stages of the construction process<sup>15</sup>. According to Hooper (2015), benefits of BIM are spread

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<sup>15</sup> In detail (pp 20 -26), the areas are earlier and more accurate visualizations of a design, automatic low-level corrections when changes are made, generation of accurate and consistent 2D drawings at any stage of the design, earlier collaboration of multiple design disciplines, easy verification of consistency to the design intent, extraction of cost estimates during the design stage, improvement of energy efficiency and sustainability, use of design and fabrication benefits, quick reaction to design changes, discovery of design errors and omissions before construction, synchronization of design and construction planning, better im-

among different players and project stages, but one major potential lies in project coordination. Hooper states that “BIM is inherently efficient because it brings project partners together to use and share information through, in principle, a single structured database with multiple interfaces” (p 28). Benefits raised by Elmualim and Gilder (2013) point in the same direction as Eastman and Hooper: they lie in tying the construction process together with efficiency gains from a digitalized process (for instance extraction of quantities and shared properties of materials), where visualization and sharing of information is of central importance. To conclude, the potential of BIM lies in making changes to the construction process and BIM can provide increased efficiency for the entire construction process, motivating the need for studies, such as this research, for increased understanding of the diffusion process and enable increased diffusion.

Regarding the start of the diffusion process for BIM, Eastman mentions around 2004 as the first time the concept was introduced and the prevalence of BIM has grown considerably over the past several years (see for instance (Abdirad, 2016)). There are process wide applications, but as can be seen in Eastman et al. (2011), existing BIM-implementations have the potential to be used in more parts of the construction process. When reviewing different applications and solutions in Eastman et al. (2011), it can be concluded that the span of solutions that connect larger parts of the process is increasing, but there is as yet no application available from the start of the construction process into use in facilities management. Country-wise, there are also differences regarding BIM-diffusion. In Norway, diffusion and implementation has received great help from Statsbygg, a dominating actor who is pushing development forward within the BIM-field (Widén, 2010) with an open standard IFC-compliant buildings model as early as in 2005 (Hooper, 2015). Other organizations have followed and implemented the same requirements (Widén, 2010). While other countries have released building models, following Norway, Sweden began to develop BIM requirements in 2015 (Hooper, 2015). However, a driving force in the form of a large organization like Statsbygg has been missing, but the Swedish Transport Authority (Trafikverket) is attempting to take on this role and has a strategy for the development of BIM in collaboration with industry stakeholders (Hooper, 2015). One conclusion from Hooper, is that Sweden has a lot of work to do

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plementation of lean construction techniques, synchronization of procurement with design and construction, improved commissioning and handover of facility information, better management and operation of facilities, integration with facility operation and management systems.

in setting standards, requirements and support systems to force BIM diffuse at a higher pace. Since diffusion in Sweden is lagging, studies of this context provide further possibilities to study factors that facilitate or hinder diffusion, knowledge integration, mechanisms and knowledge development.

### **3.2.2.2 Multi-Storey Housing in Timber**

The second systemic innovation studied was timber-based multi-storey housing systems (hereafter denoted MSHT) i.e. building houses of more than two stories with timber as the main structural material. This diffusion process began with a change in Swedish building regulations in 1994. Height limitations were removed and instead buildings had to meet functional performance requirements (Boverket, 2014), enabling multi-storey housing in timber in Sweden (Engström and Hedgren, 2012). Following this, an expansion of active actors and buildings has occurred and timber has become an interesting alternative structural material, with clear environmental advantages (see next paragraph). A study comparing market conditions in Sweden, UK and Germany showed that Sweden had the most favourable conditions for market growth (Mahapatra et al., 2012), making Sweden interesting from a diffusion perspective to see what facilitates and complicates diffusion, how knowledge integration takes place and with what mechanisms and knowledge is developed. Different types of MSHT exist, for example prefabricated surface elements with or without insulation and sealing coat or as three dimensional volume-elements completed with plumbing, electrical installations, finishing etc. (Mahapatra et al., 2012). MSHT can be open, allowing different complementary solutions (Ågren and Wing, 2014) in the timber frame, or closed i.e. a total solution for the complete building is established and the solution is closed (Lessing et al., 2015). MSHT is currently competing with current dominating structural materials, where beliefs and assumptions about MSHT constitute one obstacle to innovation diffusion (Engström and Hedgren, 2012).

The advantages and effects of MSHT are several. One clear advantage is the environmental impact. Peñaloza (2015) for example show that forest-based materials have a lower life-cycle impact in comparison with concrete (pp 15). Nord and Brege (2013) emphasize potential in surface efficient apartments with some opportunities for add-ons and also stress that a well-defined process and early communication with clients are positive in municipalities with low building pace and where price is an important factor. Positive aspects have also been lifted by the Swedish National Board of Housing, Building and Planning (Boverket, 2006) and include; possibilities of reducing building production cost; reduction of ground support system costs

especially in weak soil conditions; short building lead times, which all in turn generates more income. There is probably also less necessity of heavy machinery (Mahapatra et al., 2012). Nord and Brege (2013) also stress that companies working with MSHT turn towards a broader labour market due to their more industrialised processes. Mahapatra et al. (2012) also emphasise that MSHT generates new jobs. In addition, the lack of wet trades and the fact that trades can work independently but in sequence is also a positive factor. Studies of the development of MSHT also show that industrial thinking is prominent, since the material is very suitable for that type of construction process (Tykkä et al., 2010). Standardization, re-use of solutions and erection through a well-defined process are visible. However, since timber is sensitive to moisture, weather protection is often required. Among the perceived disadvantages, issues such as façade maintenance costs, acoustic properties are some examples but perceptions about costs, fire safety, durability or stability vary depending on level of experience are also examples (Hurmekoski et al., 2015). To conclude, MSHT can have different shapes and affect the construction process to varying degrees, clearly with impact on several parts of the construction process, making it a systemic innovation. Furthermore, it can provide advantages for the construction industry, is diffusing and thereby constitutes a valid systemic innovation to study.

### 3.3 The research process

In this section the research process is described. Since this research has been presented in five papers, the connection between these is first presented, followed by a description of methods and approaches used and compilation of data.

#### *3.3.1 Relationship between appended papers*

Regarding the appended papers, Paper 1 is a literature review of systemic innovation diffusion. In addition to the review, it contains a concluding analysis and reflections focusing on factors influencing the diffusion of systemic innovations, methodological considerations regarding research and areas for future research. Paper 2 focuses on factors influencing supplier innovation diffusion based on the efforts of the reinforcement company to diffuse new services. Paper 3 focuses on factors influencing systemic innovation diffusion. It is based on the timber-based case-company's efforts to diffuse a high-rise multi-storey timber housing system. Papers 4 and 5, focus on knowledge integration, knowledge integration mechanisms and knowledge development in the diffusion process of the systemic innovations

studied. To summarize the organization of papers, Paper 1 may be regarded as a paper providing academic context for the studies of systemic innovations, in terms of theoretical and methodological foundation. Paper 2, besides serving its purpose, provides context for Paper 5, a focused study. In the same manor, Paper 3 served its purpose and provided context for Paper 4. A visual presentation of the connection between the papers is presented in Figure 3.1.

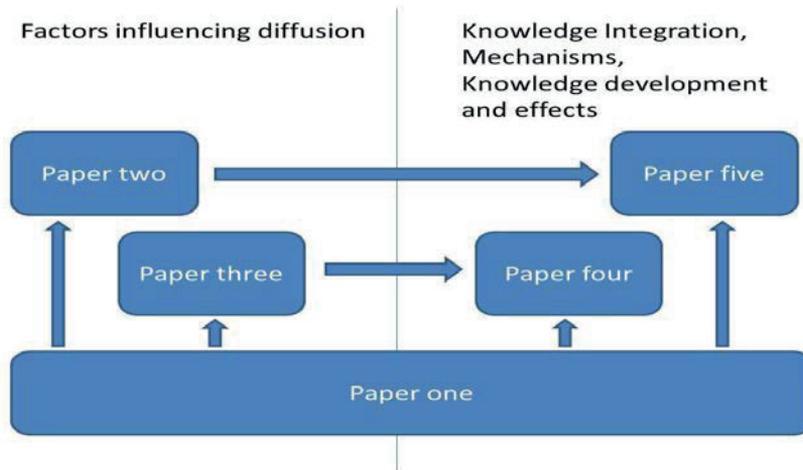


Figure 3.1 Overview of appended papers.

### 3.3.2 Methods and approaches used and compilation of data

Table 3.1 shows methods used in the appended papers:

Paper	1	2	3	4	5
Interviews		X	X	X	X
Document-studies		X	X	X	
Site-visits		X	X	X	X
Observations			X	X	
Literature-study/review	X	X	X	X	X

Table 3.1 Overview of methods used

Paper 1 is based solely on a literature review. Paper 2 consisted of visits, presentations, round-tours at the company and 25 interviews with company

internal and external actors in a first round. A second round of interviews was also conducted with four company internal actors and service descriptions were studied (services were considered innovations) in order to update the progress of the diffusion process. Initially, the purpose of the data collection was to provide a picture of the business situation for that particular company but over time by reviewing previous research, discussing findings and different compilations of the empirical material, this study stepwise became a paper for an academic journal. Paper 3 started in virtually the same way as Paper 2 with data collection. As findings continuously developed through constant interaction between previous research, empirical findings and interventions with academics and company-related people, it eventually became Paper 3. This paper included nine interviews, a site visit to the company producing the prefabricated elements followed by the monitoring of a live-project including interviews, observations and document studies. Several validation sessions were also included in this paper. Collection of empirical data for Paper 4 was carried out in parallel with Paper 3, although focus over time moved towards the focus area of that paper and several validation sessions were held with people inside the company. Paper 5 followed Paper 2 and additional data collection over time was conducted with a focus on knowledge integration, mechanisms and knowledge development. All the papers contain reviews of previous research i.e. literature-studies. Searches through key words useful for the study at hand, such as innovation, innovation diffusion, systemic innovations, context, knowledge management, knowledge integration, mechanisms have been carried out, primarily in construction management journals. Additional sources have also been identified from these journals. Recommendations from colleagues have also provided sources for review.

Much of the research conducted falls under the category of case studies as defined by Merriam (1994): a qualitative method focusing on meaning, context and with a systematic approach to gathering, organizing and integrating information to produce research results. Merriam gives an overview of contributions from a number of authors, and concludes that case studies are descriptive i.e. they provide a thick and extensive description of what is studied. They are heuristic i.e. they improve the readers understanding of what is studied by, for example, creating new meaning, widening the readers experience or confirming what is already known. The Eisenhardt (1989) view on case studies as a research strategy focusing on understanding dynamics within a single setting is also valid for the research conducted. All papers except Paper 1 focus in majority on providing empirical data and a thick empirical material. Coherent with these views, a specific phenomenon

has been studied i.e. systemic innovation diffusion and knowledge integration in two specific contexts. The systemic innovations chosen are different in their characteristics and it is of interest to illustrate differences between the different types of systemic innovations and consequently extend emergent theory (c.f. Eisenhardt, 1989).

The overview above shows that different methods have been used on different occasions in the research process, a typical characteristic for case studies (Eisenhardt, 1989). One main reason for the use of different types of methods is to capture different dimensions in the innovation studied, in line with New and Payne (1995), who stress that methods used should firstly capture the level of complexity in the studied objects (see also Maxwell, 2012). Although interviews and documents have provided much data, the observations conducted have been necessary to grasp tacit knowledge, a point stressed by Brown and Duguid (1991): workplace learning is best understood in the communities where it takes place and observing people in action can unfold how things “actually work”. This was also the reason why observations were used to a greater extent in Papers 3 and 4, where craftsmen were a more considerable part. Due to the focus in Paper 2 and 5, especially 5 where the full focus was on BIM and BIM-related solutions, observations on BIM in use were not included. It could have been useful to study KI and BIM, but this would have resulted in studies of specific mechanisms and not an overview of the mechanisms used. In the studies presented in Paper 2, 3, 4 and 5 the material also covers an extensive time period with results from different phases of development. In papers 3 and 4 the studies were made sequentially in time. Altogether this has enabled study of the diffusion process over time, changes in the innovation studied and also the consequences of the diffusion process. A study perspective over time with the inclusion of consequences has been emphasized by Rogers (2003) as an important part of the diffusion process. The research conducted also validates a point highlighted in paper one, broad approaches as suitable for studies of systemic innovations.

The approaches applied in the papers have been both inductive (Papers 2 and 3), using the empirical material as a point of departure (Arbnor and Bjerke, 2009, Merriam, 1994) and deductive (Papers 4 and 5), where existing theories and research guided the research (Arbnor and Bjerke, 2009, Kirkeby, 1994). Both Merriam and Eisenhardt emphasize that case studies should be inductive, meaning that hypotheses, concepts and generalizations come from the information that is accessed and Merriam emphasizes the ability to discover contextual characteristics from the object studied. Eisen-

hardt also stresses that theory should initially be avoided as much as possible: a characteristic most significant in Paper 2 and 3. For Papers 2 and 3 a grounded approach was used to find patterns in the collected and compiled data. In the creation of themes from the material, this have at large followed criteria set forth by Guba and Lincoln (1981); the number of people expressing a view, feedback from the “audience” regarding what is important, the obviousness of certain categories due to their uniqueness and the approach that follows the category. The creation of patterns has, as stated earlier, also been influenced at later stages by previous research and other related literature.

Papers 4 and 5 showed a more detailed focus initially and were based on Papers 2 and 3, but open-mindedness has been aimed for with regard to the frame of reference. However, reviewing the approach in Papers 2 and 3 in retrospect they have become more abductive, i.e. start from the empirical material, but with continuous iteration between theory, existing research and the empirical material (Arbnor and Bjerke, 2009, Kirkeby, 1994). In order to make valid scientific contributions, overviewing previous and current research is necessary in accordance with the view of Merriam (1994) and Glaser (1978). In addition, the view on the research and its findings has changed to some extent over time, relating to Alvesson and Sköldbberg (1994) who state that the researcher interacts with his/her research objects and continuously creates images for himself and others, thereby neglecting alternative interpretations. To conclude however, these various approaches have together been complementary and have all cooperated in producing this thesis and its appended papers.

### 3.4 Quality assessment of the research conducted

Assessment of research originates from a positivist research tradition but should be applied depending on the type of research. However, a researcher's primary interest must be to produce credible and sustainable results (Merriam, 1994, Lincoln and Guba, 1985, Arbnor and Bjerke, 2009). In order to nuance this issue from the view of a critical realist, according to Maxwell (2012) one primary challenge is to explain how results have come forward and how conclusions have been drawn from the use of a method, in a particular context for a particular purpose. In the following sections, the assessment of the research conducted will be discussed.

### 3.4.1 Descriptive and interpretative validity

In quantitative studies reliability is a central concept that refers to repeatability of the results (Merriam, 1994). For qualitative research using the approach of a critical realist, results are interpretations. Maxwell suggests the term descriptive validity which relates to whether things are true or not, simply put not made up, as useful. If another researcher studies the same domain and comes up with something completely different, the descriptive validity can be questioned (Maxwell, 2012). Lincoln & Guba (1985) states in a similar manner, that the researcher must describe the method so explicitly that others can replicate the study. Different activities described in the appended papers, with research conducted over longer time periods, using multiple methods and different types of feedback and validation activities have been conducted and all contribute to the descriptive validity. It should, however, be noted that the studies in Papers 1 and 3 have, at least from the start, been inductive and consequently individual interpretations may play a major role in how the results are presented. Papers 4 and 5 should therefore be easier to reconduct by another researcher. Maxwell also suggests interpretative validity, which relates to meaning (intention, cognition, affect, belief etc.) from the participants' view and that meanings are expressed and respected. Largely and as described in the papers, findings and research have been presented and discussed at various occasions and in different ways and different participant views have been displayed, contributing to the interpretative validity. These activities are all useful in terms of increasing both the descriptive and interpretative validity.

### 3.4.2 Internal validity

A term related to descriptive validity, which partly addresses the same issues, is internal validity (Merriam, 1994). This refers to whether results correspond to reality, capture what "exists" or what is supposed to be captured, and the concept is viewed as useful in this research. Merriam presents six strategies to assure internal validity. The first strategy, *triangulation* regards the use of several researchers and information sources as well as methods to confirm findings. Being a part of a project group and also working with co-authors in the research is an important factor regarding internal validity as well as the use of different sources. Since the thesis consists of peer-reviewed articles, external reviewers have also been used, which

should improve internal validity<sup>16</sup>. A second strategy according to Merriam is to ask informants to check if the findings are credible. This strategy can be compared with what Arbnor and Bjerke (2009) call a practical validation of the process, meaning that actors in the context studied show a continued or increased interest in the research. Actors in the context studied have been involved to different extents in studies and have confirmed and discussed results and furthermore shown an interest in the studies. Lincoln & Guba (1985) refer to *triangulation* as the use of different methods of data collection. As described both here and in the appended papers, different methods have been used extensively throughout the studies.

*Observation over time or repeated observations* is a third suggested strategy, and this strategy has been used in all studies in appended papers, except Paper 1. This has enabled an extensive view of the diffusion studied and also confirmation of data collected. The fourth suggested strategy has also been used, *horizontal audit and criticism*, i.e. asking colleagues to provide comments and views on results. The supervisors have been a group who have constantly audited and presented criticism, in addition to reviewers in the scientific journals. Furthermore, seminars regarding research have been held in the research environment, providing useful criticism. This relates to what Arbnor and Bjerke (2009) denote as scientific validation of results, i.e. whether or not the results might be useful to develop the scientific field and this has been a standing item in the criticism that has been made. The fifth strategy, *participative approach* in the research, i.e. the people studied being involved in all stages of the final report is, however, a strategy less used. One major reason was the design and also the necessity of working as efficiently as possible with people in the study and not taking too much of their time. Furthermore, some contacts have left the case study companies over time. In these cases, other people have been present and replaced them.

*Clarification of skewness* is the final suggested strategy, meaning that the researcher clarifies points of departure, underlying assumptions, view of the world and theoretical perspectives. This can be related to what Arbnor and Bjerke (2009) denote as *scientific validation of the process* meaning that logic and reasonableness in the development of interpretative patterns is shown. This thesis especially together with the papers, provide clarifications regarding skewness. However, as Merriam (1994) stresses that the creation

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<sup>16</sup> Concerning published papers, Paper 1 had 2 reviewers, Paper 3 had 4 reviewers and Paper 4 had 4 reviewers.

of meaning in information, discovery of patterns, relationships or a theory is not a logical process but contains elements of intuition and depends on the researchers sensitivity to the information, meaning that there is always a subjective touch in how the material collected is presented. She also states that every researcher probably has their own type of system of managing information.

### *3.4.3 The researchers position and ability*

As highlighted by Merriam (1994) the abilities of the researcher form a key characteristic in conducting case studies and it is through the researcher the results are collected and analysed. Lincoln & Guba (1985) set the researcher's position in focus and states that the researcher's underlying assumptions and theories should be explained and described, their position in relation to the group studied, criteria for choosing informants and the social setting from which data is collected (in line with Maxwell, 2012). These issues have been described in the appended papers and should be visible there. However, many different sources of influence exist and these may affect interpretation, presentation of findings and contributions. A part in this is also that the view of the researcher and his/hers previous experiences, i.e. preunderstanding affects results presented (Merriam, 1994, Alvesson and Sköldbberg, 1994, Maxwell, 2012). As a critical realist, actual beliefs, values and dispositions brought into the study must be accounted for (Maxwell, 2012). These issues are present and during the PhD-process, the position changes affected by new experiences, additional readings and other influences. In the research conducted, understanding and seeing patterns affect what is studied. Different tools and approaches are useful for understanding and this can be carried out in different ways. However, with all the different activities conducted, research has been analysed with different people in different settings, thereby addressing the quality of the research.

### *3.4.4 External validity & generalizability*

This criterion regards to what extent results are applicable in different situations i.e. their generalizability. At the centre of this issue is, of course the focus of a specific study. Merriam (1994) states that case study methodology is chosen to study a certain situation, person or event more deeply and a key criterion must be understanding, widened experiences and increased certainty regarding what is already known. The definition of generalizability at the beginning of this paragraph is therefore impossible to use, but the aspect must be judged in other ways. Maxwell (2012) also emphasizes that

the goal of most qualitative studies is not to generalize claims that differences exist between groups, categories of individuals or relationships between specific variables for some populations. He also states that the goal is to “understand the processes, meanings, and local contextual influences for the studied phenomena of interest, for the specific settings or individuals studied” (pp 94). Furthermore, according to Maxwell (2012) generalizability for qualitative studies is valid in terms of generating theory for use elsewhere. In this area, it may also be relevant to mention theoretical validity, which refers to using concepts and their application in a correct manner (Maxwell, 2012). This is a prerequisite to later discussions of whether the theory generated can be used elsewhere. In addition, Maxwell discusses internal generalizability within a specific setting and external generalizability outside a specific setting. In this research, concepts and frames of reference outside construction management research have been introduced. Since the findings point towards usefulness of these concepts and frames of reference, these indicate both internal generalizability and external generalizability.

One issue regarding generalizability is to highlight specific details in order to also see the general details. When putting the concept systemic innovation diffusion in focus, this research enables this issue since two types of systemic innovations are studied. Another important aspect is that the reader of results can judge if results are general or not, and it may be left totally for the reader to assess. In relation to this Lincoln and Guba (1985) discuss the concept transferability as a direct function of similarity between contexts, meaning that if the reader is able to assess the context and compare it to others, the reader possesses a good prerequisite for generalization. Goetz and LeCompte (1984) discuss this in another way, meaning that descriptions of how typical a case is, enables comparisons for a reader. Following this, surrounding the concept external validity, it is important to describe the context in which the collection was made in order to enable conclusions from a specific case (Lincoln & Guba, 1985). To conclude, Merriam (1994) suggests that a rich, thick description for each and every one interested improves the external validity of the research, and enables transfer of results (see also Lincoln & Guba, 1985). These latter aspects of generalizability are hopefully described in each paper in a manner that enables transferability of results. Furthermore, one of the key points of departure in this research is to highlight the context, since this is influential for diffusion and also a key component in the interplay between content, context and process in this thesis (Pettigrew and Whipp, 1991).

### 3.5 Summary

The qualitative research presented in this thesis has been conducted from the position of critical realism. Furthermore, the process of setting aims and the systemic innovations studied, Building Information Management and Multi-Storey Housing in Timber have been described and motivated. These systemic innovations differ in their characteristic which is of interest in order to display differences between different types of systemic innovations and extend emergent theory. Case studies of the diffusion of these types of systemic innovations have been conducted using different methods to capture different dimensions in the systemic diffusion process. In addition, quality assessment of the research has been discussed in terms of descriptive and interpretative validity, referring to the presentation of real findings and expressing opinions from the field. Furthermore, criteria for accomplishing internal validity, i.e. that results correspond to reality and display what they are supposed to, has been dealt with. Finally, external validity and generalizability were discussed, referring to the applicability of results to other situations. By providing extensive descriptions, this enables opportunities for the reader to generalize and transfer results.

## 4. Extended summary of appended papers

This thesis includes 5 appended papers. Their connection and approach is described in section 3.3.1-2. The papers are published, accepted with major/minor revision or submitted to scientific journals. The papers have in different ways influenced each other with their different contributions. In the following summary, their main title, author(s), publication status, background & introduction, purpose, method, summary of main contents, results and contributions are presented. Viewing the different papers and studies, the approach was initially broad and then over time became narrowed.

### 4.1 Summary of Paper 1

**Title:** Diffusing systemic innovations: influencing factors, approaches and further research

**Author:** John Lindgren

**Publication status:** Published in Architectural Engineering and Design Management:

Lindgren, J. 2016. Diffusing systemic innovations: influencing factors, approaches and further research. *Architectural Engineering and Design Management* 12 no. 1: 19-28.

**Which research questions of the thesis are primarily in focus? 1**

**Keywords:** Systemic Innovations; Diffusion; Influential factors; Approaches; Construction

**Background & introduction:**

A number of different reasons influence innovation diffusion in construction. Many difficulties can be related to the specific characteristics of the

construction context. These difficulties explain why different innovations diffuse at different speed. Systemic innovations that are holistic and relational to their character, are a type of innovation that diffuses at a low speed, due to their impact and demands on the construction process. However, studying the diffusion of systemic innovations is important since many innovations of this type are predicted to result in major efficiency improvements for the construction industry. In addition, systemic innovation has only been studied to a minor extent. These final two points emphasize the need to study systemic innovations.

### **Purpose**

The aim of this paper was to discuss factors influencing the diffusion of systemic innovations and highlight central approaches and areas for future study.

### **Method**

The method in this case was a literature review. Focus was set on research treating systemic innovation diffusion in construction, but general research on the subject matter was also included, as well as related areas with regard to the purpose.

### **Summary of main contents**

The paper begins with a review of innovation diffusion and its part in the innovation process. After this, the concept systemic is reviewed and described. Systemic innovations is described as covering many parts, actors and relationships, requiring significant adjustments in other areas of the business system of which they are a part. Usually they span beyond the boundary of the firm. Coordination of different parts of the value network is also a distinguishing feature for systemic innovations. Examples of systemic innovations include lean manufacturing and lean construction. The paper continues with a review of constructs identified by Taylor (2006) influencing the diffusion of systemic innovations, covered with complementary references, adding substance to their meaning. An added section deals with learning and the dynamic reality in projects, since the constructs can be complemented with insights on the dynamics of a potential messy reality.

### **Results and contributions**

The paper contributes with a literature review of factors influencing the diffusion of systemic innovations. Systemic innovation diffusion is presented as challenging, mainly due to its scope which results in many influential factors. This also affects research methods. Studying systemic innovations over a longer time horizon make complexities of the construction environment more evident, especially with regard to interdependencies in and between projects. A broad methodological approach, using different methods seems potentially useful to capture complex dynamics and unexpected twists and turns in the innovation process. Actor Network Theory and the Industrial Network Approach (INA) were given as examples of useful frameworks to capture this. INA was further used in the paper to complement and nuance the constructs identified by Taylor, since it offers understanding of how companies interact over time in a network. In addition, due to the nature of systemic innovations, research on supply chain integration and supply chain management in construction seems very relevant with the construction context taken into consideration. The reciprocal interdependencies in construction that require more frequent and direct interaction between the actors to enable mutual adjustments is one example. Another consideration is the difficulties related to integration of temporary supply chains (specific projects) with permanent supply chains.

Conducting case studies using data collection in multiple ways, with different focus areas and from different frames of reference seems very relevant to build further on this paper and contribute with understanding of the diffusion of systemic innovations. A more standardized process and defined interfaces would give potential efficiency gains through reduction of project specific characteristics. The paper addresses the necessity of designing normative models that concretely address what members to work with, processes of central importance and on what level. The context is especially highlighted as important and the paper emphasizes the need to specifically address the type of the construction area that is in question in future research, for instance multi-storey buildings, infrastructure projects etc., since each segment might have unique characteristics which affect diffusion. Another area of interest to study is the effects of different types of interventions on the diffusion of systemic innovations, since they have been found to exert a significant impact. Specifically, managing different professions is a major part of the diffusion of systemic innovations. The type of knowledge needed and integrated differs and different types of knowledge can be integrated in many different ways. Combining new and previous knowledge, that is knowledge integration, is of importance. It also empha-

sized that this can be achieved through different mechanisms for knowledge transfer and that this therefore needs to be studied further.

## 4.2 Summary of paper 2

**Title:** Exploring effects of the interplay of context, content and process for supplier innovation diffusion in construction

**Author:** John Lindgren

**Publication status:** Submitted to Construction Innovation

**Which research questions of the thesis are in focus?** 1

**Keywords:** Construction process, Diffusion, Interpretative position, Innovation Content, Innovation Context, Innovation Process

### **Background & introduction:**

Context has been extensively emphasized as a necessity in innovation diffusion studies. However, according to studies by Pettigrew & Whipp (1991) on the strategic change process, its' progress can be explained by how the strategic change process, interacts with the context but also the content of the process. In innovation diffusion there are examples of research explicitly referring to this interplay, but a conclusion is that there is a potential in using it to a greater extent, based on criticism towards innovation diffusion research: there is a need to increase the level of detail in innovation diffusion research and show how diffusion processes proceed and emerge. In addition, needs have also been raised to study the ID-processes with an inter-organizational focus.

### **Aim**

The aim was to provide additional understanding and insights for the innovation diffusion process, by exploring the interaction between innovation content, innovation diffusion process and the innovation diffusion context, by studying three different diffusion processes, diffused by a supplier. An important part of the aim is to gain understanding of what facilitates and complicates ID from the perspective of a supplier in a construction industry context.

## **Method**

The method was initially inductive, but has over the course of the study become abductive to its character. It displays characteristics of qualitative case study. The initial motive was to understand the company's business situation, but over time there has been narrowed focus towards innovation diffusion. By increasing the interaction with current and this research, the inductive approach decreased stepwise through the process and enabled the clarification of the contributions for the article.

The empirical collection consists mainly of interviews but document studies, site visits and studies of other informative material have also taken place. The interviews have been conducted in two different rounds. In the first phase, 13 company internal and 11 company external semi-structured interviews were conducted. The questions what has changed (content), how has it changed (process), why has it changed (context) have functioned as point of departure for the study, with special focus on the subcontractors context. In the first round of interviews these were focused on the RS business situation, including development, objectives and challenges. The character and context of the construction industry, its development and IT-related issues were also included. Detailed questions were raised about the diffusion of the services that were developed by the RS. The questions were considered interesting from a diffusion point of view since they provided a picture of what innovations that are spread (diffused) and not. Based on the material, groups of themes were created and a search for patterns describing the context, problem areas and potential improvement was addressed, which over time was refined to more clearly relate to diffusion. In the second round of 4 interviews, the data compiled from the first round served as a support material and enabled specific questions about the development and diffusion of specific services, to whom, why and under what circumstances.

## **Summary of main contents**

After the introduction, the paper starts by defining innovation and then context, content and the innovation process in construction management research are examined. Besides stressing the project-based work method and issues influencing diffusion, emphasis is put on the differing contexts of supplier and the project based context that they deliver to, where the different context differ in their ability to work with continuous knowledge flows, a key issue for Innovation Diffusion. Then different types of innovations in construction are reviewed. A conclusion from this part is that the extent of

the innovation is a key point related to innovation diffusion. The last part of the review regards the innovation diffusion process, where its meaning is defined and different views on its progression. Basically it seems to be described as linear or iterative, but by lending concepts from change management studies, different approaches are nuanced. After this research methodology and design is described, followed by findings and analysis, discussion and conclusions.

## **Results and contributions**

The results were described in each of the dimensions, followed by an analysis of how they interact. As a supplier the RS often competes with price and is often a low prioritized supplier. It is often in the hands of the customers regarding the possibility to diffuse innovations. The innovations that was studied was BIM and related electronic solutions, a new system used to specify and work with reinforcement and color sorting and labelling (reinforcement comes sorted and labelled for simplified assembly). Following this, the diffusion process or how the RS are working to diffuse their developed services are described. Generally, the RS has tried to diffuse their service through a traditional sales approach but has had to change and consider the context for the services they aim to diffuse. Problems or barriers in the diffusion process have led the RS to change their implementation process, the implementation context as well as modifying the services (the innovations) and when not, the dimensions interplay in a beneficial way. Hence, in the findings section, the interplay between content, context and process in the diffusion process and how it affects the outcome is dealt with in the different sub-contexts of the innovations.

The study validates the interplay as useful to display detail in current research, capture diffusion processes and their potential dynamics. One contribution is also that it explores an inter-organizational context, from a supplier perspective. It shows how complexity and that the interacting factors, contributes as a way to understand complexity in the diffusion process. Main enablers that enable diffusion relates reduction of complexity, manage boundedness of the innovations, impact on the construction process and to increase control. Complexity is also a challenge, since it revolves around managing continuity (suppliers) in relation to discontinuity (construction projects) simultaneously. It also emphasizes the necessity of nuancing sub-contexts in terms of different construction projects since different contexts have differing characteristics with impact on the diffusion process. Concerning further research, there is a potential in conducting extensive longitudinal

studies to increase the level of detail, or study an array of interacting innovations and their development over time. The study furthermore emphasizes use of the framework of innovation in organizations in diffusion research, since it suits the interactive environment where interaction between different groups or clusters occurs.

### 4.3 Summary of paper 3

**Title:** Diffusion of a systemic innovation: A longitudinal case study of a Swedish multi-storey timber housebuilding system

**Authors:**

John Lindgren and Stephen Emmitt

**My contribution:**

Review, data collection, major part of the analysis and writing

**Publication status: Published in Construction Innovation**

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**Which research objectives of the thesis are in focus? 1**

**Keywords:** Case Study, Diffusion, Multi-Storey Housebuilding, Sweden, Systemic innovation, Timber construction.

**Background & introduction:**

Technological innovation is of interest to a number of different stakeholders and may have several different kinds of starting points. Changes in regulations are one type and a change in regulations in 1994 has allowed multi-storey housing of more than two stories in timber. This change in regulations has opened up potential for innovation and has generated diffusion of multi-storey housing in timber. Sweden is of special interest since studies show that Sweden has favourable market conditions in comparison with Germany and UK. In addition, a number of actors are active on the market and the case study organization in focus for the research is one. The current situation has generated opportunities to study the diffusion of systemic innovations in construction. Systemic innovation is of interest and importance since it is quite complex and with effects on the construction process.

**Objective:**

The objective was to identify factors that influence the innovation diffusion process.

**Method:**

The development and construction of timber multi-storey buildings by an established timber producer was researched over a series of projects. A longitudinal case study was used with multiple data collection methods to study the development of a multi-storey timber house system. The starting point was a change in regulations and the case study reflects the response to these changes from the perspective of one organization. The method comprised of interviews, observations, document studies and literature studies stretching over a time-period of 20 months. Data collection covered projects completed and monitoring a live project, and a round of interviews with external individuals who had purchased other building systems in timber. The longitudinal perspective has given a good view of systemic effects and consequences. The identification of diffusion factors can be related to thematic analysis, in short finding implicit and explicit ideas from the data. Validation of the data has furthermore been extensive and conducted through a number of different individual and group meetings.

**Summary of main contents**

The paper contains a review of the innovation diffusion process of individuals as well as organizations in which the process is more complex, with a number of individuals playing roles in different types of decision making. Rogers' point that consequences are an essential part in diffusion studies is further emphasized. Characteristics regarding innovation diffusion in construction are reviewed, with emphasis on the project-based work method. The review covers studies of specific parts of the diffusion process but also the usefulness of studying diffusion processes over time. Furthermore, the concept systemic innovation, diffusion and influencing factors are reviewed, providing a clarification of what is meant by systemic innovations. Whether changes are an effect of a number of innovations or just changes (not innovations) in different parts of the construction process is not a focus. Special interest is instead placed on the inter-organisational effects/consequences from innovations with possible effects on the entire construction process (including its actors and their resources). The Swedish context for timber-

based building systems is further examined, displaying characteristics of market leading systems as well as obstacles to diffusion.

## **Results and contributions**

The research provides a view of development and diffusion over a series of projects. The research contributes an overall understanding of a number of interacting factors influencing the diffusion of the innovation studied in construction. The identified factors were; *recognition and tradition*, meaning that existing methods and materials constitute a specific obstacle to diffusion and that there is an existing path-dependency. However, recognition and tradition may also facilitate diffusion since MSHT is based on the same process as for prefabricated family houses; *external drivers*, meaning that external drivers in the surrounding environment in this case provides a helpful push for diffusion; *complexity in managing the system and active clients*, meaning that coordination and control is a challenge and that the construction process requires initial understanding from the client side for a well-executed process; *financial aspects*, relate to the necessity of provision of financial resources to develop over a long time period and having the stamina to move through the necessary development steps before there is return on investment; *the definition level*, i.e. it is necessary to define and set the system to enable increased diffusion, and to manage complexity, consequences and problems. One main contribution is also that decision-making with this type of systemic innovation has the character of a collective activity relating to the framework of diffusion in organizations by Rogers (2003). Since the system has been changed from project to project, this shows an extensive implementation phase characterized by redefinition and restructuring. It was advised to use this framework in futures diffusion studies of systemic innovations for further validation. Furthermore, the study design supports Rogers' view that studying consequences has a value in diffusion studies.

Of specific interest is that the study revealed how the case study organization through a series of projects, conducts a learning process and how they continuously transfer knowledge from the performed projects and make continuous improvements from project to project. Based on this the manner in which the knowledge integration mechanisms are applied and their effects was emphasised as being in need of further research given the complexity in relation to systemic innovations (where many professionals, trades and organisations participate and where a considerable amount and range of knowledge must be managed). This motivated Paper 4.

## 4.4 Summary of paper 4

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

**Authors:** John Lindgren, Kristian Widén and Stephen Emmitt

**My contribution:** Review, data collection, major part of the analysis and writing

**Publication status:** Accepted with minor revision to Engineering, Construction and Architectural Management

**Which research objectives of the thesis are in focus?** 2, 3, 4

**Keywords:** Innovation Diffusion, Systemic Innovation, Knowledge Integration, Mechanisms

### **Background & introduction:**

The often recurring short-term view and stressful atmosphere in the construction industry, stresses the need for a more long-term approach and more continuous interaction in the construction process in order to increase the innovativeness in the construction industry, especially upstream in the construction process. In addition to interaction being positive for innovation and innovation diffusion, it is also of central importance to the creation and exchange of knowledge, another area central to the innovation process, diffusion included. However, a primary barrier to innovation in construction is the project-based work method, much due to its negative influence on continuous knowledge flows. This constitutes an even greater challenge for systemic innovation diffusion i.e. diffusion of innovations with inter-organizational impact. Inter-organizational knowledge flows are affected by changes in population from project to project, number of organizational boundaries the innovation spans, scope, and the complexity of the innovation. In addition, different types of professionals can be affected by systemic innovations; architects, engineers, project managers, craftspeople etc. The variety of actors implies that different types of knowledge and skills must be managed simultaneously in different projects. In addition, the manner in which previous knowledge is organized and managed may be a barrier for how it is applied in a new product. As can be seen, knowledge integration challenges exist to the diffusion of systemic innovations, however managing

these is of great interest for their diffusion, not least when taking into account that they can contribute positive effects to the construction sector.

### **Aim & objective:**

The aim of the research presented in this paper was to study how knowledge integration takes place during the diffusion of a systemic innovation. The objectives were to understand what mechanisms are used, when and what their effects are in general and in terms of knowledge development.

### **Method:**

The collection of data was partly carried out in parallel to Paper 3. The development and construction of the timber multi-storey buildings over a series of projects was in focus according to the aim. A longitudinal case study was used with multiple data collection methods. As the study has proceeded, more focus has gradually been set on the aim of this paper, enabling a more focused study.

### **Summary of main contents**

The frame of reference begins by stating the research focus, inter-organizational effects/consequences of an innovation on the construction process. Then the meaning of Knowledge Integration is reviewed and the essential role of common knowledge is explained. The paper thereafter deals with different types of mechanisms and their use based on general and construction management research, concluding that codified knowledge is efficient when it works and could be used more extensively, but construction requires that they are used in balance with soft-personalization strategies. However, although construction being dominated by personal networks and oral communication, platforms are provided as an example of another sort of useful tool to share and accumulate knowledge. The interaction level is then stated as a point of departure in the research, since it has a direct connection to knowledge integration effectiveness and examples are provided; *Rules and directives, sequencing, routines and group problem-solving and decision making*. These show an increasing amount of interaction and also reflect growing complexity and insecurity. In order to analyse knowledge development and its effects, domain-specific, procedural and general knowledge are introduced to construction management research. The interaction and usefulness of these knowledge types have been shown in product development and innovation studies outside construction and

complement the current use of tacit and explicit knowledge. The method is then described in two sections. The first section describes the development of the system and the second section describes findings from the perspective of the framework. The final sections discuss the findings and presents conclusions and further research.

## **Results and contributions**

The findings show the main features of the conducted and monitored projects including mistakes and problems. The most prominent knowledge development regards domain-specific knowledge, most likely depending on timber being a new structural material. A result from the study is to divide domain-specific knowledge into the interacting subtype's domain-specific product and process knowledge, to nuance knowledge development further. Domain specific product knowledge development shows in more advanced design aimed at fulfilling demands for construction strength, acoustics and fire protection. Domain specific process knowledge development is visible in a higher level of prefabrication and industrialized house-building. The use of previous experiences in tests and evaluation of the projects shows a systematic approach and a gradual increase in procedural knowledge. Integration of general knowledge does *not* take place to a great extent and construction can be regarded as a somewhat closed sector in these terms, however there is potential in developing this as the domain-specific knowledge develops. The system has increased its competitiveness and by moving activities upstream away from the projects and applying continuous KI is enabled due to an increasingly defined setting. Due to the development of the system with a simplified erection process, the need for specialized knowledge has decreased, but can momentarily increase when specific development takes place.

According to the research, one major challenge lies in the level of complexity, the extent of the innovation and in what degree it affects different types of knowledge and groups. The emphasis on running actual projects as the most crucial activity for KI is a major contribution and adds understanding to why development is preferably made in small steps and in a series of projects. 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 in this case is a platform that efficiently serves as a boundary object bonding and bridging different stocks of knowledge. Through increased understanding of innovation diffusion and different flows of knowledge (albeit preliminary) this research provides

guidance on how to proceed in the implementation of a new material. One experience from the study is that common knowledge could be studied more in depth to see how different knowledge bases connect and which types of common knowledge that are used when, where and why, for example with a focus on different professions. Since previous studies outside construction highlight positive effects of integrating various types of knowledge, especially general knowledge, this indicates a need to further explore general KI in construction; especially for different types of systemic innovations in order to understand them in context.

Continuous KI is furthermore improved by moving activities upstream into a continuous organization, enabled by an increasingly well-defined setting. The need for specialized knowledge thereby decreases and with reduced complexity on site, diffusion can be simplified. Regarding mechanisms, the study connects to studies emphasizing the need of a balance between soft personalization strategies and use of codified knowledge and contributes to the questions of when and why strategies should be mixed. As the system becomes more defined the need for more interaction-intensive mechanisms decreases and a more systematic approach to KI can probably take place. However, interaction intensive mechanisms are especially necessary when methods and solutions deviate from current practice, implying a technological change. In addition to written instructions, monitoring and education is needed as integration mechanisms in order to prevent mistakes when current practice plays a significant role. Finally, contrary to previous results, the construction area in this case is dominated by the use of drawings, i.e. codified knowledge, pointing out the need for a more nuanced discussion on what types of codified knowledge to use when and where.

## 4.5 Summary of paper 5

**Title:** Diffusing building information management– knowledge integration, mechanisms and knowledge development

**Authors:** John Lindgren and Kristian Widén

**My contribution:** Review, data collection, major part of the analysis and writing

**Publication status:** Published (online) in Architectural Engineering and Design Management:

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**Which research questions of the thesis are in focus?** 2, 3, 4

**Keywords:** Building Information Management, Innovation Diffusion, systemic innovations, Knowledge Integration Mechanisms, Knowledge Development

**Background:**

Building Information Modelling (or Management as used in this paper) is of great interest to the construction industry, mainly due to its predicted improvements for the construction process and industry in general. Implementation and usage is also steadily increasing. However, diffusion has anyhow been slower than expected, where barriers relate to technology and management, where research has prioritized technical concerns over managerial. With the view of BIM as an innovation with inter-organizational effects, in this research denoted systemic innovation, many barriers can be identified due to its basic characteristics i.e. its effects and consequences for the construction process. For diffusion to occur, a central issue is to manage knowledge integration through different types of mechanisms. Furthermore, when dealing with knowledge integration and innovation, it is essential to expect knowledge development to take place, not least knowledge creation. However, in the construction process, many different types of professionals and different types of knowledge are necessary, and this may constitute a challenge. One fundamental question is therefore, what mechanisms are needed and used for knowledge integration to occur? Another question is what type of knowledge must be developed and integrated and what are the prerequisites for this?

In addition, in innovation diffusion studies in construction, much interest has been placed on actors that control the diffusion process, such as clients and contractors. The focus of this study is a reinforcement supplier (RS) who is trying to diffuse developed services. Suppliers often work in a traditional manufacturing industry context with continuous processes, while customers work in a project-based context. Since the different contexts affect how work takes place, they also affect KI. The case is therefore inter-

esting in order to increase understanding for innovation diffusion in construction and how knowledge integration takes place.

### **Purpose:**

The aim of this research is to study the KI mechanisms used by the RS and its customers, when diffusing BIM and related services. The influence of context on KI and the effects, especially in terms of knowledge development, is also discussed.

### **Method:**

The collection of data was partly carried out in parallel to Paper 2. The material collected in that study was reviewed using the focus of this paper. In a second round of interviews with four company internal employees, questions were raised that address the research in this paper. Specific mechanisms used for knowledge integration were reviewed with their effects as well as future plans and predicted effects.

### **Summary of main contents**

The frame of reference defines innovation and classifies BIM as a systemic innovation. The characteristics of a systemic innovation are described. Systemic Innovation and the research interest is focused on inter-organizational effects/consequences of innovations with possible effects on the whole construction process (actors and resources included). Interaction between different parts of a system within a specific context is closely examined. Furthermore, the view of BIM is defined as a move from paper-based modes of communication to a process based on electronic information and electronic tools, but it also emphasizes that BIM is more than just technology. The position by Hooper (2015) that BIM constitutes “*a combination of **process, technology and people** who endeavour to **create, enable and manage construction information**” (pp 26). In this research BIM is therefore defined as Building Information Management to address an extensive view of BIM. Furthermore, based on a research review, BIM-diffusion is viewed as an emergent process where the level increasingly becomes more advanced.*

The meaning of KI in an innovation context is then reviewed, stating that integration of created knowledge is essential and a definition of knowledge integration by Jetter et al is used: as processes of external knowledge identification, acquisition and internal utilization of external knowledge, where external knowledge refers to knowledge outside a specific context and that

the different parts (identification, acquisition and internal utilization) interact during the process. Mechanisms are also reviewed and this research takes its point of departure in the level of interaction. Knowledge development is assessed through the knowledge types domain-specific, procedural and general knowledge. Domain-specific knowledge relates mostly to specific, technical aspects, procedural knowledge to knowledge about what to do next, i.e. the level of the process being systematic and general knowledge can be influential in the development of a product (or innovation). The section is followed by a method description, describing the research approach and research context, data collection and data analysis and assessment of the research.

Following this, results from and analysis of the study is presented, which is then discussed and the paper ends with conclusions and suggestions for future research.

## **Results and contributions**

The findings describe the company and its development and the efforts that have been experienced. Contextual factors influencing the diffusion of BIM are presented such as project stress, short term view and a divided chain, lack of project evaluation and systematic learning. They altogether have a negative influence on diffusion. It was found that larger companies are most likely to push development forward due to the cost of investments and possible redistribution of activities in the construction process. It-maturity was brought forward as a central factor influencing BIM-diffusion, and with younger generations entering the sector, this most likely influence BIM-diffusion positively. In specific, the positive and negative aspects with visualization was discussed, where the positive aspects concerned decreased misinterpretation and better understanding, while it at the same time should not be overused.

Regarding mechanisms, it is not the mechanisms per se that appear to be a key issue, in this case it is more about considering contextual factors when diffusing and adapting mechanisms to conditions in the context. One important part is to move straight into real projects to show immediate benefits. Another important part is the availability of simple tools that enable diffusion and also the use of modern and generally available tools like YouTube. If something is to be stated about mechanisms, however, it seems as if more interaction-intensive mechanisms are most useful, at least in the start of the process. Concerning knowledge development, domain-specific

knowledge increases over time as well as procedural knowledge. General knowledge regarding ICT was also specifically highlighted as useful, since this type of knowledge simplifies diffusion of BIM and BIM-related solutions. Domain-specific knowledge is however needed to develop software, since construction knowledge is essential for developing ICT-solutions that work in the construction context.

The study contributed an understanding of which mechanisms are used, when and what their effects are when diffusing BIM and BIM-related solutions. It also provided insights into domain-specific knowledge, procedural knowledge and general knowledge and how these knowledge types are developed through the diffusion process and also how they interact. It also provided a significant difference with regards to domain-specific knowledge and general knowledge. In this case a large amount of general knowledge exists that could be integrated with domain-specific knowledge. Furthermore, it seems as if construction in general does not use experiences from IT-development in other sectors as they diffuse BIM. Consequently, there is a lot of potential to integrate Procedural knowledge into the process.

## 5. Analysis and discussion

*In this chapter the findings of the thesis are analysed and discussed, by connecting all the appended papers together. The papers relate to each other and contribute to the different research questions in different ways. In the treatment of the different research questions, these begin with a comparative analysis of the cases followed by reflections and discussion in relation to previous research. Following this, conclusions, practical implications and advice for practitioners are presented. The chapter ends with reflections on the research conducted and suggestions for further research.*

### 5.1 Introduction

The key focus in this thesis is systemic innovation diffusion. The content of the systemic innovations studied differ. MSHT is a new product in terms of building with timber as the primary structural material, resulting in changes in the construction process. With BIM the end result is to generate a largely changed construction process that is digitalized, enabled by technological innovations and solutions in the information and communications area. When reviewing the diffusion processes, the interplay between the content, context and the diffusion process, explains the progress and results of each diffusion process. For MSHT, a change in context at a specific point in time enabled the development of the content. During diffusion and development, the complexity has decreased as the definition level has increased, making the erection of MSHT easier and more cost-efficient: the content has changed to meet the demands of the market better and this has also affected the diffusion and the construction process. There has also been an apparent change of attitude towards MHTS enabling more houses to be built, i.e. increased recognition. For BIM and the RS, changes in context over time

have created the necessity to change the business and its competitive position pushing BIM-development forward as a way to create competitive advantage. Comparing the contexts, there is also significant difference between acting in a market with domestic competition only (MSHT), and operating in an international market (RS), primarily since the population of competitors is far greater. However, in both cases the current business situation is a result of contextual changes over time which has exerted effects on how work with the diffusion process takes place. In conclusion, with this interplay as a point of departure this displays dynamics in each diffusion process. When reviewing these innovations both similarities and differences can be found, where the differences especially appear more clearly with the increasing level of detail in the studies. Hopefully, this research has contributed to the point made by Tidd (2010) that more understanding is needed regarding how and why systemic innovations are adopted. In the following sections, the research questions will be reviewed more in detail.

## 5.2 Facilitating and hindering factors for the diffusion of systemic innovations

*“What facilitates and hinders the diffusion?”*

### 5.2.1 *Comparative analysis of cases and papers*

Facilitating and hindering factors for diffusion were addressed in Papers 2 and 3. However, these issues have been addressed in the other papers as well. The literature review, reflections and conclusions in Paper 1 dealt with issues that have been covered and developed in the empirical studies. When reviewing the diffusion process, the changes that have taken place (better market orientation, more well-defined system, change of attitude towards MSHT) altogether facilitate diffusion. For BIM, diffusion is complicated due to project stress and the position of the RS in the construction process, but it seems to be facilitated by an overall changing attitude in combination with a simplified implementation process. Both innovation types are affected by established traditions and work procedures but for MSHT other structural materials is a major obstacle, while for BIM it is established work procedures and methods.

Systemic innovation diffusion depends on its impact on the construction process, which concerns processes, structure and activities but also attitudes and behaviour. As stated in the introduction of this chapter the interplay between content, context and the diffusion process explains progress and results. The review concerning diffusion of different BIM and BIM-related services in paper two, showed differences in the interacting factors. How the different interacting factors were managed had a direct impact on the diffusion, as well as when these factors were not taken into consideration, it complicated diffusion. Based on Papers 2 and 3, it can furthermore be concluded that the diffusion process cannot be isolated to certain specific factors. Instead there are a number of interacting factors that facilitate and complicate the diffusion process, all in all implying the dynamic in the diffusion processes. Furthermore, the research shows that the degree to which the new systemic innovation challenges current structures is decisive for the speed of diffusion. MSHT is based on methods for producing prefabricated family houses, which provides the systemic innovation with advantages, but it also challenges current methods and materials regarding multi-story housing. Hence, it both builds on and challenges current methods and materials and both recognition of MSHT and current traditions influences diffusion. One difference when comparing this with BIM, it challenges current structures, methods and processes to a greater extent.

When moving further on the comparisons between these cases, it becomes evident that the ability to control the construction process exerts a major impact on systemic innovation diffusion, since dependence on different parties in the construction process increases. Contractors were given as an example of this in paper two. Evident from the research regarding MSHT is that actors with business in several parts of the construction process have better opportunities to diffuse systemic innovations due to their extended possibilities to manage the construction process. The MSHT-diffusion is also facilitated by being an environmentally-friendly alternative and being promoted by requirements stated in the municipality's detailed development plan. The reinforcement company is much more in the hands of the client and in Sweden the push from the outer context is limited compared to other countries such as Norway. Despite this, the RS has succeeded when the interplay between process, content and context has been beneficial. It was also stated in Paper 5, that a broadly-based business with the possibility to distribute costs across the construction process is essential for systemic innovation diffusion, a factor shown in the studies of MSHT. Different business areas funding each other have provided the financial stamina to develop MSHT. The broadly-based business for the MSHT CSO (Case Study

Organization) also provides opportunities to manage and shape the context and influence the diffusion process. Possibilities to control and reduce complexity are also key themes throughout the research. In Paper 2, facilitating innovation diffusion was thorough planning, long term focus and reducing unresolved issues to a minimum before the start of production. Complicating diffusion was in many ways the opposite: price focus, stress, and disorder. Regarding MSHT, the importance of control is also evident in different ways: there was a stated complexity in managing and coordinating all the parts of the system and development was also preferably made in small steps over a series of projects to stay in control and reduce complexity, where the system was refined between the projects. Other signs for increased control are the relocation of activities away from projects and the efforts to standardize and define MSHT in order to improve control. However, both innovations studied are considerably influenced by the necessity of applying a long-term focus. For MSHT, this also relates to industrialized house-building, for which a long-term focus is essential for development and diffusion.

Regarding the influence of context on systemic innovation diffusion, both cases display the influence of the dominating project based work method in construction. Judging from the cases facilitating systemic innovation diffusion is to reduce uniqueness in projects and moving activities away from the projects into a continuous organization. Another is to adopt a systems view or make platforms that can be used in several projects and consequently make use of experiences from completed projects. By transferring activities from projects into project-delivering units, implementation is simplified and in total, this facilitates diffusion. The cases also provide several examples of how to conduct these activities. Different sub-contexts also appear in both cases between suppliers and clients providing different prerequisites for working with diffusion and related development. There are also contextual differences between different types of projects for example a building project differs from an infrastructure project, as emphasized in Paper 2.

Another key concept evident in the studies and of central importance for innovation diffusion is interaction. The studies show disrupted interaction with the project-based work method and especially in the studies regarding BIM and the RS, interacting thoroughly with customers is problematic and projects often change both regarding people and set-up. This places more emphasis on reducing project-specific activities, but not on the necessity of interacting and means an even greater focus on efficient interaction. However, challenges seem greater for the RS regarding diffusion of its BIM-

services than for MSHT. The picture provided by the BIM-studies is also that the different trades, or clusters<sup>17</sup>, in the construction process, need to interact to a greater extent, in order to share their views and ideas on the development of the construction process. The challenge lies in conducting this efficiently. In the case of MSHT, work is conducted across business areas and previous contractors are used to a greater extent, not necessarily with experience of MSHT, but from similar areas, and as shown in the studies this provides advantages.

### *5.2.2 Reflections and discussion regarding conducted and previous research*

This research is an example of how context shapes action and action shapes context (Pettigrew, 1997). The research shows, especially when comparisons between different types of innovations are made, that there are many different issues in the context that influences innovation diffusion and demonstrating those fairly constitutes a challenge. As Rip (2012) points out, innovation depends on its context, old and new technology fight alongside each other and there is an independence between actors in the process. These cases show that the transition from old to new is a challenge. The Taylor (2006) studies on systemic innovation diffusion concluded that the extent of the systemic innovation has an effect on its diffusion and his aim was to identify general factors that influence diffusion. Besides validating the structural focus evident in Taylor, this research also emphasize attitudes and beliefs as influencing factors. Furthermore, the MSHT-studies show that for many professions in the construction process, the innovation entails no or only slight changes to their “normal” way of working. The research also shows examples of how to act in the diffusion process and the effects of this, which also is an important issue for the understanding of innovation diffusion.

Setting the studies in relation to Taylor, they do not contradict Taylor’s findings. At large, the impact on the construction process is highly influential for innovation diffusion. However, these studies contribute a dynamic perspective on the diffusion process and put a greater focus on how people perceive the innovation. The dynamic perspective visualizes the innovation diffusion process as highly iterative. The innovations themselves change throughout the diffusion process. Although they aim at providing individual

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<sup>17</sup> Clusters can be trades but also other types of groups with a mutual denominator, for example project management group or people from an organization active in a specific project.

users a value in the end, users belong to subgroups. Hence, Rogers's framework of innovation in organizations appears to provide greater relevance for systemic innovation diffusion in a construction context. Reviewing the implementation steps, in the case of MSHT redefinition took place over several projects before moving into the clarifying phase. With the RS, redefinition occurred several times, although the RS-innovations were less extensive. Comparing several of the examples brought forward by Rogers such as e-mail and software systems, the systemic innovations and the business environment to which diffusion is taking place seems more complex and the project-based context seems more varying regarding stability.

The implications from different sub-contexts can be added to the current research especially for systemic innovations with its inter-organizational focus, due to the inter-organizational character of construction projects. The inter-organizational focus in the research also places focus on different roles in the construction process, interaction between these and ways to act to make the systemic innovation a reality. Current research has placed a lot of emphasis on end actors in the construction process, for example contractors and clients, due to their ability to control. This research has also emphasized control of the construction process as a central issue to facilitate innovation diffusion, but it also shows how actors in the other end of the process, i.e. suppliers can act and what their challenges are as well as the impact of managing larger parts of the construction process. The research does not contradict previous findings by Larsson et al. (2006) and clearly emphasizes the need of interaction in the construction process for innovation to take place. There is, however, a challenge with the project-based work method and it is also obvious that it is too time consuming for everyone to interact, so it is necessary to have an efficient interaction strategy for successful diffusion to take place.

Due to the point of departure in the interaction between content, context and process, managing the how, or the process dimension, comes into focus and is a significant facilitating factor. As stressed in the frame of reference the emergent character of the innovation process requires ability to handle the context (Rip, 2012) and to manage the process in relation to context is a challenge. When reviewing innovation diffusion research and also the closely related change management area, the research shows potential in "problemizing" and reflecting on the process-dimension. In the frame of reference, Carlsson (2000) was referred to and using the three different approaches used by Carlsson (2000) or others, might provide additional understanding of the diffusion process and maybe visualize dimensions that affect

the process. In order to relate this to the conducted research, a linear approach is evident when benefits are easily shown, i.e. the content is easily understood and the context is fairly unproblematic, often related to magnitude of the context. In some cases, implementation has also been simplified by reducing the sphere of influence (c.f. Harty, 2005, 2008). The research has also described when the diffusion is more complex mainly related to convincing specific actors about the benefits of the systemic innovation in question. For example in the case of MSHT, it is evident that political decisions play a significant role for diffusion. The necessity of a critical mass for increased diffusion has also been shown in case of the MSHT, since this is essential to show that it really works.

It might also be useful to reflect on the five areas that should be handled differently according to Pettigrew and Whipp. Putting them altogether they make sense, not least when setting them in relation to systemic innovation diffusion and the cases studied, but the challenge seems to be with coherence in relation to the project-based work method and the way that the construction sector currently works. It is essential for an organization to understand its environment (environmental assessment), it has to be perceptive and show action during a systemic innovation diffusion process (leading change) and since many parts of the construction process might be affected. Strategic and operational change needs to be linked, especially significant in this research as systemic innovation diffusion needs to show real, actual benefits in the projects and on site and there are many parts that may be affected. However, challenges still remain if the population, at least in the most affected parts, vary too much. Possessing a knowledge base that matches changes in the competitive environment (Human assets as resources and liabilities) has also been addressed through the focus, but there is a difference here since it actually addresses the fact that both the knowledge base and the systemic innovation interplays in their development. In the case of MSHT the entire diffusion process can be considered a learning process which develops knowledge. Although this is also evident in the case of BIM, the general ICT-level in this case apparently exerts influence, both as a facilitating and hindering factor.

Relating to Taylor and Bernstein (2009), creating a more integrated approach and an efficient construction process requires many steps of gradual development. When reviewing the situation of the RS, it seems that development is taking its first steps, but there are many more remaining. In the case of MSHT, the situation is different due to a vertically integrated construction process, which has been emphasized as a way forward in construction

(see for instance (Taylor, 2006)) in relation to conventional industry which emphasizes horizontal integration (Christopher, 2011b, Lambert and Cooper, 2000). An additional point when reflecting on Pettigrew and Whipp is that the organizations studied seems to have more power to change autonomously and control its supply chain. In relation to these systemic innovation construction cases, it all seems to go back to the project-based method and construction as a fragmented industry. Most potential however seems to be at present in the MSHT, who through its setup has possibilities to tie into and affect the construction process set-up. Furthermore, the necessity of creating more long-term relationships seems beneficial for systemic innovation diffusion, but this also requires building a critical mass of actors to choose from.

### 5.3 Knowledge integration and mechanisms used

*How does knowledge integration take place  
and what mechanisms are used?*

#### 5.3.1 Comparative analysis of the cases

As shown by the comparison in the previous research question, increased interaction across the construction process is essential. Interaction is a central concept in knowledge integration and interaction takes place in different ways both between people using the innovation and also between the innovation itself and people using it i.e. both people and the systemic innovations are bearers of knowledge. As development and knowledge progresses and the systemic innovation becomes more defined or more used, the need for interaction decreases. Especially in the case of MHTS it is visible, that as development progresses, the need for less interactive intensive mechanisms decreases due to an increasingly defined system.

The existing knowledge base plays a key role when it comes to knowledge integration and the mechanisms to use, since it is about connecting new knowledge to that base. Put in another way, this can be viewed as a knowledge leap, and with a larger knowledge leap more interactive mechanisms and more efforts to integrate knowledge are needed. For MSHT in the final project studied, there were groups of professions (for example electricians) who stated that the MSHT was just like virtually any project (while some just thought it was a nicer and warmer environment to work in). For other professions, mainly the carpenters (with experience of erecting prefab-

ricated timber frames), the system was learnt fairly quickly, through instructions and learning-by-doing. The knowledge leap can be considered minor and initial integration mechanisms were not especially resource-consuming. The primary difficulties in these cases occurred when there was a large deviation from current practice. These matters were not resource-consuming, but really *required* instructions as a mechanism. However, when the whole diffusion process is taken into consideration, a vast amount of knowledge has been developed through a number of different mechanisms. Performed projects are the most important mechanism and the diffusion process is characterized by trial-and-error and a continuous learning cycle, and with continuous redefinition of the system. In the case of MSHT, there is a large amount of knowledge creation taking place, and the mechanism to integrate this simply seems to be learning-by-doing and then integrating well-functioning solutions into the MSHT platform. Returning to the initial issue, the most unsuccessful project was the project where the leap was too big. A key point is therefore to work in small steps, not make the knowledge leap to big and adapt the mechanism to the context and current situation.

Regarding the diffusion of BIM, the RS was in a much more stressful situation than the MSHT CSO and with less control of the construction process. IT-maturity and interest were identified as key factors that simplify diffusion, thereby also highlighting the knowledge leap factor. Relevance of use has been another important criterion for diffusion in these cases, which can be seen as connecting to the current knowledge base. Easy-to-learn mechanisms and face-to-face contact is preferable when diffusing BIM. Demonstrations on site have been a successful mechanism and written instructions were neglected in favour of instructions on you-tube and oral contact. It is worth noticing that the choice of *what* to initially diffuse is important for the diffusion of other innovations. As stated by the RS employees, if customers use solutions that provide benefits, they often become interested in other types of solutions supplied by the RS.

### *5.3.2 Reflections and discussion regarding conducted and previous research*

The emphasis in this research on projects as primary mechanisms for knowledge integration implies a difference for the construction sector in relation to other sectors. In the case of MSHT, full-scale buildings were needed to really know how new solutions worked even though some part-tests gave indications. Since implementation is more iterative, the innovation also becomes more iterative. Previous criticism regarding the linear model not showing interaction and feedback (Rothwell, 1994) finds rele-

vance in this research. In addition, in many other sectors it is possible to carry out extensive tests before launching a product onto the market, which also is evident in many innovation models (see for instance Gopalakrishnan and Damanpour (1997)). This provides the opportunity seeing consequences of the diffusion before diffusing for real, and consequences are as stated by Rogers (2003) an important part in studies of the diffusion process. For other systemic innovations, in this thesis the study of BIM, testing is possible in another manner since BIM does not per se constitute the built object. Since this is about information for the erection and management of the building, consequences are not that severe if a test fails. Instead this type of systemic innovation is positive in finding problems and challenges before the building object is in place.

The cases show that it is vital to manage different types of interactions and interdependencies with different types of mechanisms, which change over time. When comparing the two innovations, it seems as if in the production phase of MSHT, the need for interaction has more to do with insecurity (see Van De Ven et al. (1976) while for BIM it has to do with a more advanced innovation technically (Johnsson, 1992),. This anyhow demands more interaction-intensive mechanisms. One point in the studies is also that the use of drawings actually shows that construction is quite dominated by the use of codified knowledge. New media, such as easily-accessible instruction films is also a kind of codified knowledge that has proven useful. This is a point of interest since previous research has shown that construction has been quite hesitant regarding its use (Styhre, 2008, Bresnen et al., 2005) and therefore it might be useful to be more nuanced concerning what that is specifically meant and review development with new types of media. Both innovations studied also show that current practice is an obstacle for diffusion. For MSHT, large deviations from current practice highlights a special need to work with instructions, explanations and also supervision to avoid mistakes, thereby validating the view of for example Senaratne and Sexton (2008) and Bröchner et al. (2004), that a combined use of soft and hard mechanisms is preferable. Regarding BIM it is in many cases about learning something new and there is no colliding knowledge that in that sense constitutes a barrier. It is also not unusual that knowledge integration has differences in the cases since it is the same as with learning, it cannot be isolated from its context and the preconditions for learning (Brown and Duguid, 1991).

## 5.4 The development of knowledge types and their impact

*How do different types of knowledge develop and what is their impact?*

### 5.4.1 *Comparative analysis of the cases*

In the two types of innovations studied in this thesis, the type of necessary knowledge developed differs. In the case of MHTS, domain-specific knowledge, which as a result from the study was divided into domain specific product knowledge and domain specific process knowledge to nuance knowledge development, is the major knowledge type in focus, mainly since new knowledge needs to be created and integrated. General knowledge seems to be of less concern, at least until a higher definition level is reached. However, as MSHT has become more defined with major matters solved, more fine-tuning of the innovation has taken place. Therefore, there is a possible opening to work more with general knowledge to develop the innovation further. As stated in the case, plans were made to work more with BIM, but also to improve and use tools and aids in the process (for instance automate the weather-protection system for which general knowledge is useful) where general knowledge can play a much greater role. In the case of BIM and electronic solutions, general knowledge seems to have greater impact on diffusion and knowledge integration, since much needed knowledge relates to this type of knowledge. One example is that for younger generations, the use of cloud services and mutual platforms/servers are more natural and the use of these types of services is a part of everyday working-life. Although there seems to be differences in how knowledge types develop when the innovation types are compared, there seems to be potential in developing the work in between the actual construction process, firstly the administrative parts. One crucial difference is that for MSHT it is about learning something new, while for BIM it is about re-learning.

### 5.4.2 *Reflections and discussion regarding conducted and previous research*

One overarching contribution has been the introduction of the interacting knowledge types general, domain-specific and procedural knowledge. In previous research these knowledge types have been helpful and, judging from this research, they are useful in order to understand innovation diffusion and contribute to the debate on innovativeness in construction. Depend-

ing on the applicability of different knowledge types and the type that is needed, the innovativeness of the sector can be discussed in a more nuanced manner. As an example from these studies, the construction sector can be seen as having low innovativeness regarding IT- and IT-solutions due to a low level of general knowledge. In the development of multi-storey housing in timber, knowledge is highly domain-specific and this type of knowledge must be developed and solutions need testing and validation. Consequently, it can be hard to affect diffusion with other types of knowledge and thereby influence the pace of diffusion. This also relates to what Berggren et al. (2011) emphasizes that in an innovation context, knowledge integration is a process of knowledge creation and is intertwined with the application of existing knowledge.

Referring to the use of tacit and explicit knowledge and the development, it is clear that the knowledge development process is aimed at making tacit knowledge explicit. Overall, diffusion is dependent on this to make it happen and to simplify it. Creating a more defined systemic innovation, with descriptions and set processes, makes the innovations clearer and easier to implement. This also shows how to work with making knowledge explicit, but it also means that the knowledge necessary in the erection phase is simplified (see point 5.4). By integrating the created knowledge into the systemic innovation, the innovations themselves become a tool for the diffusion of explicit knowledge along with other ways that makes the integration of explicit knowledge possible. This also shows how the knowledge types domain-specific, procedural and general knowledge can be dealt with as tacit and explicit knowledge.

The different knowledge types are all affected by, and affect, knowledge integration and the mechanisms used. Independent of the systemic innovation that come into question, it can however be concluded that domain-specific knowledge is needed to make use of any knowledge that comes into question. This can also be related to general and specialized knowledge in specific and the need of common knowledge. In the thesis there is a level of general ICT-knowledge that has been stated as helpful in order to give diffusion of BIM and BIM-related services a helpful push. Where this is possible, it can be concluded that there is domain-specific and general knowledge that intersects.

## 5.5 Effects of the knowledge integration process

*What are the effects of the knowledge integration process?*

### 5.5.1 *Comparative analysis of the cases*

Judging from the overall development of the two cases, the diffusion and knowledge integration process has provided the case study organizations with competitive advantage. In what sense could however be discussed. There are many parts of these companies that have developed and the systemic innovations studied are a part of their overall development. The reinforcement company has, due to their overall development, created a position as the most technically competent reinforcement-supplier on the market. They have influenced their customers' processes as well as their own to make them more efficient. In case of MSHT, they had not yet as was the case with their competitors, sold their system to an external customer. However, their diffusion rate is increasing with more projects ongoing which imply that the competitiveness of the system has increased. Furthermore, since MSHT is becoming more advanced in design and at the same time less complicated in the production phase, it should become more competitive, thereby contributing to the organizations competitiveness.

Over time knowledge has been created and integrated in both cases. In the case of BIM and the RS, different services have opened up for the diffusion of other services. It seems as if the increased maturity over time in the whole sector has been of help to the diffusion of their services, at the same time as they have simplified and adapted their integration mechanisms and solutions to simplify diffusion, knowledge has been integrated into the solution. In the case of MSHT, the situation is the same. As development progresses and certain solutions are set and reused, this is another example of how knowledge is integrated into the product. Regarding the effects on the construction process in the case of MSHT, there is a shift of activities away from the projects, thereby improving the possibilities for knowledge integration. This also changed the work division across the construction process. In the case of the RS, it is also evident that some activities are moved away from the projects as the MSHT becomes more and more defined. In the MSHT case, increased maturity has also pushed diffusion forward.

Reviewing the knowledge integration process and value parameters that specifically address KI, simplifications in the process, products and services in combination with the KI have contributed to knowledge being more easily transferred. For MSHT it has become easier to introduce new people in to the system, and the simplifications made by the reinforcement supplier has also made knowledge easier to transfer. The usefulness of knowledge and whether it contributes to return on assets, is addressed in its appropriability

and this is shown through the increased competitiveness and overall development. An important part of an organization is, as emphasized above, to have people with diverse skills performing different tasks which place emphasis on specialization in knowledge acquisition. One main point here is that if knowledge is too general it does not add value or competitiveness. This is a duality, developing MSHT has meant that a lot of domain specific knowledge is also implemented into the system, but in the erection phase they strive for simplicity. The reinforcement company has actually needed less specialized knowledge in order for their services to diffuse and with the overall knowledge development taking place and as younger generations come into construction, this simplifies diffusion. Altogether, the general development in both cases is that meeting knowledge requirements, especially in the production phase is essential, and is a constant aim regarding both systemic innovations. However, as development progresses solutions in the systemic innovations are simplified and becoming easier to diffuse, i.e. less specialization is necessary. The appropriateness, i.e. usefulness of the created knowledge has therefore increased and the knowledge requirements in the production phase have become lower. This can be viewed as knowledge becoming more explicit, and thereby also easier for others to imitate. The diffusion of the systemic innovation thereby becomes easier, but the competitive advantage for the case study companies also consequently decreases. However, all knowledge must be contextualized for the target group in question, and this relates to all of the knowledge types used.

### *5.5.2 Reflections and discussion regarding conducted and previous research*

One basis for innovation and innovation diffusion is to contribute some type of value and due to this diffusion progresses. The efficiency potential, a classic criterion, is perhaps most evident in the case of BIM, but it also decreases use of resources and thereby creates a social value in terms of less environmental impact. Since social values have been more emphasized in innovation research (Bhattacharya, 2013, Cajaiba-Santana, 2014), it is worth noting and an area for more research, not least since construction projects delivers a result remaining for a considerable period of time. One example of the necessity of emphasizing social values in Construction Management research is Loosemore (2016), studying social procurement, i.e. procurement that delivers extra social benefits and create social value in local communities. He concludes that this area has not been researched at all. As discussed in the comparison of the cases, it is however a challenge to separate a specific systemic diffusion process when there is considerable devel-

opment ongoing in the context. As in the case of the RS, it has been stated that their different services work as door-openers for others, thereby implying that the overall “whole” is important as well as the separate innovations. For systemic innovations, it might also be that the less extensive, less systemic innovations are important in order to improve the diffusion of systemic innovations. In the case of MSHT, its development is enabled by the CSO’s overall business that allows profit sharing between its different business areas.

It is also worth noticing that the diffusion has led to a restructured supply chain, thereby stressing constructs identified by Taylor relating to the extent and impact on the construction process as exerting influence. An addition to the constructs identified by Taylor is that creating a consistent construction process that enables diffusion to a greater extent requires a population of not only contractors but also subcontractors and that the activity structure becomes set, a process that requires knowledge integration and is thereby an effect of the knowledge integration process. Furthermore, a useful strategy to enable diffusion is also to decrease project-dependence and thereby enhance inter-organizational knowledge flows. A natural effect of the knowledge integration process is that new knowledge has been created and integrated and it is, as Berggren et al. (2011) stresses, a combination of established and newly generated knowledge bases that have to be combined and integrated. One important lesson from the cases studied is also that this combination and integration is dependent on the size of the knowledge leap. It is however also interesting to note that diffusion also requires that knowledge in the production phase must be less specialized in order to simplify knowledge integration.

## 6. Conclusions

The overall aim of this thesis was to contribute to the understanding of the diffusion of systemic innovations in the construction sector. In addition to exploring what facilitates and complicates innovation diffusion, a special focus was placed on knowledge integration, mechanisms used and effects regarding knowledge development in the diffusion process. The research was presented in this thesis and in five appended papers. Firstly, the aim was fulfilled through studies focusing on what influences diffusion in construction through two overarching empirical studies from two viewpoints and one theoretical study, where central approaches and areas for future studies were especially highlighted. Secondly, the aim was fulfilled through two studies focusing on how knowledge integration takes place during the diffusion of two types of systemic innovations (timber based multi-storey buildings and BIM), the mechanisms that are used and what their effects are in general and in terms of knowledge development. In the studies different data collection methods have been used simultaneously with different approaches. The research has been conducted from the position of a critical realist and the overall aim was specified through four research questions, which are specifically addressed below under separate headings.

1. What facilitates and hinders the diffusion?
2. How does knowledge integration take place and what mechanisms are used?
3. How do different types of knowledge develop and what is their impact?
4. What are the effects of the knowledge integration process?

### 6.1 Facilitating and hindering factors for the diffusion of systemic innovations in construction

### *What facilitates and hinders the diffusion?*

Context shapes action and actions shape context. Systemic innovation diffusion is largely affected by its impact on the construction process. Understanding and acting based on the interplay between content, process and context is a facilitating factor. It sets management conditions for diffusion, stressing a significant value in reviewing and understanding diffusion processes through the interaction between the context, content and the diffusion process, since this shows specific nuances and understanding with regard to different cases. One consequence is that there is uniqueness in different systemic innovation diffusion cases. This places further emphasis on nuancing these dimensions in studies of systemic innovations. It also adds understanding regarding transferability of results from studies of different types of systemic innovations. In conclusion, one of the major contributions of the research is that while it contributes details and nuances for the diffusion process, it thereby also reviews the theoretical generalizability of certain concepts. An additional conclusion is that there seems to be more validity in using Rogers work on innovation in organizations for studies of systemic innovation in order to understand its facilitation, mainly due to the fact that the diffusion process of systemic innovations is characterized by interaction between a vast number of people and groups of people in an iterative process.

This research also shows how to handle the context and thereby influence diffusion. Influencing factors differ between the types of systemic innovations studied and context-specific factors have been addressed, highlighted and contributions provided that enable opportunities to assess the transferability between different types of systemic innovations. Several factors interact, affect diffusion and differ in the different cases. Facilitating factors largely relate to the level of control and management of the construction process and working with active clients. One element of influence significant to systemic innovation diffusion is the notion of different sub-contexts across the construction process, since different sub-contexts provide different prerequisites for innovation diffusion. A final point in this part of the aim is also to highlight the necessity of researching the how-dimension of innovation diffusion research, in order to increase understanding for diffusion, where the project-based work method and the fragmented character of the industry appear to be a significant challenge.

## 6.2 The knowledge integration process and mechanisms used

*How does knowledge integration take place and what mechanisms are used?*

The nature of the systemic innovation and its context sets and affects the mechanisms used. Besides contextual differences when diffusing the same systemic innovation, the context in which the diffusion takes place affects the process, the mechanisms that are used and their effects. Its inter-organizational nature also means that there are a number of different professions that are affected to varying degrees. For some it is business as usual and for others changes have a greater impact. In question of mechanisms, real projects are the most crucial with many underlying mechanisms when it comes to MSHT, since projects are a result of the development and an evaluation of work performed.

## 6.3 The development of knowledge types and their impact

*How do different types of knowledge develop and what is their impact?*

In the research, the domain-specific, procedural and general knowledge types have been introduced as complementary to tacit and explicit knowledge. Domain-specific knowledge has furthermore been divided into domain-specific product knowledge and domain-specific process knowledge, since this nuances the analysis of knowledge development. These have been useful to gain an improved understanding of diffusion and the knowledge flows that are in question and have enabled a detailed comparison of knowledge development for the different types of systemic innovations. The knowledge types introduced are also able to nuance discussions on innovativeness in the construction sector, since one major factor is the ability and resources to integrate general knowledge with domain-specific knowledge. Furthermore, it seems as if construction in general does not use experiences from IT-development in other sectors as they diffuse BIM. Procedural knowledge therefore has a lot of potential for integration into the process. The necessity of clarifying the systemic innovations and developing knowledge in order to do so, shows that it is essential to make tacit

knowledge explicit for increased diffusion. In addition, it also shows that domain-specific, procedural and general knowledge may be regarded as tacit and explicit and vice versa, and development towards the knowledge types becoming more explicit, influences diffusion in a positive manor, but there all knowledge must also be contextualized for the target group in focus.

## 6.4 Effects from the knowledge integration process

*What are the effects from the knowledge integration process?*

Overall the diffusion and knowledge integration processes have led to competitive advantages in different ways, although Building Information Management diffusion is dependent on the diffusion of other services, in some cases less complicated, to create interest. In both cases development in the context supports the diffusion process. One effect is also that the amount of activities in projects are decreased and transferred from the projects, thereby enabling more continuous knowledge flows and knowledge integration. Furthermore, the need for specialized knowledge has decreased in the projects, due to the knowledge development taking place that makes knowledge easier to transfer. This simplification could also be viewed as knowledge becoming more explicit, thereby becoming more transferable, easier to aggregate and more appropriate. However, due to the decreased need for specialized knowledge, knowledge requirements also become lower. As development has proceeded, knowledge is also integrated into the systemic innovations. The influence of changes in population between projects has previously been stressed, and an addition is that building up knowledge is necessary in introducing and working with different resources in the projects.

## 6.5 Theoretical contributions, research implications and practical implications

This research relates to research in Construction Management emphasizing interaction and the dynamic character of the diffusion process in (see for example Harty, 2008) and has provided additional understanding for complexity in the diffusion process. One point of departure is the interaction between the innovation content, the innovation diffusion process and the innovation context. The emphasis in this thesis is on empirical data collection and the interplay has been exemplified through the studies of two types of systemic innovations. The research also places emphasis on both using

and developing the framework of innovation in organizations by Rogers (2003) in diffusion studies in construction management research (see section 6.6 Suggestions for future research). This interactive view has also followed the research into the studies of knowledge integration and provided additional understanding for the most prominent mechanism, the construction project and the connection between different types of mechanisms. This thesis also provides insights into mechanisms to use, when and why. This has also been connected to knowledge development. The introduction of the knowledge types domain-specific, procedural and general knowledge into construction management research has been proven useful to understand knowledge development in the innovation diffusion process.

The research has been assessed in section 3.4. To conclude the qualitative studies conducted these should be assessed from the viewpoint of the specific cases and their contributions. The aim was to provide context and meaning for the systemic innovations studied. Hopefully, the described cases enable comparisons with other studies. Other examples of similar types of systemic innovation might show other results, but as stated there is an uniqueness in different systemic innovation diffusion processes. The extensive data collection provides extensive insights into the diffusion processes. However, the inductive approach in two of the papers and the focus on extensive data collection constitutes a challenge regarding what to emphasize and not. Broad approaches gather many issues, where a more focused study might contribute with data seen as more replicable. However, it has been deemed a necessity for the studies conducted. In addition, the researcher is the primary instrument for data collection and interprets data. There is always a possibility that other research results may appear by other researchers. The trustworthiness, in this research addressed under descriptive, interpretative and internal validity, has been managed through interaction with different types of activities and with different types of people, which should strengthen the trustworthiness of the research. The researchers position, underlying assumptions and theories has been described which is a central part in understanding and assessing the research.

Regarding practical implications the research shows how the case-study companies have managed the diffusion process including facilitating and hindering factors. The diffusion process has been a learning experience. Studying these processes and their results may be useful for other companies attempting to diffuse systemic innovations, in order to more efficiently handle the diffusion process or understand its progress. Since one of the key contributions from the work is the emphasis on projects as a key mechanism

to integrate knowledge and the case study companies have integrated knowledge based on performed projects. In a wider context, this emphasizes the importance of project evaluation to develop the business, although its effectuation often is neglected due to stress and a focus on finishing projects.

Based on the studies made, it is apparent that opinions, beliefs and attitudes vary and in many cases it is not the most well worked facts that guide action. Since many problems have occurred in the implementation phase for the case-study companies, a central issue from a practical point of view is to place more efforts on planning the implementation, but also be perceptive for what happens during the implementation process. For the case-study companies, their management of the interplay between process, content and context has explained the progress of the ID-process. This could also be used as a guide in practice for other companies when diffusing innovations. As shown in the studies, changes in one factor, deliberate or not, has effect on the others. It might also be used as a way of thinking in new or alternative ways, as in asking the question, so, we are not moving forward, is there anything we can change regarding content, process or context?

## 6.6 Suggestions for future research

Frames of reference that are especially holistic in their approach have been proven useful, not least the interplay between process, context and content. This has also resulted in methodological consequences, implying that broad methodological implications should be used to capture the eventual complexity and implications of the diffusion of systemic innovations. A specific frame of reference that should be developed and used more extensively in research on systemic innovation diffusion is Rogers framework of innovations in organizations. Albeit that everything in the end comes down to individuals, the interaction between groups and the iterative character of the systemic innovation diffusion process motivates the use of this framework. In addition, future research could benefit from scientific approaches and frames of reference that emphasize and illuminate dynamics in the context of study.

As shown in the studies and also highlighted under “Theoretical contributions, research implications and practical implications”, using the interplay as a basis of research and for practical use is advised. Looking back at how the authors, emphasized by Pettigrew in a number of articles (Pettigrew, 1985, Pettigrew, 1987, Pettigrew, 1990, Pettigrew et al., 2001) conduct re-

search, massive data collection over long periods of time takes place and they place considerable emphasis on the empirical material. This could be an opening for further studies. In their case, as in Pettigrew and Whipp (1991), the case is strategic change and with this follows that the size of the companies studied as well as understanding their changes, requires massive empirical data collection. When minor changes are studied, this might require less empirical data collection, and instead viewing a number of minor changes could be a way to work. To put this approach into a construction diffusion context, one suitable method would be to follow and participate more closely in several projects over time, to study more closely in detail how things progress. This would probably provide better opportunities to study the how or process dimension more closely which, as can be noted by the analysis, discussion and conclusions, diffusion research could benefit from. In addition, Rogers (2003) framework on innovation in organizations has also been identified as most suitable for studies of systemic innovation diffusion. This research shows that the complexity of systemic innovation diffusion may require extensive redefinition before moving into the clarifying phase. Systemic innovation diffusion in the construction sector is of interest due to its complicated business context that is project-based, decentralized and more unstable in comparison with more stable business contexts. The framework could therefore be more explicitly used and evaluated in studies of systemic innovation diffusion in the construction sector.

Regarding knowledge integration, project evaluation and feedback are central activities necessary to improve the construction process and also to diffuse solutions. Since it is evident in the studies that this activity often is neglected and knowledge transfer takes place anyway between projects through different methods, the area would be interesting to study further. Having a well-planned and well-thought-out strategy for conducting project evaluations probably also leads to a number of issues to deal with and implement in future projects. Studying project improvements over several related projects while they happen could be an interesting way to continue this research. This would probably give better opportunities to study the process dimension live, when things actually happen and reduce the risk of embellished images of what took place a while after the end of the projects and avoid retrospective explanations (Voss et al., 2002). One main issue in the studies is also that what has taken place has been studied to a considerable extent. This provides valuable input in order to become normative, and in further studies, it could be useful to focus on what mechanisms to use and consequently expand and develop this area. One contribution from this research is for example that mechanisms are context-specific. As shown in

these studies, different factors affect the use of mechanisms and also their effects. For instance, the way work is currently conducted has implication both regarding multi-storey housing and BIM, but it concerns different matters and has different implications. Briefly stated, the research nuances systemic innovation diffusion and there might also be a point in working more actively with normative models and concepts in research, building on actual input on how different dilemmas have been handled.



# Sammanfattning

Ett ofta nämnt begrepp i dagens samhälle är Innovation. En grundläggande del är att det innebär en introduktion av något nytt. I denna avhandling innebär begreppet att det är något nytt för den som skall bruka den. Ordet kan ses i väldigt många sammanhang och inte minst har forskningen inom området innovation ökat dramatiskt, där forskning inom byggandet inte utgör något undantag. Byggsektorn har också fått utstå mycket kritik för att inte vara innovativ, vilket forskningen behandlat på en mängd olika sätt. Byggsektorn sägs ofta vara tidspressad och kortsiktig vilket också kan fungera som en förklaring till de som kritiserar byggsektorn för att inte vara speciellt innovativ. I takt med att forskningsmängden ökat har det också skett en ökad nyansering av olika fokusområden inom forskningen. En typ av forskning fokuserar på behovet och effekterna av förändringar som har effekter på större delar av byggprocessen, vilket forskningen i denna avhandling knyter an till.

Fokusområdet i denna avhandling är innovationer med interorganisatoriska effekter, så kallade systemiska innovationer. Denna typ av innovationer är speciellt intressanta eftersom de kan innebära genomgripande förändringar och förbättringar av och för byggprocessen. Avhandlingen fokuserar på spridningen av systemiska innovationer, ett mått på hur framgångsrik en innovation är. Forskning inom detta kan även bidra med ökad förståelse för vad som påverkar spridningen, vilket aktörer aktivt kan dra lärdom av i sitt eget innovationsarbete. Denna forskning har fokuserat på två olika typer av systemiska innovationer, flervåningshus i trä (FIT) och Building Information Management/Modelling (BIM). Forskningen har presenterats i fem artiklar som sammanfattas i denna sammanläggningsavhandling. Innovationerna är knutna till varsitt fallföretag och deras arbete med att sprida innovationerna. Forskningen har till att börja med undersökt vad som påverkar spridningen av respektive innovation. Ett nyckelområde för spridning är kunskapsintegration, vilket handlar om att kombinera gammal kunskap med ny. Detta kan göras på olika sätt med mekan-

ismer. Forskningen har mer specifikt undersökt vilka mekanismer som använts för kunskapsintegration och vilka effekter dessa har. De fyra artiklar som behandlar ovanstående omsluts av en femte artikel som i en litteraturstudie behandlat faktorer som påverkar spridningen av systemiska innovationer, vilka angreppssätt som kan vara att föredra forskningsmässigt samt intressanta forskningsområden att studera vidare. Enligt rekommendationerna i denna artikel har ett brett angreppssätt valt där olika insamlingsmetoder valts beroende på studiens karaktär. Vissa av de utpekade fortsatta forskningsområdena berörs av de artiklar som ingår i avhandlingen.

Forskningsresultaten bygger på att diffusionsprocessen beror av samspelen mellan innovationens innehåll, kontext och sättet på vilket diffusionsprocessen genomförs. Vikten av detta samspel för att förstå diffusionsprocessen har validerats med den genomförda forskningen. För de två innovationstyperna innebär detta att det finns skillnader i hur diffusionsprocessen fortgår och vad som påverkar den. Det är dessutom av betydelse att i forskningen uttrycka sig nyanserat om samtliga dimensioner. En avgörande skillnad mellan fallföretagen är att företaget som arbetar med FIT, styr stora delar av byggprocessen, medan företaget som arbetar med BIM levererar till byggföretag/projekt och är därför beroende av sina kunder på ett annat sätt. Längs byggprocessen är olika organisationer verksamma i olika subkontexter, vilket påverkar spridningen på olika sätt. Detta är därför betydande för innovationsspridningen eftersom det skapar skillnader rörande möjligheten att sprida lösningen. Olika faktorer interagerar och påverkar spridningen men de är olika i de olika fallen. En likhet är i alla fall att det finns fördelar med att flytta aktiviteter från projekt in i den löpande som levererar till projekten. Några påverkande faktorer liknar varandra på en övergripande nivå, men på detaljnivå ser de olika ut. Båda innovationstyperna påverkas av etablerade traditioner och tillvägagångssätt, men för MSHT är andra strukturella material ett hinder, medan det för BIM är etablerade arbetsprocesser och metoder. Externa drivkrafter skiljer sig också i fallen, där miljöpåverkan är påtaglig för MSHT, medan det för BIM inte finns externa drivkrafter med påtaglig effekt. Båda fallen stöds av aktiva kunder, men det handlar också om att förenkla implementeringen så mycket som möjligt. Implementeringen är också att föredra i små steg, beroende av den komplexitet som ska hanteras. Till sist, spridning kräver finansiella resurser som är beroende av storleken på investeringen och de risker de medför. Genom att arbeta i steg är det också möjligt att

på ett kontrollerat sätt göra förenklingar och justeringar mot användare, vilket förenklar spridningen genom förenklad implementation. MSHT är också i mycket större grad beroende av riktiga projekt för sin implementering. För digitala lösningar, som BIM är det lättare att testa lösningar innan spridning in i en verklig miljö. I synnerhet för MSHT, visar detta på en skillnad mot många traditionella modeller av innovations- och innovationsspridningsprocessen, där tester förutsätts vara möjliga.

Rörande mekanismer är projekt också den mest avgörande mekanismen med många underliggande mekanismer, främst när det kommer till MSHT, eftersom projekt är ett resultat av utvecklingen och en utvärdering av genomfört arbete. Det finns ett grundläggande intresse för att använda kodifierad kunskap inom byggsektorn, eftersom när det fungerar är ett effektivt sätt att integrera kunskap, men i kombination med mer interaktionsintensiva mekanismer. Inom forskningen, där de tre kunskaps typerna domän-specifik (domain-specific), kunskap om tillvägagångssätt (procedural) och generell kunskap har introducerats. Dessa har varit användbara för att erhålla en förbättrad förståelse för spridning och de kunskapsflöden som kommer i fråga. Det verkar finnas en avgörande skillnad rörande hur kunskaps typerna utvecklas vid en jämförelse mellan innovationstyperna. För BIM verkar generell kunskap mer användbar och har en avgörande roll i sin spridning. Medan MSHT handlar om att skapa ny kunskap utifrån faktiska erfarenheter och integrera denna. När det gäller applicering av kunskap om MSHT, komplicerar praxis kunskapsintegration, beroende på hur uppenbar nuvarande praxis är i tillämpning och hur mycket det avviker från etablerade arbetssätt. En avgörande skillnad är att MSHT handlar om att lära nytt, medan det för Bim handlar om att lära om.

Forskningen betonar interaktion och dynamik i spridningsprocessen och har bidragit med ytterligare kunskap rörande komplexitet i spridningsprocessen baserat på samspelet mellan innovationsinnehållet, spridningsprocessen och innovationskontexten, exemplifierat genom studier av två typer av systemiska innovationer. Detta sätter också tonvikt på att både använda och utveckla referensramen om innovationsprocessen i organisationer av Rogers (2003) i spridningsstudier inom forskningen inom Construction Management. Detta interaktiva perspektiv har också följt forskningen in i studierna av kunskapsintegration, de mest framstående mekanismerna, byggprojekten som

den mest framstående mekanismen, byggprojektet likväl som kopplingen mellan olika typer av mekanismer och vilka som skall användas när, var och hur. Mekanismerna har också knutits till kunskapsutveckling. Införandet av kunskapstyperna domain-specific, procedural och general knowledge i forskningen inom construction management har visat sig nyttig för att förstå kunskapsutveckling i innovationers spridningsprocess.

# References

- ABDIRAD, H. 2016. Metric-based BIM implementation assessment: a review of research and practice. *Architectural Engineering and Design Management*, 1-27.
- ADDIS, M. 2016. Tacit and explicit knowledge in construction management. *Construction Management and Economics*, 34, 439-445.
- ALMEIDA, P., SONG, J. & GRANT, R. M. 2002. Are firms superior to alliances and markets? An empirical test of cross-border knowledge building. *Organization Science*, 13, 147-161.
- ALVESSON, M. & SKÖLDBERG, K. 1994. Tolkning och reflektion - Vetenskapsfilosofi och kvalitativ metod [Interpretation and Reflection - Philosophy of science and qualitative method]. *Lund: Studentlitteratur*.
- ANDERSEN, H. 1994. *Vetenskapsteori och metodlära: En introduktion [Theory of science and method theory: An introduction]*, Lund, Studentlitteratur.
- ANDERSEN, V. & GAMDRUP, P. 1994. Forskningsmetoder" (research methods) in Andersen, Heine (ed.)(1994) *Vetenskapsteori och metodlära (theory of science and methodology)*. *En introduktion*.
- ANNAN, C.-D. 2012. IMPROVED INTEGRATION IN CONSTRUCTION SUPPLY CHAIN. *International Journal of Construction Project Management*, 4, 107.
- ARB NOR, I. & BJERKE, B. 2009. *Methodology for creating business knowledge*, Sage Publications Ltd.
- BARLOW, J. 2000. Innovation and learning in complex offshore construction projects. *Research policy*, 29, 973-989.
- BARRETT, P. & SEXTON, M. 2006. Innovation in Small, Project-Based Construction Firms\*. *British Journal of Management*, 17, 331-346.
- BERGGREN, C., BERGEK, A., BENGTTSSON, L. & SÖDERLUND, J. 2011. Exploring knowledge integration and innovation. In: BERGGREN, C., BERGEK, A., BENGTTSSON, L., HOBBDAY, M. & SÖDERLUND, J. (eds.) *Knowledge integration and innovation. Critical challenges facing international technology-based firms*. Oxford: Oxford University Press.
- BHASKAR, R. 2008. *A realist theory of science*, Routledge.
- BHATTACHARYA, C. 2013. The Importance of Marketing for Social Innovation. *Social Innovation*. Springer.
- BOVERKET 2006. Sundsvalls inre hamn – ett utvecklings- och informationsprojekt för trahusbyggnad i massivträ [Sundsvall's inner harbour – a development and information project for solid wood construction].

- BOVERKET. 2014. *BBR från 1994 [The Construction rules from 1994 by the Swedish National Board of Housing, Building and Planning]* [Online]. the Swedish National Board of Housing, Building and Planning. Available: <http://www.boverket.se/sv/lag--ratt/aldre-lagar-regler--handbocker/aldre-regler-om-byggande/bbr-fran-1994/> [Accessed].
- BRESNEN, M., EDELMAN, L., NEWELL, S., SCARBROUGH, H. & SWAN, J. 2005. Exploring social capital in the construction firm. *Building Research & Information*, 33, 235-244.
- BRESNEN, M. & MARSHALL, N. 2000. Partnering in construction: a critical review of issues, problems and dilemmas. *Construction Management & Economics*, 18, 229-237.
- BRISCOE, G. & DAINTY, A. 2005. Construction supply chain integration: an elusive goal? *Supply chain management: an international journal*, 10, 319-326.
- BROWN, J. S. & DUGUID, P. 1991. Organizational learning and communities-of-practice: Toward a unified view of working, learning, and innovation. *Organization science*, 2, 40-57.
- BRUSONI, S., PRENCIPE, A. & SALTER, A. 1998. Mapping and measuring innovation in project-based firms. *Brighton, UK: University of Sussex*.
- BRÖCHNER, J., ROSANDER, S. & WAARA, F. 2004. Cross-border post-acquisition knowledge transfer among construction consultants. *Construction Management and Economics*, 22, 421-427.
- BUCHHOLZ, B., PAQUET, V., WELLMAN, H. & FORDE, M. 2003. Quantification of ergonomic hazards for ironworkers performing concrete reinforcement tasks during heavy highway construction. *AIHA journal*, 64, 243-250.
- BYGBALLE, L. E., HÅKANSSON, H. & JAHRE, M. 2013. A critical discussion of models for conceptualizing the economic logic of construction. *Construction Management and Economics*, 31, 104-118.
- CAIN, C. T. 2003. *Building down barriers: a guide to construction best practice*, Routledge.
- CAJAIBA-SANTANA, G. 2014. Social innovation: Moving the field forward. A conceptual framework. *Technological Forecasting and Social Change*, 82, 42-51.
- CARLSSON, J. 2000. *Logistiskt förändringsarbete: olika ansatser för operativ utveckling [Logistics Change-strategies for operational transformation]*. PhD-dissertation, Linköping University.
- CARRILLO, P. 2004. Managing knowledge: lessons from the oil and gas sector. *Construction Management and Economics*, 22, 631-642.
- CARRILLO, P. M., ROBINSON, H. S., ANUMBA, C. J. & BOUCLAGHEM, N. M. 2006. A Knowledge Transfer Framework: the PFI context. *Construction Management and Economics*, 24, 1045-1056.
- CELSA. 2015. [Accessed 20160401].
- CHESBROUGH, H. W. & TEECE, D. J. 1996. When is virtual virtuous. *Harvard business review*, 74, 65-73.

- CHRISTOPHER, M. 2011a. *Logistics and supply chain management*, Pearson UK.
- CHRISTOPHER, M. 2011b. *Logistics and supply chain management: creating value-added networks*, Edinburgh, Pearson education.
- COURT, A. W. 1997. The relationship between information and personal knowledge in new product development. *International Journal of Information Management*, 17, 123-138.
- COWAN, R., DAVID, P. A. & FORAY, D. 2000. The explicit economics of knowledge codification and tacitness. *Industrial and corporate change*, 9, 211-253.
- CROSSAN, M. M. & APAYDIN, M. 2010. A multi-dimensional framework of organizational innovation: A systematic review of the literature. *Journal of management studies*, 47, 1154-1191.
- DAINTY, A. R. J., BRISCOE, G. H. & MILLETT, S. J. 2001. Subcontractor perspectives on supply chain alliances. *Construction Management and Economics*, 19, 841-848.
- DUBOIS, A. & GADDE, L.-E. 2002. Systematic combining: an abductive approach to case research. *Journal of business research*, 55, 553-560.
- EASTMAN, C., TEICHOLZ, P., SACKS, R. & LISTON, K. 2011. *BIM handbook: a guide to building information modeling for owners, managers, designers, engineers, and contractors*, Wiley.
- EGAN, J. 1998. *Rethinking construction*, UK Department of the Environment, Transport and the Regions, HMSO, London.
- EISENHARDT, K. M. 1989. Building Theories from Case Study Research. *The Academy of Management Review*, 14, 532-550.
- EKESKÄR, A. & RUDBERG, M. 2016. Third-party logistics in construction: the case of a large hospital project. *Construction Management and Economics*, 1-18.
- ELMUALIM, A. & GILDER, J. 2013. BIM: innovation in design management, influence and challenges of implementation. *Architectural Engineering and Design Management*, 10, 183-199.
- EMMITT, S. 1997. *The diffusion of innovations in the building industry*. PhD thesis, University of Manchester.
- ENBERG, C., LINDKVIST, L. & TELL, F. 2006. Exploring the dynamics of knowledge integration acting and interacting in project teams. *Management Learning*, 37, 143-165.
- ENGSTRÖM, S. & HEDGREN, E. 2012. Sustaining inertia? *Construction Innovation*, 12, 393-413.
- ERIKSSON, P. E. 2015. Partnering in engineering projects: Four dimensions of supply chain integration. *Journal of Purchasing and Supply Management*, 21, 38-50.
- FAWCETT, S. E., MAGNAN, G. M. & MCCARTER, M. W. 2008. Benefits, barriers, and bridges to effective supply chain management. *Supply Chain Management: An International Journal*, 13, 35-48.

- FORDE, M. S. & BUCHHOLZ, B. 2004. Task content and physical ergonomic risk factors in construction ironwork. *International Journal of Industrial Ergonomics*, 34, 319-333.
- FORMAN, M. 2013. Inertia and change: lean construction and health and safety work on construction sites. *Construction Management and Economics*, 31, 647-660.
- FRISHAMMAR, J., LICHTENTHALER, U. & RUNDQUIST, J. 2012. Identifying technology commercialization opportunities: the importance of integrating product development knowledge. *Journal of Product Innovation Management*, 29, 573-589.
- GAO, S. & LOW, S. P. 2013. The Toyota Way model: an alternative framework for lean construction. *Total Quality Management & Business Excellence*, 25, 664-682.
- GLASER, B. G. 1978. *Theoretical sensitivity: Advances in the methodology of grounded theory*, Sociology Pr.
- GODIN, B. 2006. The Linear model of innovation the historical construction of an analytical framework. *Science, Technology & Human Values*, 31, 639-667.
- GODIN, B. 2011. καινοτομία: An old word for a new world, or, the de-contestation of a political and contested concept. *Project on the Intellectual History of Innovation, INRS: Montreal. A shorter version has been published in Karl-Erik Sveiby, Pemilla Gripenberg and Beata Segercrantz (eds.), Challenging the Innovation Paradigm, London: Routledge, 2012, 37-60.*
- GOETZ, J. & LECOMPTE, M. 1984. Ethnography and qualitative designs in ethnographic research. *New York: Academic.*
- GOLDSMITH, R. E. & FOXALL, G. R. 2003. The measurement of innovativeness. In: SHAVININA, L. V. (ed.) *The international handbook on innovation*. Oxford: Elsevier.
- GOPALAKRISHNAN, S. & DAMANPOUR, F. 1997. A review of innovation research in economics, sociology and technology management. *Omega*, 25, 15-28.
- GOULDING, J. S., POUR RAHIMIAN, F., ARIF, M. & SHARP, M. 2015. New offsite production and business models in construction: priorities for the future research agenda. *Architectural Engineering and Design Management*, 11, 163-184.
- GRANT, R. M. 1996. Toward a Knowledge-Based Theory of the Firm. *Strategic Management Journal*, 17, 109-122.
- GRANT, R. M. 2013. Reflections on knowledge-based approaches to the organization of production. *Journal of Management & Governance*, 17, 541-558.
- GREEN, S. D. 1999. The missing arguments of lean construction. *Construction Management & Economics*, 17, 133-137.
- GREEN, S. D., HARTY, C., ELMUALIM, A. A., LARSEN, G. D. & KAO, C. C. 2008. On the discourse of construction competitiveness. *Building Research & Information*, 36, 426-435.

- GREEN, S. D., KAO, C.-C. & LARSEN, G. D. 2010. Contextualist research: iterating between methods while following an empirically grounded approach. *Journal of Construction Engineering and Management*, 136, 117-126.
- GUBA, E. G. 1987. Naturalistic evaluation. *New directions for program evaluation*, 1987, 23-43.
- GUBA, E. G. & LINCOLN, Y. S. 1981. *Effective evaluation: Improving the usefulness of evaluation results through responsive and naturalistic approaches*, Jossey-Bass.
- GUSTAVSSON, B. 2000. Kunskapsfilosofi-Tre kunskapsfomer i historisk belysning [Philosophy of Knowledge: Three forms of knowledge in a historic perspective].
- HADJIMANOLIS, A. 2003. The barriers approach to innovation. *The International Handbook on Innovation. Elsevier Science, Oxford*.
- HARTY, C. 2005. Innovation in construction: a sociology of technology approach. *Building Research & Information*, 33, 512-522.
- HARTY, C. 2008. Implementing innovation in construction: contexts, relative boundedness and actor-network theory. *Construction Management and Economics*, 26, 1029-1041.
- HAVENVID, M. I., HULTHÉN, K., LINNÉ, Å. & SUNDQUIST, V. 2016. Renewal in construction projects: tracing effects of client requirements. *Construction Management and Economics*, 1-18.
- HEMLIN, S., ALLWOOD, C. M. & MARTIN, B. R. 2008. Creative knowledge environments. *Creativity Research Journal*, 20, 196-210.
- HENDERSON, R. M. & CLARK, K. B. 1990. Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms. *Administrative science quarterly*, 9-30.
- HJORT, B., WIDEN, K. & LARSSON, B. ADOPTION OF A WORKING ENVIRONMENT INNOVATION: "ROLLOUT BAR CARPETS". CIB W099 Benefitting Workers and Society through Inherently Safe(r) Construction, 2015 Belfast, Northern Ireland.
- HOOPER, M. 2015. *BIM Anatomy II: Standardisation Needs & Support Systems*, Lund University.
- HOOPES, D. G. & POSTREL, S. 1999. Shared knowledge, "glitches," and product development performance. *Strategic management journal*, 20, 837-865.
- HOWALDT, J., SCHWARZ, M., HENNING, K. & HEES, F. 2010. *Social Innovation: Concepts, research fields and international trends*, IMA/ZLW.
- HURMEKOSKI, E., JONSSON, R. & NORD, T. 2015. Context, drivers, and future potential for wood-frame multi-story construction in Europe. *Technological Forecasting and Social Change*, 99, 181-196.
- JACOBSSON, M. & LINDEROTH, H. C. 2010. The influence of contextual elements, actors' frames of reference, and technology on the adoption and use of ICT in construction projects: a Swedish case study. *Construction Management and Economics*, 28, 13-23.

- JETTER, A., KRAAIJENBRINK, J., SCHRÖDER, H.-H. & WIJNHOFEN, F. 2006. *Knowledge integration: the practice of knowledge management in small and medium enterprises*, Springer Science & Business Media.
- JOHNSON, B. H. 1992. Institutional learning. *Institutional Learning*, 23-44.
- KALE, S. & KARAMAN, E. A. 2011. Evaluating the knowledge management practices of construction firms by using importance-comparative performance analysis maps. *Journal of Construction Engineering and Management*, 137, 1142-1152.
- KANJI, G. K. & WONG, A. 1998. Quality culture in the construction industry. *Total quality management*, 9, 133-140.
- KIRKEBY, O. 1994. Abduktion. I H. Andersen (Red.), *Vetenskapsteori och metodlära: en introduktion*. (CG Liungman övers.). Lund: Studentlitteratur (Originalarbete publicerat 1990).
- KIVRAK, S., ARSLAN, G., DIKMEN, I. & BIRGONUL, M. T. 2008. Capturing knowledge in construction projects: knowledge platform for contractors. *Journal of Management in Engineering*.
- KLINE, S. J. & ROSENBERG, N. 1986. An overview of innovation. In: LANDAU, R. A. R., N. (ed.) *The positive sum strategy: Harnessing technology for economic growth*. Washington D.C.: National Academy Press.
- KRAAIJENBRINK, J. 2012. Integrating knowledge and knowledge processes: a critical incident study of product development projects. *Journal of product innovation management*, 29, 1082-1096.
- KRAAIJENBRINK, J., WIJNHOFEN, F. & GROEN, A. 2007. Towards a kernel theory of external knowledge integration for high-tech firms: Exploring a failed theory test. *Technological forecasting and social change*, 74, 1215-1233.
- LAMBERT, D. M. & COOPER, M. C. 2000. Issues in Supply Chain Management. *Industrial Marketing Management*, 29, 65-83.
- LARSEN, G. D. 2005. Horses for courses: relating innovation diffusion concepts to the stages of the diffusion process. *Construction Management and Economics*, 23, 787-792.
- LARSEN, G. D. 2011. Understanding the early stages of the innovation diffusion process: awareness, influence and communication networks. *Construction Management and Economics*, 29, 987-1002.
- LARSEN, G. D. 2015. Innovation Diffusion Across Firms. *Construction Innovation*, 103-117.
- LARSEN, G. D. & BALLAL, T. M. A. 2005. The diffusion of innovations within a UKCI context: an explanatory framework. *Construction Management and Economics*, 23, 81-91.
- LARSSON, B. 1992. *Adoption av ny produktionsteknik på byggarbetsplatsen [Adoption of new construction technology at a building site]*. PhD Thesis, Chalmers University of Technology.

- LARSSON, B., SUNDQVIST, J. & EMMITT, S. 2006. Component manufacturers' perceptions of managing innovation. *Building research & information*, 34, 552-564.
- LESSING, J. 2015. *Industrialised House-Building-Conceptual orientation and strategic perspectives*. Lund University.
- LESSING, J., STEHN, L. & EKHOLM, A. 2015. Industrialised house-building—development and conceptual orientation of the field. *Construction Innovation*, 15, 378-399.
- LEUNG, M. Y., SKITMORE, M. & CHAN, Y. S. 2007. Subjective and objective stress in construction cost estimation. *Construction Management and Economics*, 25, 1063-1075.
- LICHTENTHALER, U. & ERNST, H. 2009. The Role of Champions in the External Commercialization of Knowledge\*. *Journal of Product Innovation Management*, 26, 371-387.
- LIM, J. N. & OFORI, G. 2007. Classification of innovation for strategic decision making in construction businesses. *Construction Management and Economics*, 25, 963-978.
- LINCOLN, Y. S. & GUBA, E. G. 1985. *Naturalistic inquiry*, Sage.
- LINDELL, M. 2012. Do Major Innovation Models Consider Unintended Consequences? A review and revised framework. In: SVEIBY, K.-E., GRIPENBERG, P., SEGERCRANTZ, B (ed.) *Challenging the Innovation Paradigm*. London Routledge.
- LLOYD-WALKER, B. M., MILLS, A. J. & WALKER, D. H. 2014. Enabling construction innovation: the role of a no-blame culture as a collaboration behavioural driver in project alliances. *Construction Management and Economics*, 32, 229-245.
- LOOSEMORE, M. 2016. Social procurement in UK construction projects. *International Journal of Project Management*, 34, 133-144.
- LOOSEMORE, M. & RICHARD, J. 2015. Valuing innovation in construction and infrastructure—getting clients past a lowest price mentality. *Engineering, Construction and Architectural Management*, 22.
- LOVE, P. E. D., LOPEZ, R. & KIM, J. T. 2014. Design error management: interaction of people, organisation and the project environment in construction. *STRUCTURE AND INFRASTRUCTURE ENGINEERING*, 10, 811-820.
- LUNDVALL, B.-Å., JOHNSON, B., ANDERSEN, E. S. & DALUM, B. 2002. National systems of production, innovation and competence building. *Research policy*, 31, 213-231.
- MAHAPATRA, K., GUSTAVSSON, L. & HEMSTRÖM, K. 2012. Multi-storey wood-frame buildings in Germany, Sweden and the UK. *Construction Innovation*, 12, 62-85.
- MARINOVA, D. & PHILLIMORE, J. 2003. Models of innovation. *The international handbook on innovation*, 44-53.

- MAULA, M. V., KEIL, T. & SALMENKAITA, J.-P. 2006. Open innovation in systemic innovation contexts. *Open innovation: researching a new paradigm*, 241-257.
- MAXWELL, J. A. 2012. *A realist approach for qualitative research*, Sage.
- MERRIAM, S. B. 1994. *Fallstudien som forskningsmetod [Case Study Research in Education]*, Lund, Studentlitteratur.
- MEZHER, T., ABDUL-MALAK, M. A., GHOSN, I. & AJAM, M. 2005. Knowledge management in mechanical and industrial engineering consulting: a case study. *Journal of Management in Engineering*, 21, 138-147.
- MILAKOVICH, M. 1995. *Improving service quality: achieving high performance in the public and private sectors*, CRC Press.
- MIOZZO, M. & DEWICK, P. 2002. Building competitive advantage: innovation and corporate governance in European construction. *Research Policy*, 31, 989-1008.
- MIOZZO, M. & IVORY, C. 2000. Restructuring in the British construction industry: Implications of recent changes in project management and technology. *Technology Analysis & Strategic Management*, 12, 513-531.
- NAAR, L., NIKOLOVA, N. & FORSYTHE, P. 2016. Innovative construction and the role of boundary objects: a Gehry case study. *Construction Management and Economics*, 34, 688-699.
- NESS, K. 2010. The discourse of 'Respect for People' in UK construction. *Construction Management and Economics*, 28, 481-493.
- NEW, S. J. & PAYNE, P. 1995. Research frameworks in logistics: three models, seven dinners and a survey. *International Journal of Physical Distribution & Logistics Management*, 25, 60-77.
- NONAKA, I. 1994. A Dynamic Theory of Organizational Knowledge Creation. *Organization Science*, 5, 14-37.
- NONAKA, I. & TAKEUCHI, H. 1995. *The knowledge-creating company: How Japanese companies create the dynamics of innovation*, Oxford University Press.
- NORD, T. & BREGE, S. 2013. Värden för världen—konsekvenser av ett ökat industriellt träbyggande [Values for the world - consequences of an increased industrial timber-based building]. *Linköpings universitet*. Linköping.
- OECD 2005. *Oslo manual: Guidelines for collecting and interpreting innovation data*, OECD publishing.
- PEMSEL, S. 2012. *Knowledge processes and capabilities in project-based organizations*. Lund University.
- PEÑALOZA, D. 2015. *Exploring climate impacts of timber buildings: The effects from including non-traditional aspects in life cycle impact assessment*. Royal Insitute of Technology.
- PETTIGREW, A. & WHIPP, R. 1991. *Managing change for competitive success*, Blackwell Publishing.

- PETTIGREW, A. M. 1985. Contextualist research and the study of organizational change processes. *Research methods in information systems*, 53-78.
- PETTIGREW, A. M. 1987. Context and action in the transformation of the firm. *Journal of management studies*, 24, 649-670.
- PETTIGREW, A. M. 1990. Longitudinal field research on change: theory and practice. *Organization science*, 1, 267-292.
- PETTIGREW, A. M. 1997. What is a processual analysis? *Scandinavian Journal of Management*, 13, 337-348.
- PETTIGREW, A. M., WOODMAN, R. W. & CAMERON, K. S. 2001. Studying organizational change and development: Challenges for future research. *Academy of management journal*, 44, 697-713.
- POLANYI, M. 1962. *Personal Knowledge - towards a Post-Critical Philosophy*, London, Routledge.
- POLANYI, M. 1966. *The Tacit Dimension*, London, Routledge & Kegan Paul.
- PORTER, M. E. 2011. *Competitive advantage of nations: creating and sustaining superior performance*, Simon and Schuster.
- POSTREL, S. 2002. Islands of shared knowledge: Specialization and mutual understanding in problem-solving teams. *Organization Science*, 13, 303-320.
- PRENCIPE, A. & TELL, F. 2001. Inter-project learning: processes and outcomes of knowledge codification in project-based firms. *Research policy*, 30, 1373-1394.
- PRICE, A. D. & CHAHAL, K. 2006. A strategic framework for change management. *Construction Management and Economics*, 24, 237-251.
- RAMESH, B. & TIWANA, A. 1999. Supporting Collaborative Process Knowledge Management in New Product Development Teams. *Decision Support Systems*, 27, 213-235.
- RIP, A. 2012. The context of innovation journeys. *Creativity and innovation management*, 21, 158-170.
- ROBINSON, H. S., CARRILLO, P. M., ANUMBA, C. J. & AL-GHASSANI, A. M. 2004. Developing a business case for knowledge management: the IMPaKT approach. *Construction Management and Economics*, 22, 733-743.
- ROBINSON, H. S., CARRILLO, P. M., ANUMBA, C. J. & AL-GHASSANI, A. M. 2005. Knowledge management practices in large construction organisations. *Engineering, Construction and Architectural Management*, 12, 431-445.
- ROGERS, E. M. 2003. *Diffusion of innovations (fifth edition)*, New York: Free Press.
- ROOKE, J. & CLARK, L. 2005. Learning, knowledge and authority on site: a case study of safety practice. *Building Research & Information*, 33, 561-570.
- ROTHWELL, R. 1994. Towards the fifth-generation innovation process. *International marketing review*, 11, 7-31.
- RUAN, X., OCHIENG, E. G., PRICE, A. D. F. & EGBU, C. O. 2012. Knowledge integration process in construction projects: a social network analysis

- approach to compare competitive and collaborative working. *Construction Management and Economics*, 30, 5-19.
- RUNDQUIST, J. 2008. Knowledge integration efficiency in distributed product development projects. *International Journal of Product Development*.
- RUNDQUIST, J. 2009. *Outsourcing and knowledge integration in new product development*. Luleå University of Technology.
- RUNDQUIST, J. 2012. The ability to integrate different types of knowledge and its effect on innovation performance. *International Journal of Innovation Management*, 16.
- RUNDQUIST, J., EMMITT, S., HALILA, F., HJORT, B. & LARSSON, B. 2013. Construction Innovation: Addressing the Project–Product Gap in the Swedish Construction Sector. *International journal of Innovation Science*, 5, 1-11.
- SAMUELSON, O. & BJÖRK, B.-C. 2013. Adoption processes for EDM, EDI and BIM technologies in the construction industry. *Journal of Civil Engineering and Management*, 19, S172-S187.
- SARV, H. 1997. *Kompetens att utveckla: om den lärande organisationens utmaningar [Competence to develop: about the challenges of the Learning organization]*, Liber.
- SCHMICKL, C. & KIESER, A. 2008. How much do specialists have to learn from each other when they jointly develop radical product innovations? *Research Policy*, 37, 473-491.
- SENARATNE, S. & SEXTON, M. 2008. Managing construction project change: a knowledge management perspective. *Construction Management and Economics*, 26, 1303-1311.
- SEXTON, M. & BARRETT, P. 2003. A literature synthesis of innovation in small construction firms: insights, ambiguities and questions. *Construction Management and Economics*, 21, 613-622.
- SHABANESFAHANI, A. & TABRIZI, M. 2012. Barriers of systemic innovation to increase productivity of engineering and construction industries of the world. *IOSR J. Mech. Civ. Eng*, 4, 43-50.
- SHIBEIKA, A. & HARTY, C. 2015. Diffusion of digital innovation in construction: a case study of a UK engineering firm. *Construction Management and Economics*, 33, 453-466.
- SIMONSSON, P. & RWAMAMARA, R. Consequences of industrialized construction methods on the working environment. 15th Annual IGLC Conference, Michigan, 2007. 18-20.
- SLAUGHTER, E. S. 1998. Models of construction innovation. *Journal of Construction Engineering and management*, 124, 226-231.
- SLAUGHTER, E. S. 2000. Implementation of construction innovations. *Building Research & Information*, 28, 2-17.
- SOMMERVILLE, J. 1994. Multivariate barriers to total quality management within the construction industry. *Total quality management*, 5, 289-298.

- STYHRE, A. 2008. The role of social capital in knowledge sharing: the case of a specialist rock construction company. *Construction management and economics*, 26, 941-951.
- STYHRE, A. 2011. The overworked site manager: gendered ideologies in the construction industry. *Construction Management and Economics*, 29, 943-955.
- STYHRE, A. & GLUCH, P. 2010. Managing knowledge in platforms: boundary objects and stocks and flows of knowledge. *Construction Management and Economics*, 28, 589-599.
- SULLIVAN, G., BARTHORPE, S. & ROBBINS, S. 2010. *Managing construction logistics*, Oxford, Wiley-Blackwell.
- SUNDQVIST, J., LARSSON, B. & LINDAHL, G. 2012. Cooperation in the Building Sector between Building Material Manufacturers and Contractors to Develop Products. *Construction Economics and Building*, 7, 45-53.
- SVEDBERG, L. 2007. *Grupp-psykologi: Om grupper, organisationer och ledarskap [Group-psychology: About groups, organizations and leadership]*, Lund, Studentlitteratur.
- TAYLOR, J. E. 2006. *Three perspectives on innovation in interorganizational networks: Systemic innovation, boundary object change, and the alignment of innovations and networks*. PhD Thesis, Stanford University.
- TAYLOR, J. E. & BERNSTEIN, P. G. 2009. Paradigm trajectories of building information modeling practice in project networks. *Journal of Management in Engineering*, 25, 69-76.
- TAYLOR, J. E. & LEVITT, R. E. 2005. Inter-organizational knowledge flow and innovation diffusion in project-based industries. *Proceedings of the Annual Hawaii International Conference on System Sciences*, 247.
- TELL, F. 2011. Knowledge integration and innovation: a survey of the field. In: BERGGREN, C., BERGEK, A., BENGTSSON, L., HOBDAI, M. & SÖDERLUND, J. (eds.) *Knowledge Integration and Innovation: Critical challenges facing international technology-based firms*. Oxford: Oxford University Press.
- TIDD, J., BESSANT, J., PAVITT, K. & WILEY, J. 1998. Managing innovation: integrating technological, market and organizational change.
- TROST, J. & HULTÅKER, O. 2007. Enkätboken (the book about surveys) *Lund: Studentlitteratur*.
- TYKKÄ, S., MCCLUSKEY, D., NORD, T., OLLONQVIST, P., HUGOSSON, M., ROOS, A., UKRAINSKI, K., NYRUD, A. Q. & BAJRIC, F. 2010. Development of timber framed firms in the construction sector—Is EU policy one source of their innovation? *Forest Policy and Economics*, 12, 199-206.
- ULLMAN, D. 2010. *The mechanical design process*, McGraw-Hill Science/Engineering/Math.
- WALKER, D. H. T. 2016. Reflecting on 10 years of focus on innovation, organisational learning and knowledge management literature in a

- construction project management context. *Construction Innovation*, 16, 114-126.
- VAN DE VEN, A. H., DELBECQ, A. L. & KOENIG, R. 1976. Determinants of Coordination Modes within Organizations. *American Sociological Review*, 41, 322-338.
- VASS, S. & GUSTAVSSON, T. K. 2017. Challenges when implementing BIM for industry change. *Construction Management and Economics*, 1-14.
- WIDÉN, K. 2006. *Innovation diffusion in the construction sector*, Lund University.
- WIDÉN, K. 2010. *Construction Innovation: Statsbygg, the Driving Client*, Lund University.
- WIDÉN, K. & HANSSON, B. 2007. Diffusion characteristics of private sector financed innovation in Sweden. *Construction Management and Economics*, 25, 467-475.
- WINCH, G. 1998. Zephyrs of creative destruction: understanding the management of innovation in construction. *Building Research & Information*, 26, 268-279.
- WINCH, G. M. 2003. How innovative is construction? Comparing aggregated data on construction innovation and other sectors—a case of apples and pears. *Construction Management and Economics*, 21, 651-654.
- VOSS, C., TSIKRIKTSIS, N. & FROHLICH, M. 2002. Case research in operations management. *International Journal of Operations & Production Management*, 22, 195-219.
- ZOLLO, M. & WINTER, S. G. 2002. Deliberate learning and the evolution of dynamic capabilities. *Organization science*, 13, 339-351.
- ÅGREN, R. & WING, R. D. 2014. Five moments in the history of industrialized building. *Construction Management and Economics*, 32, 7-15.
- ÅLANDER, C. Advanced systems for rational slab reinforcement. Proceedings of the Conference “Heading for concrete solutions, 2004.