

THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

## Developing a collaborative planning tool for construction

A Building Information Model-enhanced planning and scheduling tool for production.

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## ABSTRACT

Construction projects are becoming increasingly complex with a higher degree of specialization, resulting in more sub-contractors as well as in more information needed in the project. This results in a bigger project organization with an increased need for information exchange, an area where construction has been criticized by academics. The increasing specialization is related to an increase in more technically advanced buildings. The amount of information created and managed in construction projects has been recognized as hard to manage at the construction site. This is a problem since the site-management uses this information in the scheduling and planning of the production. One way to address this is to utilize the sub-contractors in the planning of the production, thus drawing upon their work-experience for their specific tasks. This creates a collaborative planning approach that somewhat addresses parts of the problem, however, the amount of information is still hard to manage, especially since it has to be coordinated between disciplines to get the full picture. Information and communication technologies, (ICT), have attempted to solve this, with potential found in building information modelling (BIM). However, most use of BIM is seen in the design phase of construction projects, with some BIM visualization appearing at the construction site. The lack of adoption at the construction site is partly attributed to lack of time to alter processes to new tools.

This thesis addresses this potential for BIM tools aligned to a collaborative planning process. Furthermore, it recognizes that prior literature lacks a focus on both the people and the social context the technology is used in as well as the development of the technology itself. Thus, a sociotechnical systems view is adopted. Design Science is used as the method to observe the current collaborative planning process, develop a BIM-system supporting the collaborative planning approach and document the research process. This is done with a strong focus on the user, using people, processes and technology as dimension to analyze the requirements of the BIM system developed. Thus, the research's contribution is threefold; the thesis contributes with a documentation of an existing collaborative planning process, a BIM-enabled collaborative planning tool enhancing a current work practice and an example of how Design Science can be used as a method to support ICT development in construction.

Keywords: Construction Informatics, Information Technology in construction, Design Science, Collaborative planning process, BIM



# Preface

First and foremost, I would like to thank my main supervisor Petra Bosch and co-supervisors Mattias Roupé, Mikael Johansson as well as my examiner Christian Koch. You have guided and pushed me to finally deliver this thesis, it took some time and sometime I doubted myself but you pushed me forward.

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Mikael Viklund Tallgren

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# Appended Papers

This thesis is based on the following appended papers:

## **Paper I:**

“An empowered collaborative planning method in a Swedish construction company - A case study”

Viklund Tallgren, M., Roupé, M. and Johansson, M. (2015), in 31st annual Association of Researchers in Construction Management Conference, ARCOM, Lincoln, United Kingdom., pp. 793–802.

## **Paper II:**

“A BIM-supported framework for enhancing joint planning in construction”

Viklund Tallgren, Roupé, M., Johansson, M., Andersson R. (2015) in 32nd CIB W78 Conference, Eindhoven, The Netherlands, pp. 696–705.

## **Paper III:**

“The Development of a collaborative planning system for pre-construction”

Viklund Tallgren, M., Roupé, M., Johansson, M., Bosch, P. (working paper 2018)





# Additional publications

## **Conference Papers:**

“Immersive visualisation of building information models: Usage and future possibilities during design and construction”

Mattias Roupé, Mikael Johansson, Mikael Viklund Tallgren, Fredrik Jörnebrant, Petru Andrei Tomsa, 21st International Conference on Computer-Aided Architectural Design Research in Asia: Living Systems and Micro-Utopias: Towards Continuous Designing, (CAADRIA 2016) s. 673-682

## **Other publications:**

“Virtuell Produktions Modell I skala 1:1 på byggarbetsplatsen”

Mattias Roupé, Mikael Johansson, Mikael Viklund Tallgren (2017)

“BIM Management. Ett pilotprojekt för forskning och kunskapsutveckling”

Petra Bosch, Janni Tjell, Mattias Roupé, Mikael Johansson, Mikael Viklund Tallgren (2016)

”Virtuell produktionsplanering med BIM och visualisering”

Mattias Roupé, Mikael Viklund Tallgren, Mikael Johansson, Roger Andersson (2014)

“From BIM to VR - Integrating immersive visualizations in the current design process”

Mikael Johansson, Mattias Roupé, Mikael Viklund Tallgren (2014)



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# 1 Introduction

Scholars have characterized as well as criticised the construction industry for fragmentation, low productivity, inefficient work processes as well as a culture of poor information exchange and communication (Nepal & Staub-French, 2016). It has also been reported by several academics that construction projects are becoming more difficult to manage due to a rising complexity of projects (Bryde et al., 2013). This complexity is manifested in several ways. Partly in the project organisation, where stakeholders vary depending on design, construction and FM and where the number of stakeholders in each of these phases, including consultants, contractors, sub-contractors, and financiers etc (Bryde et al., 2013; Gidado, 2004; Winch, 2010). Complexity is also manifested in more technologically advanced buildings as well as buildings with higher performance expectations (Winch, 2010). There is also an increase in information amount and complexity, with more information available in today's design and review tools than previously available in drawings (Berlo & Natrop, 2015). The amount of information has been argued to be harder to manage, resulting in an overwhelming situation at the construction site (Lofgren & Rebolj, 2007).

These types of complexities need to be managed in some way on the construction site. Much of this task falls on the site-manager, who has been identified to have a hard-pressed situation balancing administrative tasks with managing the site and the workers (Styhre & Josephson, 2006). One common task that site-management practices is planning. There have been indications that for example better planning of production leads to projects with a better performance in terms of time and budget, as well as quality (Verheij & Augenbroe, 2006). In the area of planning, research has mentioned that the involvement of sub-contractors helps reducing the complexity of the project, since a common and shared understanding of the project can be discussed (Laufer, 1992; Faniran et al., 1994; Dvir et al., 2003; Winch & Kelsey, 2005; Simonsen, 2007; Friblick & Olsson, 2009). Empowerment of the sub-contractors and workers has also shown to lessen the effects of the fragmentation of the construction organisation (Dainty et al., 2002). Scandinavia and especially Sweden has been shown to have a collaborative culture, with low-power distance (Bröchner et al, 2002) which would support such a collaborative approach. However, it is argued that current project planning suffers a lack of methodological support, especially when a more collaborative planning process is needed and multiple stakeholders are involved (Verheij & Augenbroe, 2006). An example of a collaborative planning approach is the Last Planner System, where one of the planning stages of the method focuses on the engaging the sub-contractors and in the collaborative planning of work as close to production as possible (Ballard & Howell, 2003).

In parallel with this, the construction industry has seen an adoption of different Information Communication Technologies (ICT) (Bryde et al., 2013; Davies et al., 2015; Merschbrock & Munkvold, 2012). ICT in construction has been gathered under the umbrella of Construction Informatics (Merschbrock & Munkvold, 2012; Turk, 2007), which Turk (2007) defines as encompassing the connection between construction information and fields in computer science broadly. Names for this field has been many, such as 'computer integrated construction', 'computing in civil engineering' and 'information technology in construction', but Turk (2007) gathers them under the term Construction Informatics (CI). Building Information Modelling (BIM) is perceived as part of CI (Merschbrock & Munkvold, 2012). Furthermore, BIM is a common denominator for many of the technologies that are meant to facilitate construction processes (Davies et al., 2015; Davies & Harty, 2013).

BIM can trace its origins back to the 1970:s parametric modelling and is inherently computer based (Eastman et al., 2011; Samuelsson & Björk, 2013; Tulenheimo, 2015). Today BIM is regarded as the process and policies as well as the technologies for managing information throughout the construction life-cycle (Eastman et al., 2011; Succar & Kassem, 2015). The adoption of BIM is growing as shown in both industry sponsored reports as well as more academic ones (Succar & Kassem, 2015). Furthermore, the uptake of BIM has been identified to be greatest in the design phase of projects rather than during construction or the following facility management phase (Linderoth, 2013; Ghaffarianhoseini et al., 2017; Svalestuen et al., 2017). BIM use in specific has been studied in on-site construction projects in Sweden in a series of bachelor and master theses and is found to still be limited in use to mostly visualizations and clash detection (Dave et al., 2008; Karlsson, 2009; Böregård & Degerman, 2013; Birging & Lindfors, 2014; Bergqvist & Sköld, 2017; Persson & Gårdelöv, 2017; Brantitsa & Norberg, 2018). Challenges in implementing new technologies such as BIM systems can be found in literature and spans from risk factors such as financial, management, personnel and technical factors (Chien et al., 2014). Along with these challenges there is also the expectations of the personnel on new technology and its compatibility with current ways of working (Davies & Harty, 2013). This highlights findings from other studies that BIM technology adoption should not just be focused on technology but employ a bottom-up approach to implementation (cf. Arayici et al., 2011). Hartmann et al. (2012) extends this discussion and argues for an alignment with current construction management processes and a technology pull-approach. The relevance of existing work practices is further strengthened in Adriaanse et al. (2010), where its relevance for ICT in general is stressed. As shown a set of challenges related to construction management on-site today are identified, mainly concerning information, communication and collaboration. Communication and collaboration are inherently social activities common in construction and as such becomes part of a sociotechnical system (Sackey et al., 2014). A BIM system addressing the mentioned challenges thus falls into the sociotechnical system context. Further, BIM has been identified to show positive benefits both in fostering communication and collaborative work (Khanzode, et al., 2006; Bhatla & Leite, 2012).

The complexity in the construction industry and challenges with ICT and more specifically BIM adoption in production are recognized above. However, there is great potential to gain benefits of BIM in collaborative production planning. This thesis addresses the development of a BIM system which supports existing collaborative planning processes. This has guided the forming of the aim and objective.

## 1.1 OVERALL AIM, OBJECTIVES AND RESEARCH QUESTIONS

The main aim of this thesis is twofold, first it is to contribute to the field of construction informatics, supporting the discussion about how the development process of ICT tools in the form of a BIM-system could be performed. This thesis aligns a BIM system with existing work processes in a collaborative production planning context. This brings the second aim, in which the objective of the alignment to BIM is to inform the development of a BIM tool that enhances these existing work processes. A strong focus is put on the users and the current process, which is clarified by showing how to relate BIM to current processes. As part of this CI gives the context of the research while Design Science (DS) has been selected as the research method. Johannesson & Perjons (2014) defines DS as:

*“... the scientific study and creation of artefacts as they are developed and used by people with the goal of solving practical problems of general interest.”*

The objective is that CI with the use of DS can show and help understand how ICT tools can be shaped and developed with regard to existing context and processes rather than disbanding known processes and replace with new ones.

From these aims and objectives, a set of research questions have been derived to guide the process to explore the BIM-system through design and development of the ICT tool.

***RQ1: How is the collaborative planning process applied in a Scandinavian context?***

Different types of collaborative planning processes are described in current literature, but there is a need for accounts from collaborative planning practices in use, the context observed however is limited to a Scandinavian context.

***RQ2: How can a BIM system be aligned with a collaborative planning process?***

There are a number of planning and scheduling tools already in existence, a few support BIM, and many of them has been developed from having the technology as the driver rather than the process or demand from the users. In this research the main focus is on how existing processes can be enhanced with help of a BIM system. This is done through the adoption of a sociotechnical systems view.

***RQ3: How Design Science Research be used as the approach to use technology to enhance an existing process?***

In the field of construction informatics the main topics concern product modelling, integration as well as information support spanning several disciplines or life cycle phases (Turk, 2006). There has been a large focus on the development of new technologies and BIM systems (Xue et al., 2012). However, different methods for the development have been used and these methods are not always clearly discussed. In this thesis, a Design Science approach is applied and discussed in detail for the development of the BIM systems that is in line with its users.

## 1.2 STRUCTURE OF THESIS

The thesis is structured around a DS approach where the main focus is on the exploration, development, and creation of an artefact, a digital tool, to be used in a currently existing planning process. The thesis starts out with this introduction, then in chapter two, background and related work is presented. In chapter three, the research approach of design science is presented as well as the methods used to collect and analyse data and the studied planning approach is discussed in chapter four. Then in chapter five, the three papers are summarized and connected. This is followed by an account of the developed artefact, the VisualProductionPlanner 1.0 in chapter six. The thesis is then wrapped-up with the discussion around the findings and conclusions as well as future work going forward to the full PhD in chapter seven.





## 2 Background and related work

In this section, background and related work around the thesis is presented. The background starts out with general information technology and the connection to sociotechnical systems in sub-chapter 2.1. Then in sub-chapters 2.2 and 2.3 planning in construction and the problems observed in planning are discussed. After this sub-chapters 2.4 and 2.5, continues to describe planning approaches and implementations. Sub-chapters 2.6 and 2.7 finishes with a description of the analytical frame and a summary of problem and challenges found in literature.

### 2.1 TECHNOLOGY AND SOCIOTECHNICAL SYSTEMS PERSPECTIVE

ICT tools exemplifies technological artefacts developed for specific use within a social setting (Johannesson & Perjons, 2014). This demonstrates a sociotechnical system, which originates in the need to describe the interaction of people and technology, understood from the environment and work processes in which the technology is applied (Johannesson & Perjons, 2014; Sackey et al., 2014). Analysing problems in a social context are thus the key activities in research around sociotechnical systems (ibid.). A typical social context for collaborative work is meetings or workshops. A literature review of IT supported collaborative work in construction concludes that this is an active research area in construction and further showed that organisational culture, and more human related subjective factors were important but neglected in current research (Xue et al., 2012).

The view on the design and implementation of collaborative solutions has shifted over the last century, from a more technology driven perspective in general to a more sociotechnical perspective used at the turn of the last century (Dix, 2017). This shift moves the focus from the technology to the people and the organizational context in which the technology is implemented in and as such moves towards a more holistic perspective. The sociotechnical system approach focuses on describing and documenting the possible as well as the actual impact of the introduction of a specific technology in an organization (Johannesson & Perjons, 2014; Sackey et al., 2014). This kind of documentation also helps analysing the difficulties that are faced when implementing the technology. As communication and collaboration are inherently social activities common in construction and as such become part of a sociotechnical system (Sackey et al., 2014), this becomes important in the development of technology supporting these actions. Chien et al. (2014) identified a number of challenges in construction when implementing new technology, ranging from financial, management related and personnel related to technical risk factors (Chien et al., 2014). These factors can manifest themselves in expectations from the personnel to challenges in compatibility of the technology with regards to current ways of working (Davies & Harty, 2013). The success of implementations of technology in construction has mainly been research from a technology push view (Hartmann et al., 2012; Xue et al., 2012). Technology push is defined as the development of new technology that offers a business process change from a technology perspective in contrast to a demand pull where demand drives the development (Chidamber & Kon, 1994; Hartmann et al., 2012) The sociotechnical system view helps consider not just the implementation of the technology, but the environment that creates the context for the implementation as well (Arayici et al., 2011). In order to understand the context of this thesis, literature concerning planning in construction is presented below.

## 2.2 PLANNING IN CONSTRUCTION

The construction industry is often characterized for its low productivity and high fragmentation and specialisation of inefficient work processes which can be related to a culture of poor information exchange and communication (Nepal & Staub-French, 2016). It has also been reported by several academics that construction projects are becoming more difficult to manage along with a rising complexity of projects (Bryde et al., 2013). One of the core project management principles is planning (Dvir et al., 2003). The term planning has been widely debated, but is summarized as a decision-making process where information is structured into desirable outcomes which is bundled in workable packages, also known as activities (Baldwin & Bordoli, 2014; Laufer et al., 1994). Planning can thus be defined as the process of identifying what is to be done and how, drawing on experience of the production to create the schedule (Hansson et al., 2017). These activities are prioritized, sequenced and related to each other and visualized and presented in a schedule, thus giving the action of sequencing activities the name scheduling. The visualisations of schedules have differed through the decades, but a prevailing technique has been the Gantt schedule and especially critical path methods (CPM) and its visualisation through bar charts (Baldwin & Bordoli, 2014). Research has shown that the original management focus of planning has shifted from analysing options and exploring alternative construction methods, to more controlling and regulating work-processes (Koskela et al., 2014). This aside, literature states that only 50% of the activities in a typical construction project are finished according to schedule (Baldwin & Bordoli, 2014). The Last Planner System (LPS) has been introduced as an alternative approach to planning, by making sure that no task starts without every preceding task being finished. This is achieved by layering planning and scheduling depending on target stakeholder group and phase of the project (Ballard & Howell, 2003; Daniel et al., 2016).

The lifecycle of a project and thus planning and scheduling differs from country to country, but some standardized processes can be found in for example Baldwin & Bordoli (2014), where projects are layered in five reporting stages. However, as this research is conducted in a Scandinavian context, the common breakdown of Swedish projects will be used. In Figure 1 the general breakdown structure for a medium to large sized project is exemplified. Figure 1 shows phases broken down into sub-phases to the construction planning level discussed in this thesis. As shown in Figure 1, the plans and schedules create a hierarchy, and in the Swedish construction industry the construction planning phase is traditionally divided into five steps of granularity (Hansson et al., 2017). In Figure 1 they are shown at the bottom in sequence, since that is often how they are conceived; another way to visualize their relationship would be to show how each is a subset of the prior schedule. Thus, the project plan is based on the

contractual schedule and is more of an overview and milestones of the sub-sequent schedules, becoming gradually more detailed the closer it comes to production.

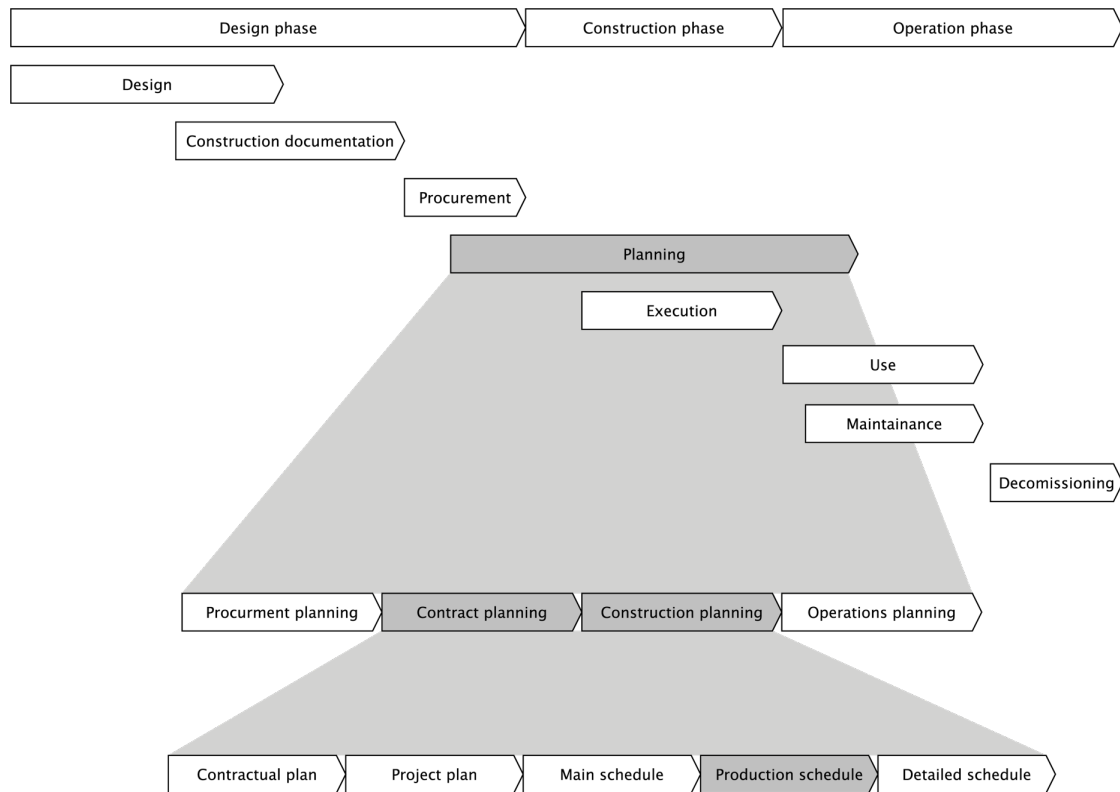


Figure 1: The hierarchy and different levels of planning and scheduling.

The production schedule is broken down into detailed schedules upon need, these can be (ibid.):

- Detailed schedules
  - The phase or cycle schedule,
  - The rolling weekly schedule,
  - The work preparation plan.

Of these five levels only two are touched upon in respect to this thesis. This research focuses on the late design and early construction phase, and thus only the production schedule and to some extent the detailed scheduling derived from this are within the area of research.

The production schedule is the main tool the contractor uses in the general control of the on-site construction (Hansson et al., 2017). The production schedule is still at a general level and does not generally show sub-tasks of an activity other than zones and phases. The phase schedule is a more detailed schedule showing each phase in more detail and often is often comprised of a couple of months' worth of work (ibid.) and is the basis for more detailed planning in production. The project plan, the main schedule, the production schedules as well as the phase schedule are created either as a collaboration between the project planner and the site manager or individually by one of them. In some cases, the sub-contractors are involved in the production schedule and cycle schedule, which are done before the project or specific cycles starts. The rolling weekly schedules are made in weekly meetings with site management, where the sub-contractors participate.

### 2.3 WHAT IS THE PROBLEM WITH PLANNING?

A common trait for construction projects seem to be the inability to keep the schedule as well as budget, however, research has shown that given sufficient time, planning does have a positive impact on both these performance indicators (Verheij & Augenbroe, 2006). Two of the key factors behind this problem are the complexity of the planning task, both in terms of more complex projects, but also in the organisation of projects' greater number of sub-contractors (Bryde et al., 2013; Gidado, 2004; Winch, 2010). The construction industry is becoming increasingly specialized, with fewer contractors actually employing their own construction workers (Christiansen, 2012; Friblick & Olsson, 2009). One of the argued solutions to this organizational complexity is more planning and production control (Dvir et al., 2003). But even though the industry in general is seen as proficient in planning, the proficiency of individuals varies greatly, and site managers are often rewarded for being able to solve last minute problems, thus countering good planning (Faniran et al., 1994; Friblick & Olsson, 2009; Kelsey et al., 2001; Koskela, 1992). On top of this site managers lack the quality time to properly plan their projects as they have been identified as hard-pressed (Styhre & Josephson, 2006; Winch & Kelsey, 2005).

The specialization of the industry also means an increase in produced documents and drawings and an increased need for coordination between disciplines, something that is hard to address using traditional drawing-based management techniques, resulting in hard to manage situations (Christiansen, 2012; Löfgren, 2007). Büchmann-Slorup & Andersson (2010) even go so far as indicating that this leaves the overall scheduling to be based on intuition and personal experience since the people responsible for the schedules have difficulties to process the vast information in the building design and the drawings and specifications produced are not suited for scheduling. With the increasing specialization, an argument to involve foremen and workers could be raised, this not only anchors the schedule with the ones realizing the work on-site it also engages the sub-contractors in the process and thus makes them take ownership of the schedule as well as their work (Daniel et al., 2014; Lindholm, 2014). Research has shown that by empowering the sub-contractors and workers the effects of the fragmentation of the construction organisation seem to lessen (Dainty et al., 2002). The involvement of sub-contractors in the planning also helps to reduce the complexity of the project, because a common and shared understanding of the project can be discussed (Dvir et al., 2003; Faniran et al., 1994; Friblick & Olsson, 2009; Laufer, 1992; Simonsen, 2007; Winch & Kelsey, 2005). This kind of collaboration can be identified in Scandinavia and especially Sweden, since Sweden has been shown to have a collaborative culture, with low-power distance (Bröchner et al, 2002).

### 2.4 PLANNING VISUALISATION

Production management in construction has mainly worked with a work breakdown structure (WBS) (Kenley & Harfield, 2014). The focus on work-packages, termed activities is derived from the connection to mass production and manufacturing, where optimization is done activity by activity rather than looking at the full process (Howell, 1999). A difference in construction projects in relation to manufacturing is that the activities move through the constructed locations, rather than as in manufacturing where the production line is set up around different activities and the product moves through the activities instead (Ballard & Howell, 1998). This has given room for an alternative stream of planning in construction, regarding location as the base object rather than the activity, also known

as location based management systems (LBMS) (Kenley & Seppänen, 2006). The use of location as key breakdown component is by no means new but has during the last decade gained interest again, especially within Lean Construction (LC) (ibid.). These two approaches, activity based and location-based planning are often visualized in two fundamentally different ways. Activity-based planning favours the bar chart, often in the form of Gantt charts, seen in Figure 2.

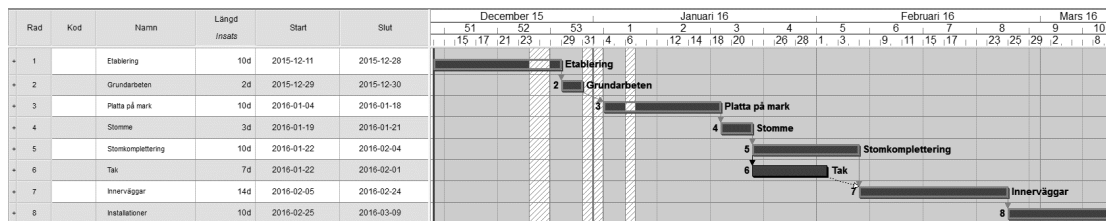


Figure 2: A typical Gantt chart (teaching reference project)

Whereas, location-based planning often is visualised with a second form of schedules, the flowline scheduling method, utilizing location as the vertical scale rather than activity, and time as the horizontal scale (ibid.). This method needs locations to be of roughly the same size to visually convey a coherent meaning. The activities are visualized as sloping lines through the locations, as seen in the lower half of Figure 3. The slope of the line is determined of the speed of the activity. Comparing the condensed Gantt chart in the upper half of Figure 3 with the lower part of Figure 3, it is visible that the flowline way of representing activities reduces the complexity by showing a less cluttered view. The information is the same but condensed. The upper illustration is also somewhat a false visualisation, since it shows each location with every activity stacked after each other. In a traditional Gantt chart, the activities would have one row each. But since each location comprises of 5 activities, it would have taken up five times as much space. Thus, traditional Gantt charts with many activities (more than a hundred), become hard to get a clear overview on (Hansson et al., 2017). A key takeaway from the comparison of the two types is that in the upper chart, each activity length is deceptively similar. However, in the lower flow chart we can see the different length of activities as different slopes of the line, this means that some locations consist of more work which is something that is hard to spot in the bar chart (Jongeling & Olofsson, 2007; Kenley & Seppänen, 2006).

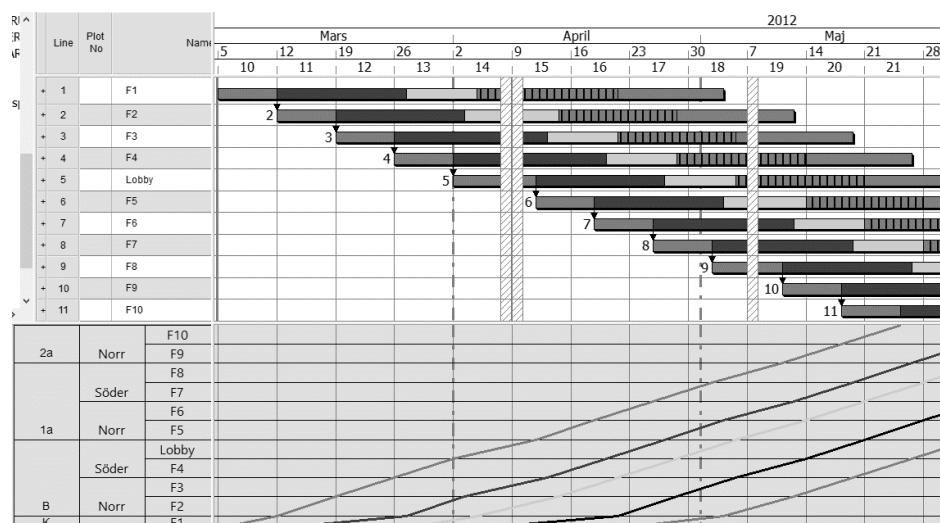


Figure 3: A line of balance diagram visualised as both Gantt and flowline (example from Asta Powerproject)

This alternative kind of visualising the schedule, the flowline method, is popularized by LC (Kenley & Seppänen, 2006), which itself lends its core ideas from lean production and Toyota in their Toyota production System (TPS). One of the core elements in the TPS is the focus on wastes and making waste visible, through for example visual control and involving the workers (Liker 2005). In TPS each worker has the power to stop production if problems occur, illustrating that each opinion is valuable and that quality is focused over quantity. A key aspect is making wastes visual, to do this several different visual management tools have been developed (ibid.). Many visual management techniques take the physical form of boards or graphics like plans, schedules, drawings, cards etcetera, but several techniques have been digitalized with the general increase of technology saturation (Urbina Velasco, 2013). However, even though automation and the enhancement of visualizations have increased, the conventional approach is still low-cost and accessible. For example, the conventional approach of using sticky notes are easy to use (Camara Jurado, 2012), while IT-systems are more expensive and can be less intuitive to use (Mann, 2005 in Tezel et al., 2009). It has been shown that recording data in visual management systems also leads to a greater understanding of the underlying data and in turn the project amongst the participants (ibid.). While some visual management systems are more geared towards the production floor, others exist for office settings, one of these are the Big room, described as the “war-room” of production where relevant and important information is used to decorate the walls to make it easily and readily available (Liker, 2005).

Similar problems of productivity have been identified in both traditional manufacturing industry as well as the construction industry and as such LC has developed from Lean Production to benefit from its experiences. LC focuses on maximizing performance on the project-level rather than at the activity level, thus production control is present throughout the life of the project (Howell, 1999). The Last Planner System mentioned earlier is one of the core elements of LC and an example where the planning process is fundamentally changed. It lends its principles from TPS, where work is structured through pull scheduling (Ballard & Howell, 2003). Pull planning differs from traditional planning in such that it is often works backwards, starting with the last activity and then identifying what needs to be done to be able to do this activity; thus, activities always produce a demand, a pull system, and focus is on value-adding activities. Traditionally, Critical path planning is sequenced from the start date, identifying in each step what can be done next. A critique from LC is that no regard is taken to the necessity of the activity to be performed, resulting in a push system (Ballard, 2000). This type of push-planning is also described in literature both internationally (Baldwin & Bordoli, 2014) as well as in Swedish literature on construction management (Hansson et al., 2017; Persson, 2012).

To counter this push planning, LPS is divided into four stages, where information is gradually added as it is needed and produced (Ballard & Howell, 2003). LPS minimizes waste in the planning process by planning in different levels, gradually as the project and design progresses, the information and the schedule become more refined. When the activities are nearing production the information regarding the activities are as most complete and thus the best conditions for detail planning rises. The name Last Planner comes from the fact that the persons responsible for the realisation of the activities are the ones participating in the detail scheduling of the activity. This approach to planning tries to remedy a weakness that traditional planning suffers, where there is a balance of planning early, with little or unprecise

information, versus planning late, with greater precision but risk not mitigating uncertainties that can cause troubles (Ballard, 2000; Laufer, 1992; Laufer & Tucker, 1988). Furthermore, LPS can be seen as an adoption of visual management principles in construction, since LPS extensively uses models, drawings and visualisations. Visual control is at the core of LPS, where different types of visualisation are used, be it schedules, workable backlogs, weekly work plans or planned percent complete charts. However, actual use of LPS still has a way to go to become established and widely adopted (Daniel et al., 2015; Lagos, et al., 2017). Examples of LPS type of implementation in Scandinavia can be found primarily in Finland (Kenley & Seppänen, 2006, chap. 3), but also in Danish production in Simonsen (2007) and in the design phase in Sweden (Tjell, 2016).

## 2.5 PLANNING TOOLS, BIM, 4D AND SCHEDULING

Research into planning with the objective to enhance and lighten the workload of planning have been made since the introduction of computers (Kang et al., 2007; Xue et al., 2012). Advancements in computer hardware and software have enabled more advanced use of analytical planning such as the programme evaluation and review technique, more commonly known as PERT, where simulations can produce likelihoods of project duration (Baldwin & Bordoli, 2014). When PCs gradually became more powerful, more use cases became possible. Computer aided design, commonly referred to as CAD, has been possible since the 1980s through the PC, but mostly in 2D. In the end of the 1990s, 3D CAD and object-oriented modelling started to gain ground (Eastman et al., 2011; Samuelson & Björk, 2013). Traditional CAD comprised only of lines, whereas object-oriented CAD made more information rich objects possible, the precursor to the building information models known today. The turn of the twentieth century saw the advent and popularisation of BIM in general and with this, new possibilities to visualize planning and scheduling arose (Baldwin & Bordoli, 2014). The use of models in visualisations of planning, also known as 4D-scheduling, unlocked new possibilities not available earlier. Simple sequencing errors could easily be spotted, even by novices. The use of 4D also opened up to analyse the plan deeper and understand the space more clearly than on paper (Koo & Fischer, 2000). The general procedure to create 4D-schedules today is by connecting building elements with a schedule, a manual piece of work (Eastman et al., 2011). However, tools available today require a schedule and a BIM of similar detail level to create the 4D-schedule (Waly & Thabet, 2003).

This manual connection and 4D-scheduling become an extra step in the planning process, which adds to the site-managers' documented strain. Theoretically, the connection between schedule and model could be made earlier on in the planning process, by utilizing the information available in the model. However, to be able to fully utilize the information in the model it needs to be classified in a standardized and structured manner, creating the possibility for common points of association for different software, for example through classification with a common standardized coding system. With this in place, the connection of recipes of activities and objects could be pre-determined, automating the creation of schedules as research points out (Weldu & Knapp, 2012).

BIM and Lean have been connected in research and shown to lead to greater benefits if adopted alongside each other, such as increased collaboration (Bhatla & Leite, 2012; Khanzode et al., 2006). This could help the information exchange and communication problems that construction is found to have (Nepal & Staub-French, 2016). Adoption of BIM

is seen as growing (Succar & Kassem, 2015), but at the moment most use is found in the design phase (Linderoth, 2013; Ghaffarianhoseini et al., 2017; Svalestuen et al., 2017). Several master theses have studied the use of BIM on the construction site and found that mainly site-managers and a few foremen use the BIM model, but they use it for communication and visualizations such as clash detections. To some extent the lack of use amongst sub-contractors can be traced to lack of education in the BIM-software as well as lack of knowledge that there were BIM models available (Dave et al., 2008; Karlsson, 2009; Böregård & Degerman, 2013; Birging & Lindfors, 2014; Bergqvist & Sköld, 2017; Persson & Gårdelöv, 2017; Brantitsa & Norberg, 2018).

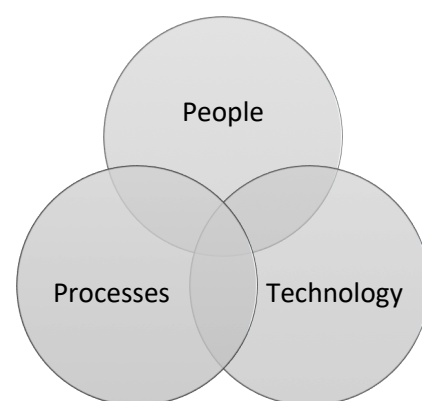
## 2.6 PEOPLE, PROCESSES AND TECHNOLOGY AS ANALYTICAL FRAME

The problems like fragmentation, low productivity, inefficient work processes that the construction industry are attributed with (Nepal & Staub-French, 2016), have led to thoughts toward a more holistic view of the construction process should be taken in R&D initiatives (Dave et al., 2008). This holistic view calls for the sociotechnical systems perspective described earlier. A combination of three important aspects, people, processes and technology from the Lean manufacturing have been identified and integrated into a framework to support the integration of these aspects (ibid.). The earlier mentioned combination of Lean and BIM in respect to the sociotechnical perspective of this research opens up to focus on a combination of the user, their work processes and the technology. Initiatives have been done to integrate these PPT aspects into a framework (Dave et al., 2008). Within knowledge management, Edwards (2011) traces people, processes and technology back to its origins in the Leavitt “diamond”, but stresses that the two original dimensions task and structure are substituted with processes, which are business processes as a whole and not just knowledge management processes.

The original model is well established in process change and improvement work, and several suggestions to expand the model have been made through the years (Prodan et al., 2015; Sackey et al., 2014).

The three-dimensional model is used for process improvement to highlight the interdependency of technology on both people and processes. Thus, it presents a more holistic perspective than previously used in technology development, where technology determinism has been a prevailing view. The three-dimensional perspective, as seen in Figure 4, is used since it gives a deeper explanation of the sociotechnical perspective. The three dimensions are briefly described below.

**Processes:** the process dimension focuses on how processes can be improved to deliver work (Prodan et al., 2015). Goulding and Lou (2013) define processes with respect to IT-systems development as following: “the ability to align processes with the proposed system’s functionalities”.



*Figure 4: The intersecting aspects of people, processes and technology (adapted from Dave, 2008).*



The people dimension highlights the most valuable asset the organisation has, the people in the company and their organisational needs. Harty (2005) extends this to construction projects by highlighting that sub-contractors are important influencers in the project as they all bring their part and their knowledge to the project. Thus, in construction, the people dimension is also true for the project organisation but becomes even more challenging because in project organisation the people do not belong to the same company. It considers the knowledge and the skills people have, and contrasts it to their tasked work; do they have the right knowledge and skills? Are they motivated and do they want to improve? (Prodan et al., 2015). Goulding and Lou (2013) describe the people dimension as “the ability of employees to accept and adapt to the system”.

The third and last dimension, technology, focuses on the tools and techniques that support the people and the process to deliver the work. This dimension regards how to support both the process and the people in the work at hand. The technology dimension is often given more importance, as it more and more is seen as a way to stay ahead of competition (Prodan et al., 2015). The technology dimension is described as “the ability of the information and communication technology (ICT) to simplify processes with minimal people involvement” by Goulding and Lou (2013).

These dimensions are used to position and limit the literature reviewed in the background and related work. As seen in Figure 5, most of the literature is positioned in the overlapping regions of two or more of the dimensions. Research around planning is from a process standpoint, whereas Lean, Lean Construction and their subthemes is described with respect to both people and processes. Going into specific technologies, like visualisations, BIM planning, 4D and LPS, these are described in literature as products of technology and process in support of each other (Xue et al., 2012).

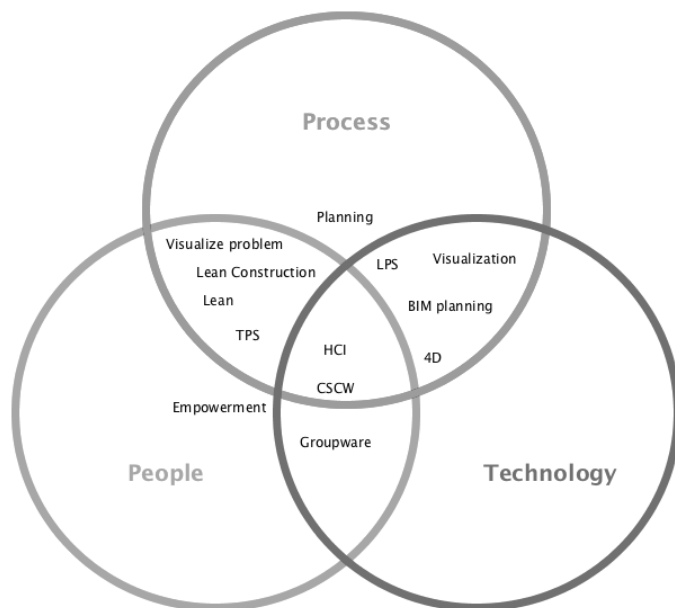


Figure 5: Literature in relation to the holistic approach.

Research into collaborative information technology in the construction industry has shown that literature tend to focus on technology and processes through concepts and systems architecture (ibid.). The different combinations of dimensions highlight the need for a sociotechnical perspective. In this view, technology needs to be developed as a part of a wider organizational environment, with respect to social, organizational and human as well as technical aspects (Dix et al., 2004). The sociotechnical perspective is used throughout the thesis to highlight that the system developed is not only technology but also a part of a wider organisation, in this case the project organisation, and implemented and used by people in that project.

## 2.7 GENERAL PROBLEMS AND REQUIREMENTS FOUND

While the People, Process, technology focus provides an analytical framework, it is related to the problems mentioned above in the background and related work section. These main problems support the initial requirements for the BIM system that enhances the current processes. To summarize the observations from the literature;

- Planning is complex, partly due to an increased complexity in the project-organisation, partly due to the wealth of information available (Dvir et al., 2003; Friblick & Olsson, 2009; Christiansen, 2012),
- There is an increased need for understanding relations between disciplines, also due to the increasing complexity of construction projects (Dvir et al., 2003; Eastman et al., 2011).
- The complexity increases the need to communicate between disciplines, thus visualisations become relevant, both as plans but also through other media like drawings and full 3D models (Bhatla & Leite, 2012; Dvir et al., 2003),
- Locations are used to reduce complexity locally, by breaking down the project into more manageable parts (Kenley & Seppänen, 2009),
- Time is scarce, especially time to plan projects. Apart from time being scarce, time for getting to know the project is scarce (Winch & Kelsey, 2005),
- Inspiration to handle processes differently are taken from Lean production,
  - empowerment of the workforce (Dainty et al., 2002; Liker, 2005),
  - increased collaboration (Bhatla & Leite, 2012; Tjell, 2016)
  - the use of visualisations to make problems visible (Liker, 2005; Tjell, 2016),
  - the use of “war-rooms” and Big rooms (Liker, 2005; Tjell, 2016),
- New processes are invented to handle shortcomings of the old ones, and new tools are created that don't fit current processes (Hartmann et al., 2012).
- In general, research has focused on a combination of either technology, processes or people. Few studies focus on all three aspects of technology, processes and people (Xue et al., 2012).

### 3 Research approach and method

The field of information technology in construction has been defined as Construction Informatics and encompasses a wide variety of possible research areas (Isikdag et al., 2009; Merschbrock & Munkvold, 2012; Turk, 2006, 2007). The scope of this thesis is limited to construction planning, methodologies and technology that support this. A sociotechnical view is adopted to address system development from a perspective where both the technology as well as the social system in which people operate and interact is addressed (cf. Sackey et al., 2014). The research is performed and studied through a design science (DS) method. DS has traditionally focused on the development of the artefact, however recently research has discussed a possible connection to a more sociotechnical view (Carlsson et al., 2011), in which not only the development of the artefact is discussed, but also the context in which the artefact is applied becomes relevant. Johannesson & Perjons (2014, p. 12) defines a sociotechnical system in relation to DS:

*“a hybrid system that includes technical artefacts as well as humans and the laws, rules, and norms that govern their actions.”*

DS differs from natural science and social sciences in such a way that DS aims to create things that serve a human purpose, rather than merely trying to understand reality (March & Smith, 1995; Simon, 1996). March & Smith (1995) define two main design processes as part of DS research: build and evaluate artefacts. The purpose of DS is

to produce and communicate design knowledge that is of general interest, this contrasts to design work that is more localized and thus may produce solutions that are less relevant in a wider context and contribute no new knowledge (Hevner et al., 2004; Johannesson & Perjons, 2014). An artefact is defined as an object made by humans, designed to address a practical problem. Artefacts can range from physical objects, drawings etc. to methods and guidelines that support people in processes. DS may use a local problem and practice to solve a problem, but the artefact and knowledge created while designing the artefact should thus be interesting in a more general practice (Johannesson & Perjons, 2014).

As shown in Figure 6 March and Smith (1995) group artefacts in four categories: constructs, models, methods and instantiations. Further, March and Smith (1995) define a set of *constructs* as the language by which shared knowledge is communicated. *Models* are defined as descriptions or representations of how things are, while a *method* is formalized as instructions or a set of steps to perform a task. *Instantiations* are artefacts realised in its environment, instantiations make use of constructs, models and methods but instantiations can also be developed and constructs, models and methods can be derived from its use.

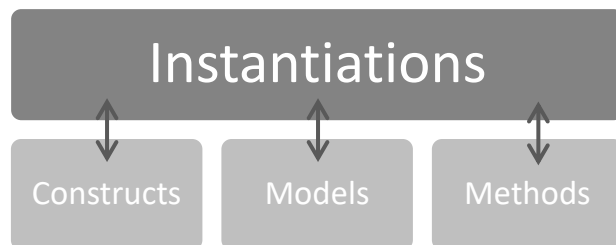


Figure 6: Relations of Instantiations, Constructs, Models and Methods.

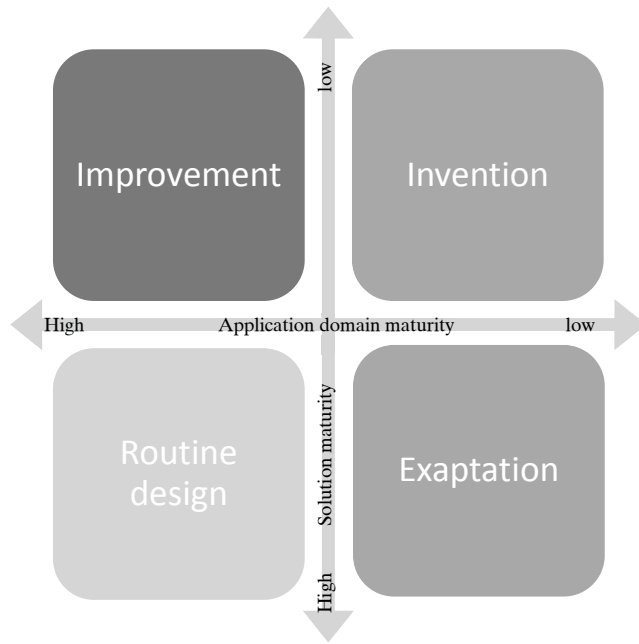


Figure 7: Design science contributions, adapted from Gregor and Hevner (2013)

This thesis mainly concerns methods and instantiations in relation to March and Smith (1995). The general planning approach observed is seen as the method, see Figure 6, in this context, while the developed artefact is the instantiation utilising the planning approach to realise the end-product of the artefact in. To more clearly show a contribution to the studied field Gregor and Hevner (2013) suggests a two dimensional positional classification of the DS-research. The axes are made up of solution maturity and application domain maturity. This results in four general fields where each of the dimensions go from low to high. Intuitively, the axes may seem reversed in comparison to traditional

visualisations of diagrams, but a high application domain maturity means that problems in the field are well known, if combined with a high solution maturity the field also has many known solutions, and thus an insignificant scientific contribution. This is classified as routine design in the lower left half of Figure 7. Routine design is typically not regarded as a valuable design science contribution since it only offers incremental innovation to known solutions and produces no new knowledge of general interest.

Improvements, defined as new solutions to known problems is a contribution where a solution to an existing problem is improved upon compared to state of the art, and thus constitutes a valuable scientific contribution compared to routine design. An exaptation is where existing solutions are applied on new problems. Inventions are the rarest of design science contributions, as inventions are new solutions to new problems (Gregor & Hevner, 2013). This thesis falls into the upper left half of Figure 7 as an improvement. The reason for classifying it as an improvement rather than routine design is that the designed artefact improves current planning practice, which can be seen as state of the art of what is used in practice. This thesis

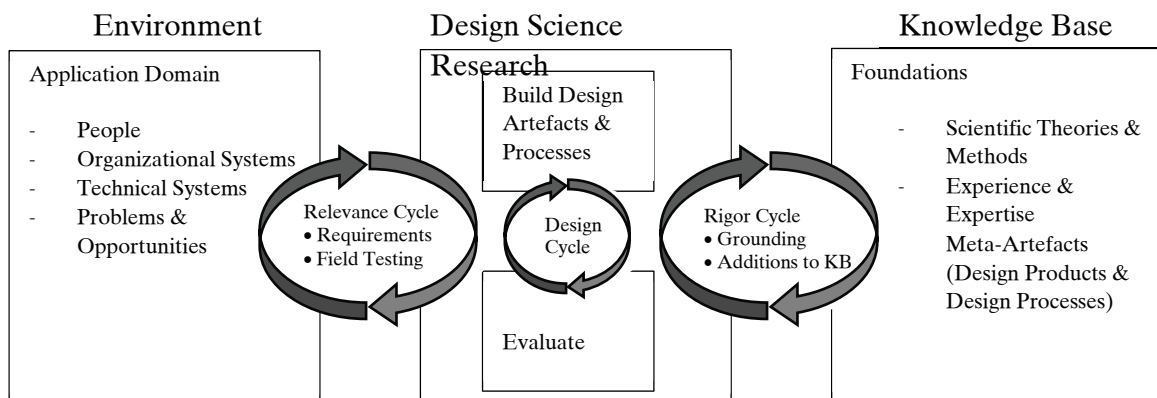


Figure 8: Design Science Research Cycles (Hevner 2007)

also contributes design knowledge which is generalizable beyond the specific artefact designed by highlighting the role of people and processes in a social context in relation to the design of the artefact.

To help position and present the development of the instantiation, the artefact, a research framework by Hevner *et al.* (2004) is used which consists of three loops; build, develop and evaluate. This framework is further enhanced in Hevner (2007) where design cycles are introduced. These design cycles are used to explain the relation of the research both to its environment, which is the application domain it is used in, as well as the knowledge base which is the academic foundation of the knowledge in the field. Hevner (2007) specifies these cycles as the Relevance cycle, the Design cycle and the Rigor cycle, these can be seen in Figure 8. The cycles presented represent steps in the DS research process. The relevance cycle ensures that the context of the research is performed in a localized context and relevant for the problem at hand. Here requirements and acceptance criteria are set. This acts as input for the development of the artefact, the output is then returned and tested in the appropriate environment against the acceptance criteria.

The rigor cycle on the other hand builds upon the existing knowledge base in the application domain of the research. A properly performed rigor cycle identifies state of the art and existing artefacts and processes. Here the additions to the knowledge base consist of extensions to original theories and methods, the new artefact in the form of design products or processes as well as the experience gained from developing and field testing the artefact in the application environment.

The design cycle is the heart of the DS research and symbolises the rapid iterations in design work of the artefact. Requirements are drawn from the relevance cycle and coupled with the design and evaluation theories and methods drawn from the rigor cycle. Here the balancing of relevance and rigor in the design cycle ensures that the contribution of the research to the application domain knowledge base is firmly based in practice and thus the rigor and relevance ensured (Hevner, 2007). This thesis and the appended papers consist of several design cycles intertwined with a set of rigor and relevance cycles. The process as seen in Figure 8 may seem quite clean and precise, but the actual research is less linear in its progression as seen in Figure 9. The actual design science research cycles conducted in this thesis are more a series of

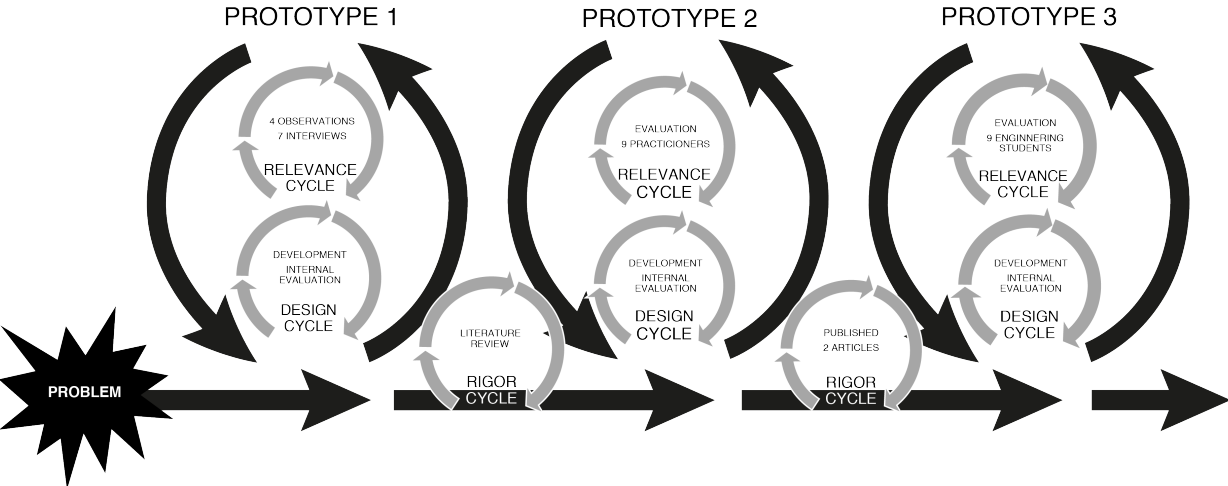


Figure 9: The general cycles of the research in this thesis (own elaboration).

connected and intertwined cycles as parts of bigger design cycles. Figure 9 shows the general layout of these cycles. In general, three main cycles can be identified, resulting in a software artefact or redesigned software artefact, henceforth named prototype one, two and three. These three main cycles are described in more detail with respect to the methods used to collect and analyse data in each of the cycles.

### 3.1 MAIN CYCLE PROTOTYPE 1

The first main cycle which resulted in software prototype 1 was instigated from a question from a planning practitioner. This is the problem seen in Figure 10, this is also the first relevance cycle since it anchors the research firmly in the context. This is the location-based production planning method, which comes from pre-construction production planning which is the application domain practice.

To understand the localized context and the problem, the initial data gathering was done through observations of three field observations (Bryman & Bell, 2011). Observations were done in two cases. The observations were located in southern Norway respectively nearby Gothenburg in western Sweden. The observations were performed in the actual construction planning workshops, observing the planning method, interaction between disciplines and request for information through sifting through available material. The participants were observed planning their work-packages through going through their available material, mostly drawings and descriptions. Only one or two direct questions between disciplines clarifying certain situations regarding HVAC, sprinkler and control and regulation systems.

The selection of which workshops to observe was limited to available projects. At the time of the observations, only one project utilized the collaborative planning workshop method, but the method had been used in five earlier executed projects of similar type and size. The

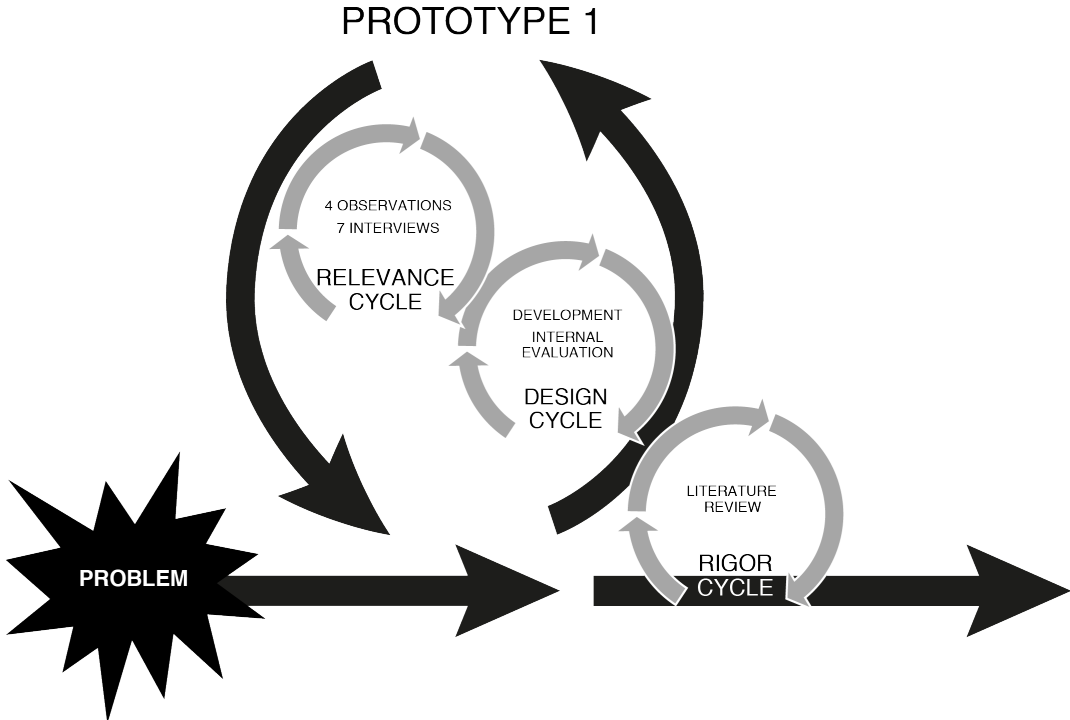


Figure 10: Main cycle of the development of prototype 1.

observations were summarized and recorded in field notes at the end of each workshop. As a complement to this, seven semi-structured interviews with practitioners were conducted (Kvale, 1996). The interviews were primarily conducted with senior fitters, which are the subcontractors' leading representative at the construction site. In two interviews experienced workers participated along with or instead of senior fitters. The interviews were divided as follows:

- One project planner
- One site manager
- One senior fitter from the electrical subcontractor
- One senior fitter from the plumbing subcontractor
- One senior fitter from the Prefab subcontractor
- Two workers, whereas one was senior fitter from the Sprinkler subcontractor
- Two workers from the HVAC subcontractor

The interview questions were mainly concerned with information in the project. The questions touched upon the following subjects:

- what kind of information they used,
- what kind of information they needed to perform their tasks,
- if they used information from other disciplines to understand the project,
- if they used information from other disciplines to solve specific tasks of their own,
- if they missed information at the current state to be able to perform their tasks.

The interviews were transcribed and coded. Furthermore, the observation data of the planning workshops were also codified and thematised by grouping observations and reflections in general themes, which later was refined and re-thematised. The analytical framework used to thematise the observations and interviews is related to the three dimensions of people, processes and technology (cf. Dave et al., 2008; Prodan et al., 2015), as described in chapter 2.6.

The main outcome were challenges identified in the current planning process as well as general requirements that the process needed to be performed. As seen in Figure 10 the observations and interview data sparked the first design cycle, where a rough outline of the artefact was formed, this is called prototype 1, which was evaluated against the design criteria focusing on learnability and user-friendliness. The evaluation of prototype 1 was conducted with one practitioner, a project planner and three researchers. The rigor cycle was then used to look at the state of the art and current knowledge-base through a literature review, from this a more refined idea of the artefact was designed, called Prototype 2.

### 3.2 MAIN CYCLE PROTOTYPE 2

The rigor cycle then turned into the development of the second prototype, as seen in Figure 11. Prototype 2 was the first instantiation of an artefact, an actual software which was tested in a workshop setting in a lab environment. Participants were the author of this thesis, two fellow researchers and one practitioner from the research project. the project planner. General discussions about what worked and not were compared to the evaluation criteria. The discussions, performed as unstructured interviews, were recorded and transcribed, along with notes taken during the discussion.

The topics of the unstructured interview were centred around usability compared to the traditional planning workshop and the recordings are about three hours long. The transcribed discussions resulted in input to better align the prototype with the requirements. This spurred a second relevance cycle where the prototype was tested in a workshop setting with the reference team of the research, consisting of practitioners from different contractors and consultants. In total nine practitioners participated for one hour during a mixed workshop and discussion setting, summary notes were taken from this session. The rationale and development of the design was published in two conference articles, which were part of a second rigor cycle which bridges over to prototype 3, as seen in Figure 11 and in Figure 12.

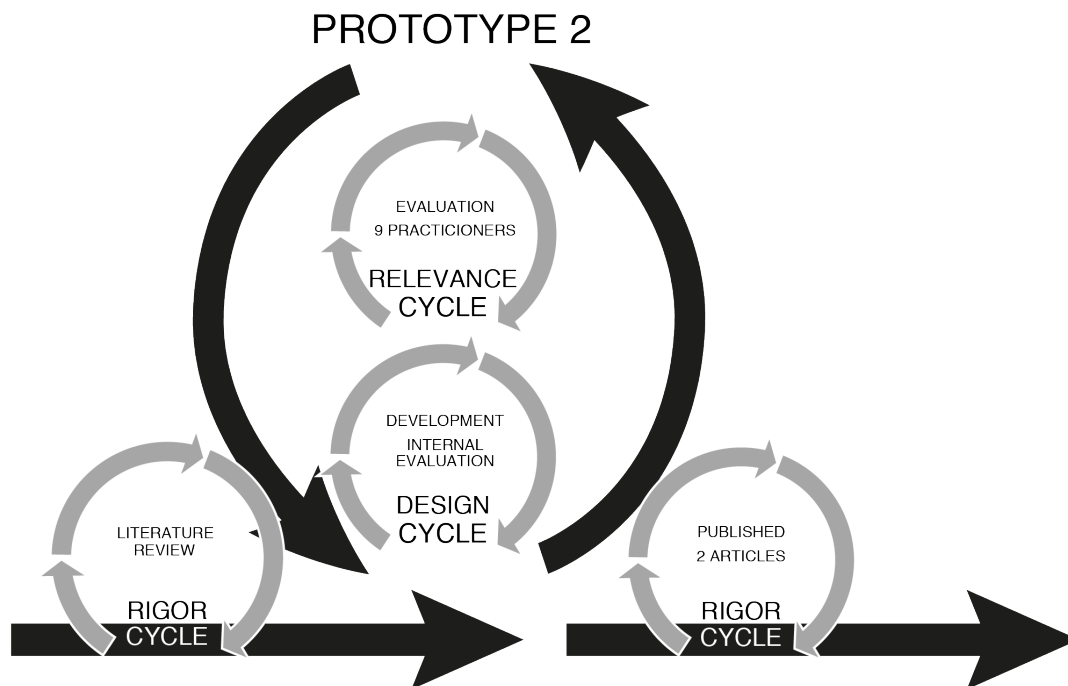


Figure 11: The main cycle of the development of prototype 2.

### 3.3 MAIN CYCLE PROTOTYPE 3

The main focus of this main cycle was the evaluation of the prototype in comparison to the un-enhanced planning workshop. This evaluation was conducted by eight engineering students that had experience of the collaborative planning method from a course they took earlier that year. In this course they practiced both quantity take-off from a BIM-model as well as the un-enhanced collaborative planning sessions.

The students were split into three evaluation groups of three students, apart from one group who only consisted of two students. The evaluation was conducted in three two-hour sets, where each group had one set each. The prior knowledge of the original planning method and workshop meant that the students could evaluate the workflow of the planning method with the prototype compared to only sticky notes and paper. These workshops were recorded in three parts. The first part, the individual work creating the activities for the schedule, was gathered by recording the screens of each of the participants, thus recording all interaction with the software. In total about two hours of screen recordings were done. Unfortunately, only six of the screen captures worked, rather than all eight, due to technical malfunctions.



## PROTOTYPE 3

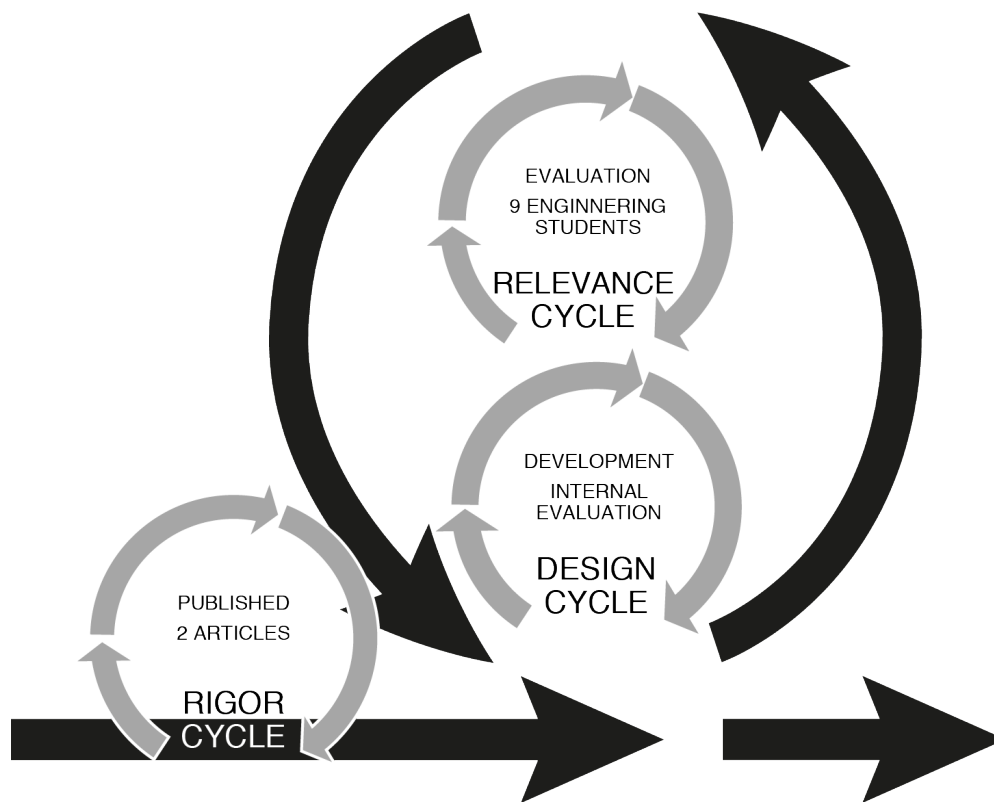


Figure 12: The main cycle of the development of prototype 3.

The second part, the collaborative scheduling, was recorded with a camera, this resulted in a total of about an hour of movie. The last part, an unstructured exit group-interview was conducted right before ending the workshop, this was recorded only with sound and amounts to about one hour of material. The main themes of the exit interviews were comparison of the prototype with the sticky-note method, and the availability of information needed to plan their tasks. In general, during the exit interview, spontaneous discussion and reactions were encouraged. As a complement to this, notes were taken simultaneously during all the workshops as grounds for evaluating how the prototype addresses the initial requirements. The exit-interviews were transcribed and the transcripts were coded and analysed to gather themes of interest discussed during the interviews. Finally, a fourth observation of the original planning method was conducted in another ongoing construction project. This project was an extension of a small ice-hockey arena with the addition of a bath-house with several swimming pools as well as a restaurant.

The workshop was conducted with fourteen participants; a site manager, a project planner, eight senior fitters from respectively the installation contractor, the control and regulation technology contractor, the tiling contractor, the masonry contractor, the dry-wall contractor, the painting contractor, the plumbing contractor. Apart from those, two subcontractors, the sprinkler installation contractor and the electric contractor participated with bot a senior fitter and a worker each. The observation was conducted to challenge the findings of requirements from the earlier workshops and the literature. In this fourth workshop the use of BIM was slightly more apparent than in the first three workshops. The HVAC and sprinkler

subcontractor repeatedly discussed the sequencing of each other's components. Here they even used the BIM-model to test sequencing by having the "model-pilot" hiding and showing components to understand the most logical sequence.

All these cycles and the data gathered from them were then combined into a third paper, not yet published, seeking to further disseminate findings to the construction informatics field. The descriptions of the cycles are generalisations of a more fluid development cycle but nonetheless the description accurately reflects the general chronological flow of the development of the artefact.

### 3.4 DATA COLLECTED

As a summary, this is the amount of data collected in this research:

- **4 distinct practice-based workshop observations** of ½-1-day workshops each + field notes
  - One with fourteen participants,
  - Two with sixteen participants,
  - One with fourteen participants.
- **7 interviews** of around 30-45 minutes each + notes
- **3 evaluation workshops**
  - One with 3 researchers and one project planner, three hours of recordings + notes
  - One with 9 practitioners, one hour of recordings + notes
  - A set of three two-hours workshops with eight proficient construction management students, about four hours of recordings + notes

The choice to initialize the research with the observations fits well with the DS method chosen, as this is one of the ways to capture context (cf. Johannesson & Perjons, 2014). The role as a both a participant and observer gave a thorough understanding of the context and the collaborative planning method as it was practiced. It also highlighted the participants' confusion and the complexity of the planning process and information digestion related to this. The observations of the workshops were conducted as observer-as-participant, where the researcher declares the intention of the observation and is open about the role as researcher, while still taking an active role in interactions (Bryman & Bell, 2011). However, while the immersion was complete during the observations, the timeframe was somewhat limited and thus does not fully qualify as a full on ethnographical study; the longest observation lasted only a full day. The interviews with the practitioners helped deepen the understanding what kind of information they need to conduct their planning and tasks. The choice to keep these interviews as semi-structured allowed for some offshoots in directions otherwise not possible (Kvale, 1996).

Several internal evaluation workshops have been performed, but only two were recorded and analysed, which in hindsight is a pity since several design insights about usability arose from these workshops. All data that has been collected has not been put to use yet. In the student workshops for example the screen recordings aren't analysed yet but may be valuable in future design loops of the prototype. Validation is in itself a difficult part of DS research, which is shown in the evaluation workshops both the internal and external ones. The requirements developed in the third paper will be beneficial for both formative evaluation of the possible

improvements of the artefact itself, but also the summative evaluation and assessment of the artefacts utility in future validation and evaluations in the next phase of the research (Johannesson & Perjons, 2014).

### 3.5 REQUIREMENTS

Requirements are essential to design science research as they define the evaluation criteria with which the artefact is to be evaluated. Furthermore, the design of artefacts as a sociotechnical system, calls for a understanding of how knowledge is represented in individuals, documents, routines and the underlying technology (Johannesson & Perjons, 2014). It is also important to identify which knowledge the artefact should represent and how this effects the organisation and the routines (ibid.). This is also stressed by Dix et al. (2004), where the capture of requirements are discussed. While the goal of introducing an artefact often is to automate some workflows, the aim of the requirements identification is to find the workflows that are suitable to automate. To do this, requirements need to be captured from the work context of the domain studied. In this thesis this is done through two case studies in real-life projects, consisting of in total four collaborative planning workshops. The literature gives a supplementary way of explicating the requirements through explicating the problem, finding root causes and from this outline requirements to remedy the root-cause. The resulting requirements are presented below in relation to the current planning approach in chapter 4.



# 4 The current collaborative planning approach

The following chapter is a description of the studied and currently used planning approach as used in the two case projects studied, along with general requirements for the planning approach related to the literature and observations.

The location-based management system (LBMS) approach used in the projects studied in this thesis is an adoption of the visual planning method introduced in Sweden by Dalman (2005) with inspiration from JMAC, a Japanese management firm and Toyota. This connection also highlights the inspiration from the LPS approach, albeit based in a Scandinavian culture and context. The approach has been given the name location-based production planning (a direct translation from the Swedish name), which will be used henceforth in the thesis.

The planning workshops gather all participants such as the main stakeholders in the construction project, i.e., site management, representatives from all sub-contractors and representatives from the customer. Before the workshop starts, the project planner and site-manager break down the project in locations to make the project more manageable. Each participant is tasked with going through each location to map their work and prepare before the workshop. This gives quality time to collaboratively schedule the activities. This becomes clearer with a quote from the specialist planner responsible for holding the workshops:

*“...Even though all actors in the production are gathered one or two times for the full day workshops, less time is spent on planning. It is also done with greater accuracy due to the practice knowledge put in by the participants... - Roger Andersson”*

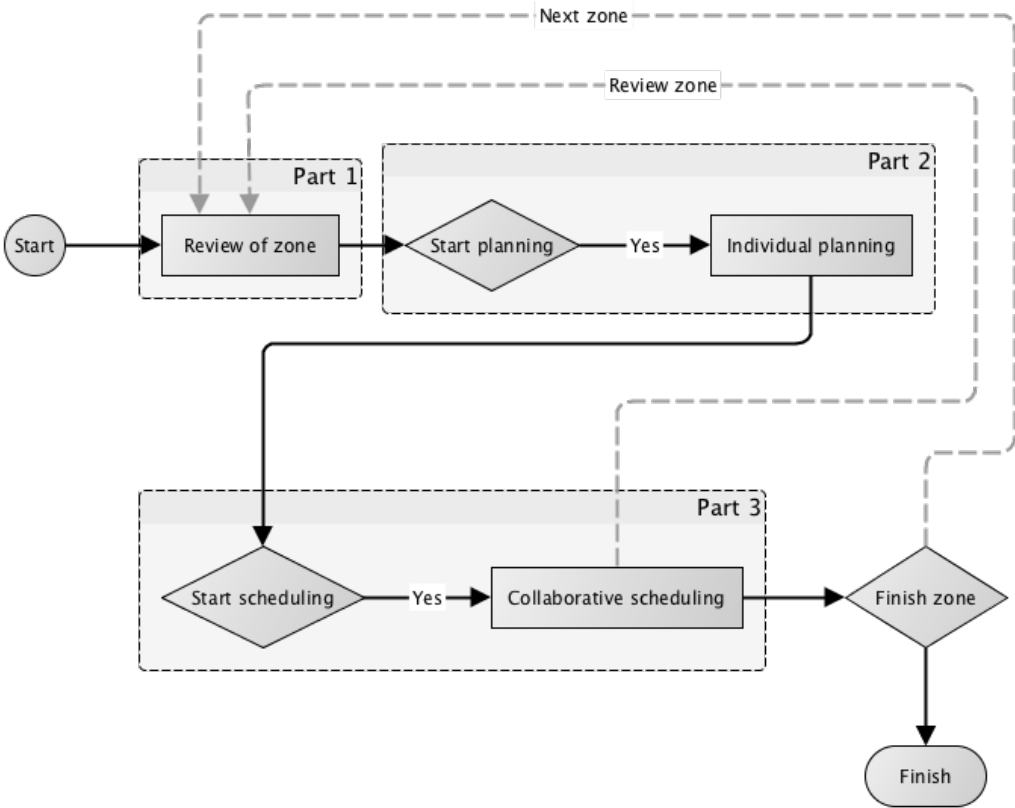


Figure 13: General overview of planning-approach

The workshop itself is divided into three parts, as seen in Figure 13, a presentation and walkthrough of the project, the creation of tasks in each location and lastly the collaborative planning and review of the locations. During the presentation and walkthrough of the project all of the locations are presented, often in the order of complexity. In the workshops, the complexity was rated by the site-manager based on the amount of disciplines and installations in each location. This means that locations can differ extensively both in size and complexity. The walkthrough is often done in a BIM viewer such as Solibri Model-Checker with a “model-pilot” to help flying through the model.

When the walkthrough of the project is done in the first part of the workshop, each of the sub-contractors obtains sticky notes and breaks off to perform their individual planning-work. Each zone is treated as a separate location and thus treated sequentially. Each participant creates work-packages on sticky notes, grouped by location. One sticky note per work-package, the work-packages are defined by name, location, needed resources and discipline. When the participants have planned all their locations with work-packages defined, the workshop reassembles. Now the structuring of the work-packages starts. This is done by a similar walkthrough as before but broken down by location and conducted as a collaborative planning session. Each location is sequenced through collaborative work and each work-package is discussed to gain the right predecessors and successors within the location. When all work-packages in the location are scheduled, the location is reviewed by the group before continuing to the next location. The resulting schedule is planned according to ideal conditions and without regard to contractual times. When all locations are structured and finished the structure plan of the project, comprising of each location, is input into a planning software by the project planner. The resulting schedule is then sent on review to each of the disciplines and is discussed in another meeting where all the participants go through the resulting schedule and agree on eventual adjustments to reach the stipulated contract times.

The workshop is repeated as needed, two or three times depending on if all sub-contractors participate. The workshops rely heavily on active participation of and collaboration between the participants. One of the main ideas behind the planning method is to get the sub-contractors to perform the planning, rather than the site management, thus ensuring an anchoring of the schedule and a feeling of ownership over the schedule with the sub-contractors.

From the description above of the collaborative planning-workshop and compared with the background and related work, a set of requirements have been produced. The list of the requirements started out fairly general, but then became more specific with the literature review and even more specific after the observations. The three prototype cycles described in section 3, gradually formed the requirements list. The first cycle outlined a rough sketch of the design for the prototype, this was then refined through the literature review and the second prototype cycle. This step was repeated with input from the evaluations and the third prototype cycle. The following requirements are the final list of requirements listed in the third paper, to give a full overview of the current requirements that have guided the research. The list has grown and developed during the design cycles.

The general requirements for a system to support the collaborative planning-method described above are:

***The system should help the users gain an overview of the project and its participating disciplines.*** Visualising the problem was one of the findings from literature (Bhatla & Leite, 2012; Dvir et al., 2003), but also stood out as a main pain-point in the workshops. From literature the insights that location based planning can help reduce the complexity and enable a logical breakdown of the project (Kenley & Seppänen, 2009), strengthens the findings of the use of locations in the observations.

***The system should support both individual and group work.*** This requirement originates in the fact that individual work creates ownership of the work conducted (Dainty et al., 2002; Liker, 2005). The collaborative planning-workshop consists of three parts, where both individual and group work is performed, albeit in different stages. As Hartmann et al. (2012) puts it, adjust the tools to current processes, thus, guiding a general workflow of a system supporting the existing collaborative planning-method.

***The system should support the user in information gathering while creating activities.*** One of the main activities that the users engage in during the collaborative planning-workshop is the creation of the individual activities that the users' discipline perform in the project. During this work-package creation the user makes extensive use of available information in the project. The system should support the user in such a way that information is gathered and made available to the user in an easily accessible, but yet not intrusive way. Thus, keeping complexity in information levels manageable by the user as needed.

***The system should support the users in the collaborative creation of the schedule.*** Another of the main activities during the workshop are the collaborative scheduling. Here the tool should support the users in the co-creation of a visually readable structure of activities. The current collaborative planning-workshop creates physical papers with sticky notes that need to be put into scheduling software.





## 5 Summary of the papers

The result of the thesis is presented in three appended papers, two conference articles and one working paper that will be submitted to a journal. The three papers highlight the research from three aspects,

### 5.1 PAPER I

Viklund Tallgren, M., Roupé, M. and Johansson, M. (2015) 'An empowered collaborative planning method in a Swedish construction company - A case study', in *31st annual ARCOM Conference*. Association of Researchers in Construction Management, pp. 793–802.

#### *BACKGROUND AND PURPOSE*

The complexity of the construction industry creates a need for proficient planning. The complexity and specialisation also mean that more sub-contractors are involved in the process. This calls for more coordination and planning. As it is at the moment, most planning is performed centrally, but literature shows that decentralization and collaborative planning is beneficial for the project.

The purpose of this paper is to position a currently implemented planning method with regard to other planning methods. The planning method is studied in the field in an ongoing project. The paper aims to describe the planning method and study the interaction with the information as well as between the participants to position this the method with regards to BIM.

#### *METHOD*

The paper combines a single case-study approach, where observations of three full day workshops are the main source of data collection, with a literature review and seven interviews as background material. The initial work consisted of mapping current planning methods and streams of planning. The interviews served to identify the kind of information that the sub-contractors used in their own planning. Three observations in planning workshops were conducted in the case study project, where the main author in the last two workshops, acted as participant as model-navigator. The observations were conducted in workshops where the collaborative planning method was utilized. Observations were recorded in field notes after the workshops. These notes, together with the transcribed interviews, were then coded through open coding, generating keywords that were grouped into category themes.

#### *FINDINGS*

Two main findings were identified, number one was that the planning method that was used was related to several collaborative planning methods, and as such also had similar benefits. The second finding was that the large amount of information available in the project and used by respective discipline made it hard for the disciplines to find the right information at the right time, thus hinting at possible enhancements.

### 5.3 PAPER II

Viklund Tallgren, M. et al. (2015) 'A BIM-supported framework for enhancing joint planning in construction', in 32nd CIB W78 Conference, Eindhoven, The Netherlands, pp. 696–705.

#### *BACKGROUND AND PURPOSE*

Construction planning has hardly changed since the 1950s. During the last decades, the visualisation and communication of the resulting plans has been questioned for their shortcomings and new methods has been developed. These new methods along with the increase of complexity in construction projects has increased the amount of information available and as such research into new ways of visualising and communicating this information has been employed. However, the increase in complexity has also led to more centralisation of the planning, which contradicts the findings in research that the inclusion of work contractors in the planning process produces more realistic schedules. This paper looks at the current implementation of a collaborative planning process in use and aims to outline a theoretical framework of a software supporting and enhancing this planning process.

#### *METHOD*

This paper shares the methodology with paper number one and the focus in this paper was on seven semi-structured interviews that were conducted. The participants in the interviews were workers and foremen from 7 disciplines, pre-fabrication, sprinkler, HVAC, plumbing, electrical/security, site-management and lastly a specialist planner. The interviews were recorded with consent from the participants and then transcribed in verbatim. The workshops observed were documented with field-notes which then were coded and analysed. The field-notes and the interviews acted as input into the framework of the prototype software.

#### *FINDINGS*

Earlier research and literature supports the observed planning method and the identified areas of improvement aligns with suggestions from literature. The paper also highlights that few implementations of planning and BIM originate from the BIM but rather connects a BIM system with a schedule, both which are produced separately and then joined in visualisation software. The outlined framework and software utilises the BIM system as building-blocks in the process of creating the schedule. The paper thus shows how the design of a software that benefit from this could look like.

## 5.5 PAPER III

Viklund Tallgren, M., Roupé, M., Johansson, M., Bosch, P. (WIP paper 2018) 'The Development of a collaborative planning system for pre-construction',

### *BACKGROUND AND PURPOSE*

Construction planning and scheduling tools are readily available, but few have been developed from a user perspective and even less so with all three aspects of people, processes and technology, PPT, integrated. With the introduction of 4D-planning, BIM and Lean construction many new tools and processes have surfaced, but most look at parts of the process, or focus on the development of new processes or technologies to remedy the disadvantages in many of the existing methods, processes and technologies. The purpose of this paper is to take a PPT perspective applied to a design science research approach of developing an enhancement of an existing planning and scheduling method and end up with a collaborative planning and scheduling tool.

### *METHOD*

The method of this paper is based on the Design Science (DS) approach where DS differs from natural science in such that it tries to create an artefact that provides something beneficial to humanity rather than observing and trying to understand reality as more traditional natural science does. This paper describes the development and evaluation of the artefact, i.e., the Visual project planner (VPP) software prototype, in a simplified manner. Thus, the paper primarily focuses on the three main design cycles, rather than discussing all intermediary versions. The main data collection was done thorough field observations in a real-life project as basis for the forming of requirements. This was complimented with seven semi-structured interviews with practitioners on how information was used and needed during planning and scheduling. The prototypes were evaluated in four stages during small simulated workshops, two times with fellow researchers and a project planner, one time with practitioners and the last time with engineering students with experience of the planning and scheduling method used.

### *FINDINGS*

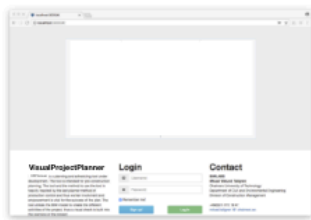
This paper shows how a tool can be developed and evaluated with regard to PPT. The paper further shows how the VPP-tool enhances the current planning process and brings technology to the process with a better visualization and a more accessible schedule for the participants, at least in the planning phase of pre-construction. However, the context is limited to the Scandinavian construction sector as well as to medium and large sized construction companies. This means that both the level of implementation of BIM in the process as well as how much the sub-contractors are involved are subject of discussion toward generalizing the results.

Going forward, more conclusive tests should be made in different settings and real-life projects with different practitioners. Findings from discussions with practitioners during the current evaluations hint at differences between different types of projects as well as project with different contractual basis.

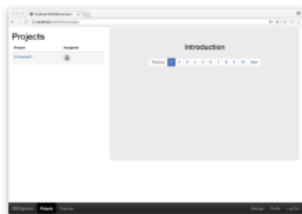


## 6 Result: The VisualProductionPlanner System

The main result of this research is the VisualProductionPlanner system, called the VPP-system. The VPP system can be described as a web-application to enhance the current collaborative planning-method when creating activities and collectively planning the schedule. The application is developed to work in all three stages of the collaborative planning-workshop, which is the walkthrough of the zones, the work-package creation separated by discipline and foremost the collaborative scheduling of each zone. In Figure 14 the main screens of the different sequences of interaction can be seen, these are further explained below.



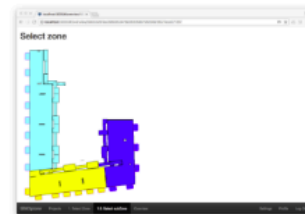
**1 - Welcome screen**



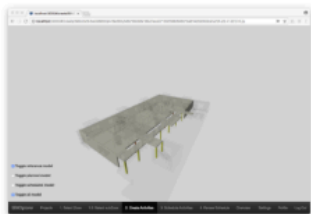
**2.1 - Project Selection**



**2.2 - Floor Selection**



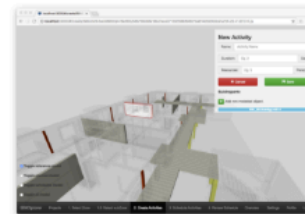
**2.3 - Zone Selection**



**2.4 - Zone Overview**



**2.5 - Unplanned Zone**



**2.6 - Task Planning**



**3.1 - Unplanned Zone**



**3.2 - Schedule overview**

*Figure 14: Main screens of VPP software.*

The general steps leading to the development of the VPP-system are described in the method chapter and thus are not discussed at length. The core requirements found from the literature review and strengthened by the observations formed the basis for the VPP-system. The four core requirements used were the following:

1. The system should help the users gain an overview of the project and participating disciplines.
2. The system should support both individual and group work.
3. The system should support the user in information gathering while creating activities.
4. The system should support the users in the collaborative creation of the schedule.

These four requirements were expanded into functionalities, or functions that the system should be able to fulfil, that resulted in the VPP-system. The foremost functionality was to utilize the BIM better in the artefact than the traditional collaborative planning-method and thus the decision was made to base the system around the BIM model. Furthermore, the system needed to be easy to use to lower the barrier for novice users. Thus, the artefact is used as a viewer initially to walk through the model and to let the users get to know the system before actually starting to work with it.

A common rule of thumb is to keep interaction to as few inputs as possible, thus a mixture of keyboard and mouse interactions should be avoided according to Dix et al. (2004). Therefore, a simple mouse-only interface was selected for the interaction. The user clicks the left button and moves around to rotate, if the mouse-pointer hits an object the object is selected instead. By using the scroll wheel, the user can zoom in and out and by clicking the right button, the user can pan or move the scene as seen in Figure 15. These modes of interaction are well established in computer software development and used.

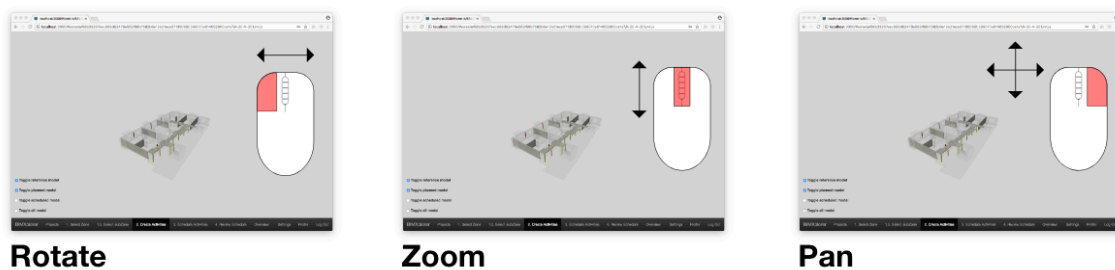
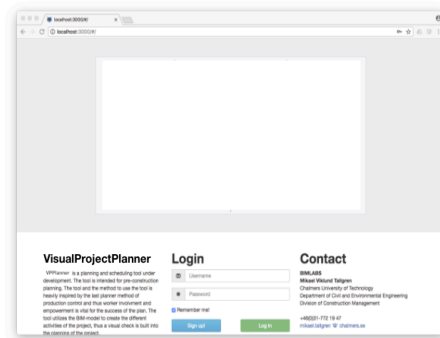


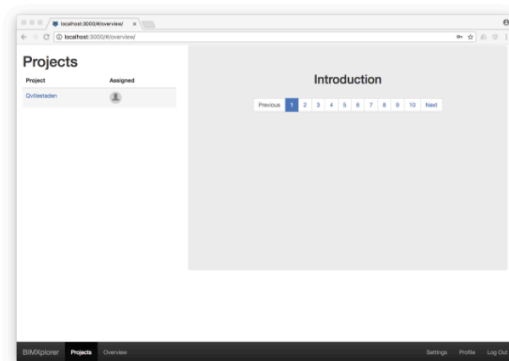
Figure 15: Basic interaction with model.

The following sections explore the VPP-system screen by screen. The exploration follows the layout of the collaborative planning-workshop in the VPP-system setting. The starting view, 1 – welcome view, Figure 16, is the landing page for all visitors of the site. The primary function here is to serve as a landing page before logging in. The system is designed to run on a webserver with a backing of a NoSQL-database that mimics the document structure of the information constituting

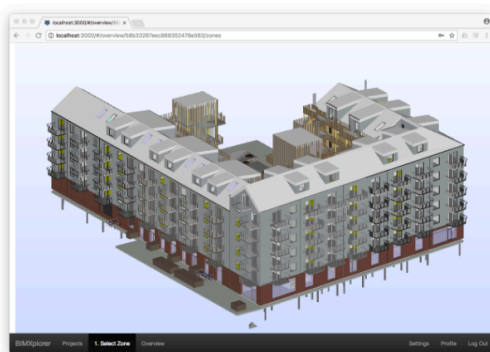


## 1 - Welcome screen

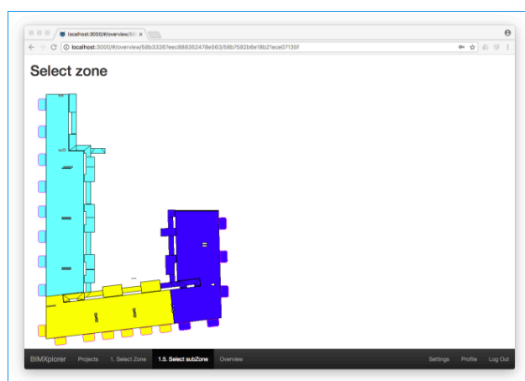
Figure 16: The welcome screen.



## 2.1 - Project Selection



## 2.2 - Floor Selection



## 2.3 - Zone Selection

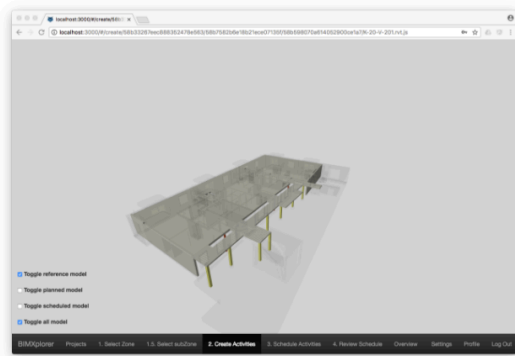
Figure 17: Main orientation views.

the BIM model, which is the reason for choosing the NoSQL database over a more traditional relational SQL-database. Both the server and the database can be run locally in an ad-hoc network with a laptop as a server if network availability is scarce, but then requires some setup and configuration compared to the online version of the VPP-system.

Once logged in, the user is directed to a project selection view. This view is company and discipline specific and is tied to the discipline of the user. Thus, only projects the user is part of will be visible here. The screen also has an introduction to the tool through a set of short instructional videos and pictures. From this view the user selects the project to work with and is then presented with an overview of the chosen project. This is part of the strategy to give the user an overview of the project as screen 2.1, 2.2 and 2.3 in Figure 17 is about orienting oneself in the project. By gradually peeling away layer of levels and zones, the user gets a feeling for where the zone is actually situated in the project.

These initial views use the architectural model as a reference while navigating through the model to the current zone to capture the spatial orientation and position of the zone. The gradual peeling away of layers also means that the model becomes more lightweight to visualize and can be real-time rendered even

in a browser once the selected zone is activated. The activation of the zone displays the building-parts belonging to the specific discipline.

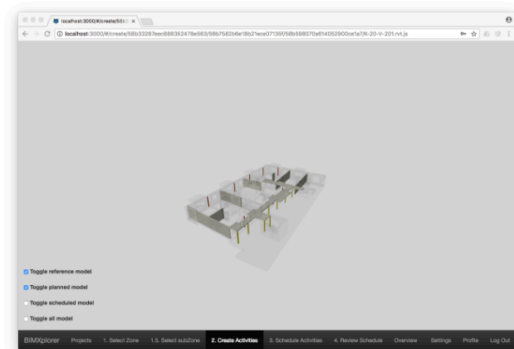


## 2.4 - Zone Overview

Figure 18: The initial discipline zone overview.

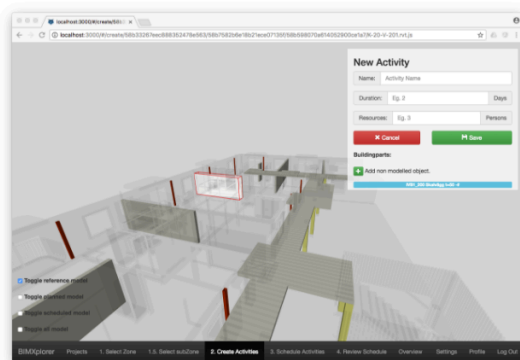
transparent the same zone. The transparent architectural model is the default reference view but could in theory be changed to any of the given disciplines in the project. This use of a reference model gives more context to the building parts of the active discipline in the model. This is especially important for disciplines such as electrical, HVAC and sprinkler, which often share space in the model. The zone overview can be used during the walkthroughs by each participant separately, and since each user has an own instance of the

The current VPP-system prototype has the floor and zone selection hardcoded into the project with floors and zones defined as clickable areas of pictures, but the aim is to make these more configurable in future versions of the system. Especially the zone definition would benefit from being more interactive when defining zones. Once a zone is selected, a 3D model will be loaded and displayed, which is defined by the size of the zone, this is seen in screen 2.4 in Figure 18. The model is filtered by the active discipline and displays the architectural model slightly



## 2.5 - Unplanned Zone

Figure 19: The unplanned building parts.



## 2.6 - Task Planning

Figure 20: Task or work-package planning

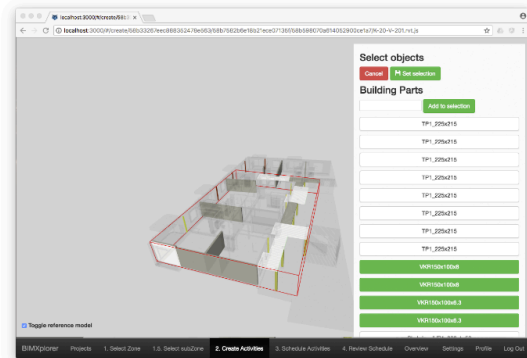
planning a zone. Thus, it is possible to resume work where one left off.

application, they see their discipline in the zone currently being reviewed on their computer. Here they can follow along and on their own query and explore the model for more information. This view is also used during the second stage, the individual planning of discipline activities. Here the users create activities from the building parts of the model. The view starts out as in Figure 18 – 2.4 – zone overview, but as the user plans building parts they are hidden as seen in Figure 19. Figure 19 also shows how the starting view of the zone would look like if the user returned after quitting to the VPP-system while in the middle of

These views support the second requirement of both individual and group work by enabling interaction with the model and enabling the users to get a better orientation in the walkthrough. It also supports the third requirement since the model is used to display relevant information for the user while planning the work-package. The user plans activities, as seen in



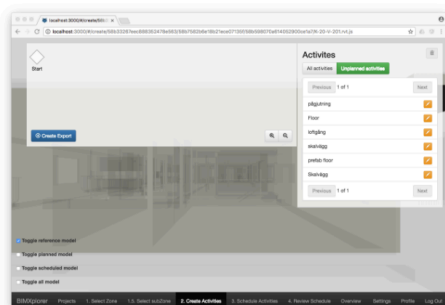
Figure 20, by selecting building parts in the model. This is equivalent to the collaborative planning-method's creation of work-packages on sticky notes, where the sticky note consists of accumulated information gathered by going through drawings and documents collecting information about each task. In the VPP-system the information is readily available in the model and thus reduces the need for accessing multiple documents to query for information. As parts are selected, relevant information of the parts is displayed to aid in the estimation of duration of the work-package, which here as well as in the collaborative planning-method is planned in full days. When an work-package is saved the parts relating to that work-package are hidden, which means that the view gradually becomes less cluttered and as all parts are planned the view should be empty except for the translucent reference model. The reference model is also possible to toggle on and off to visually confirm that no building-parts are missed.



## 2.7 - Filtering

Figure 21: Filtering of similar building parts.

During development, the selection of building parts became apparent as a tedious task in the new VPP-system. Every part had to be selected individually. Thus, a filtering method was developed where the user could select parts far away that were part of the same task, like a branch of piping going of the main feeder pipe. As the main feeder pipe probably is installed prior to the branches there is a need to distinguish these. The filtering is done by grouping similar building parts, dependent on the parts that is selected. As seen in the right part of Figure 21 a list of building parts is presented. These parts are all within the red box seen in the left part of the figure. The box spans all the elements that are selected. By selecting elements outside the box, the box expands, and with this expansion it tests to see if more building parts of the same part are within the selection box. If more parts are in the box, the parts are pre-selected without the user needing to do more. This type of additive filtering based on previously selected parts speeds up the task creation. As seen in Figure 21 there is also a field for filtering parts by name, thus the user can add parts inside the selection box that should be selected without clicking on them.



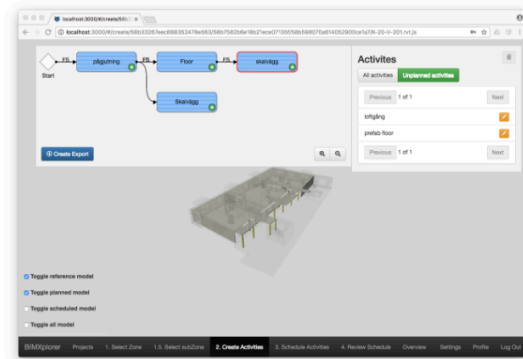
## 3.1 - Unplanned Zone Activity Overview

Figure 22: Unplanned zone task overview.

Once all parts are planned, the view of every discipline should be empty. Thus, the individual work is finished and the collaborative part of the workshop is initiated. The participants switch to screen 3.1 – the scheduling screen, seen in Figure 22. Now the model is unhidden and ready to be scheduled. Each discipline sees the list of the activities they have planned. This view is tied to the zone and is thus still limited by the zone. Apart from this list of activities, the user also sees the model in the background as well as an overview of the schedule, which only consists of a starting milestone before the planning starts. From this view, the user

can edit and schedule activities. The user can also switch the layout of the list to show only unplanned activities, which is the default mode, and show all activities.

The collaborative part of this scheduling consists of the participants discussing the order of their respective activities. The schedule is created by the user selecting, dragging and dropping activities on predecessor-activities in the schedule part of the view. The user can then add additional dependencies by connecting more activities with connections. The default connection type is Finish-Start and can be changed once the connection is connected to two activities. This is similar to placing the sticky-note in the collaborative planning-method and drawing the connections between the notes. Like the different coloured sticky-notes in the collaborative planning-method, each discipline in the VPP-system is visualized in the schedule by a block in a different colour. The most recent work-package is highlighted with a red accent around the block, as seen in the upper middle part of Figure 23.



### 3.2 - Schedule overview

Figure 23: Schedule overview while scheduling.

The schedule overview updates simultaneously for all participants which are active in the same zone via a programmatical broadcast that all clients listen for. As in previous views, the model the user sees are updated as activities and parts are scheduled by hiding the building parts that are scheduled. Once everything in the zone of the discipline is scheduled the view should be empty.



Figure 24: Example of projected full building overview of the schedule (own photomontage).

This part of the workshop is also displayed on a large screen or overhead projector, where a BIM-viewer listens for digital broadcasts with messages to update the model. The BIM-viewer displays two screens, one of the

fully assembled building, and one fully transparent view as seen in Figure 24. As the schedule takes form, building parts from all disciplines are hidden in the first view when respective activities are scheduled and displayed opaque in the formerly transparent view. Thus, as the schedule increases, so propagates the model as well. This is repeated for each zone and when the all zones are scheduled the left view of the main screen should be empty and the right view should be the full model.

The schedule is intentionally kept simple since practitioners do not need all the information a Gantt schedule conveys, since the view is about conveying relevant information to the participants at any given moment. The VPP-tool is able to, with some additional development,

export the schedule to the most common scheduling software for further refinement by the project planner.



## 7 Discussion and conclusion

The aim of the thesis is to contribute to the field of construction informatics and thereby support the discussion about how the development process of ICT tools in the form of a BIM-system could be performed. In this context design science has been applied with a sociotechnical systems approach. The sociotechnical approach has made use of the analytical framing of people, processes and technology (PPT).

The research contributes with three parts:

1. A documentation of an existing collaborative planning process.
2. The documentation and development of a collaborative planning tool meant to enhance the current work practice.
3. The use of a Design Science methodology

The scope has been limited to a collaborative planning practice that was specifically used in pre-production and production planning. This pinpoints the phase after awarding the contract after bidding, but slightly before onsite production begins. Thus, the discussion and conclusions are limited to this phase, but indications of effects beyond this phase are suggested in the section future work. The following discussion is focused around the three research questions and the contribution to these from the appended papers.

### 7.1 THE COLLABORATIVE PLANNING PROCESS

As described in the introduction, the construction industry has been both characterized and criticized for fragmentation, low productivity as well as poor information exchange and communication (Nepal & Staub-French, 2016). In this thesis the focus has been on the assumption that planning is one way to address these issues. The literature concerning construction planning shows different approaches to addressing this, partly by introducing new planning processes and partly by introducing new technology, sometimes simultaneously and sometimes separately. In the observations it was found that the project planner placed a strong focus on locations in the planning, talking a lot about zones and locations. In contrast to a traditional work-breakdown structure, the observations of this research showed more similarities to a location-breakdown-structure as discussed by Kenley & Harfield (2014). The use of location as the basic unit of analysis for work-packages also means that work is understood in terms of location and gives the workers a logical connection between work and where the works is to be performed. This kind of connection helps orientation and understanding of the project, especially in the planning phase. This thesis fills a gap of limited documentation of LPS and other LBMS approaches (cf. Daniel et al., 2015).

To some extent the collaborative elements found in the current collaborative planning approach may be traced back to Scandinavian culture and maybe in particular the Swedish construction culture with low power distance and a strong focus on informal collaboration with personal relations. To some extent collaboration is even questioned as a norm in Swedish construction culture (Bröchner et al., 2002). Next to a collaborative working culture, also empowerment is strong in Scandinavia. Literature depicts site-managers as having a strong position within their companies, with rewards for being able to handle tough situations and being “firefighters” (Koskela, 1992). Further companies tend to de-centralize power to site managers, but instead of acting as the hero the site-manager in the two cases wanted to get input from the sub-contractors to avoid “firefighting” situations. From the observations and

interviews, it was clear that the site-manager found it positive to engage the subcontractors in the planning, not only did this result in a decrease in total amount of time spent on planning, but it was also stated that by engaging subcontractors, they understood their role in the process and part of the project better. Specifically, the sub-contractors adhered to the schedule in a way that was not seen before the collaborative planning process was adopted. Further, the importance of face-to-face communication and co-location for the communication and collaboration (Bosch-Sijtsema & Tjell, 2017) is supported by the observations in the cases. Interactions between sub-contractors happened because of the co-location and discussion around the schedule and BIM model.

All in all, the documentation of this collaborative planning method compared to current construction management practices, shows that the observed method has support in literature even though it is only inspired by LPS (cf. Daniel et al., 2016). in relation to current project management practices concerning construction planning, but it also provides empirical evidence for how a collaborative planning method is actually implemented and practiced in Scandinavia (Sweden and Norway). The documentation also showed challenges and possible areas of improvement of the current process as was described in the development of the BIM planning tool in this thesis.

## 7.2 ALIGNING BIM WITH THE COLLABORATIVE PLANNING PROCESS

The collaborative aspects of the planning process highlight the social and organizational importance for the process. The literature emphasizes the need for more collaboration in the project team both in the design and construction phase, as this could help communication and information flow and reduce errors due to misinterpretation of the documents (Bhatla & Leite, 2012). The literature further shows that planning is an information intensive stage of projects and that the fragmentation of the construction industry has led to even more need for more specialized information (Van Berlo & Natrop, 2015). This shift towards more complex project organisations is seen in literature (Dvir et al., 2003; Friblick & Olsson, 2009; Christiansen, 2012). This is mirrored in the observations where it is shown that the project organisation during workshops consisted of around 16 persons, where most represented a separate sub-contractor (Viklund Tallgren, et al., 2015). This shows the need for handling the organizational complexity. What also has been seen in both literature and observations is the increasing complexity of construction projects in the form of a lot of mechanical- electrical and plumbing-work amongst others. With this growing complexity comes an increasing need to understand how disciplines relate to each other. Literature shows how this traditionally has been done with drawings and coordination-plots, but with the increased intricacy of projects there is a growing need for coordination in 3D and with BIM models (Bhatla & Leite, 2012; Dvir et al., 2003; Eastman et al., 2011). Further, literature shows that BIM use in Sweden, especially in the construction phase, mostly is limited to visualizations and clash detection ( Bergqvist & Sköld, 2017; Birging & Lindfors, 2014; Brantitsa & Norberg, 2018; Böregård & Degerman, 2013; Dave et al., 2008; Karlsson, 2009; Persson & Gårdelöv, 2017). This is reinforced by the observations, where limited use of the BIM model was seen throughout the workshops. When the model was used, it was mainly to walk through the project, and limited information gathering and discussions around the model took place. The observations also showed information challenges. The participants had a hard time to follow the BIM walkthrough on their own respective drawings. In the last observation which was conducted three years after the first set of workshops in an entirely different project, some more advanced use of the BIM model was

seen. The communication seen between the HVAC and sprinkler sub-contractors in each zone about the sequencing clearly show the lack of proper tools for this. This shows the potential of BIM support but also highlights the limitations, since this kind of interaction would not have been possible in the current BIM system without a skilled “model-pilot” to obey their wishes. The difference in time between the workshops may also hint at some general maturing around BIM knowledge and possibilities with BIM in the industry.

Continuing onwards toward answering the research question, it becomes apparent that the documentation of the current practice is important, especially in the development of the specific collaborative planning system described in this thesis. As mentioned earlier in the discussion, the documentation of the current planning process helped identify possible enhancements to the process. Combined with a thorough knowledge of planning theory, practice combined with theory could help map how a BIM system most effectively could be aligned to the process to minimize process alteration. In general BIM has been used to help reduce complexity by managing information visible to the user. Through the interaction with the model an extra dimension of information gets layered into the information flow (Svalestuen et al., 2017). This is exemplified in the use of the digital sticky notes, where information of the relevant building-parts in the task is gathered directly from the BIM upon each click on respective building-parts. Furthermore, this is an example of a slight process change, the sticky-notes are replaced by “virtual notes” in the model and drawings and documents are combined into the BIM-model. But it could be argued that the process still is kept closely to the original one and thus aligning BIM and the technology to the process rather than revers.

To align BIM with current planning processes a description of current practice is needed. BIM is seen as a change element in literature and technology is described as developed with new processes in mind (Goulding & Lou, 2013; Hartmann et al., 2012). Through the use of design science and a sociotechnical perspective, this thesis focused on an approach where the technology and subsequently the use of BIM is aligned to the process, rather than aligning processes and people to the BIM technology. Earlier research has started with the focus on technology and aligning process and people to technology as described in Goulding and Lou (2013). The way Goulding and Lou (2013) define the people, process and technology dimensions implies that people and processes are subordinate to technology, having to adjust to technology. This clearly describes the prevailing current approaches to developing BIM-tools. This research has been done with a strong focus on the user perspective and places people in the forefront. The view has been that the user should dictate the process and the technology, thus changing the three statements of the PPT dimensions as presented by Goulding and Lou (2013). The existing processes should dictate the proposed system’s functionalities during the development of the system. This has been essential for this research and a way to get closer to the technology pull strategies for BIM that Hartmann et al., (2012) suggests. Furthermore, the system should adapt to the stakeholders and their needs and ICT should simplify the right processes and support people involvement where it is sensible, such as collaborative scheduling, and minimize people involvement where computers can support the process more efficiently than people. This implies that the people or users are the starting point rather than have them and their processes adapt to the technology. Here the difference between most current literature and this research becomes visible. Literature concerning technology improvements, often focuses on one or two dimensions of people, processes and

technology rather than all three, and thus often neglects the user or people part (Liu, Van Nederveen, & Hertogh, 2017). This thesis grounds the planning process problem with a user centric perspective and places people in the forefront. Thus, the system is adapted to the people (users) and their process, but implementation still needs to be validated since no on-site testing in ongoing projects has been done with the VPP-system yet.

### 7.3 USING DESIGN SCIENCE TO ENHANCE EXISTING PROCESSES

The field of construction informatics has been discussed by several researchers and main focus has been to define the field and the areas of research (Isikdag et al., 2009; Merschbrock & Munkvold, 2012; Turk, 2006, 2007). While the focus in construction informatics has been on adoption of BIM and the development of new technology as seen in journals related to the construction informatics field (Merschbrock & Erik Munkvold, 2012), there has been less focus on the particular methods for the design and development of new technology (Xue et al., 2012). A account of all the phases of the development of technology, that are design, build as well as evaluation is scarce in the research field of construction informatics (ibid.). The choice of applying the design science approach (DS) is not often seen in current literature in construction informatics. The use of DS focuses on all aspects of technology development, both the design, build of the artefact as well as the evaluation. The design of technology and tools are often discussed in literature in terms of concepts of tools or system architecture (Xue et al., 2012). Here the people perspective is somewhat missing but could be entered partly through evaluation. The way DS is used to define requirements through the observation and documentation of people and processes further emphasises how these three dimensions can be combined in specifically the design phase, but also informs the evaluation of what should be tested against. Thus, the PPT dimensions are carried along to the validation as well. Therefore, the usage of DS in the field of construction informatics is a contribution in itself. Further, it could be argued that the method is generalisable to a wider context than just construction planning, as the methods used is not specific for construction planning. The use of DS in the sociotechnical approach and the use of people, processes and technology as elements of the analysis in any limited area of application would thus suffice. Thus, this thesis contributes to the field of construction informatics with a documentation, use case and account of the development process of a BIM system supported by the DS methodological approach.

### 7.4 FUTURE WORK

During the planning of the research done in this thesis, there were plans for on-site testing with practitioners. Unfortunately, when the possibility to perform the evaluation occurred, there was not a suitable real-life project to test the BIM system with. Therefore, one of the major future research activity will be to test the VPP system in a real-life project. Further work should be based around testing and validation of the functionality of the scheduling system in the right environment.

Some further development would also be beneficial. At the moment schedules are created zone by zone, with schedules created for each zone. At this level it would also be beneficial to be able to “play” the sequence being planned as this was one approaches that the users in the last workshop used to understand and decide upon the sequence of their work packages. Exporting the schedules to traditional planning software may also be a way forward to reduce the alteration of the process and keep some workflows for the project planner and site manager.



Going forth, a schedule of the schedules, encompassing the full building should be developed in the BIM-system to be able to visualize the full building sequence of the entire building. It would also be beneficial to conduct further observations to compare the use of the collaborative planning-method in different project, especially different types of projects It would be beneficial to see if it is possible to use, and if so how the collaborative planning-method is used in housing projects and possibly even infrastructure projects.



## 8 References

- Adriaanse, A., Voordijk, H., & Dewulf, G. (2010). The use of interorganisational ICT in United States construction projects. *Automation in Construction*, 19(1), 73–83. <https://doi.org/10.1016/j.autcon.2009.09.004>
- Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C., & O'reilly, K. (2011). Technology adoption in the BIM implementation for lean architectural practice. *Automation in Construction*, 20(2), 189–195.
- Baldwin, A., & Bordoli, D. (2014). *Handbook for construction planning and scheduling*. John Wiley & Sons.
- Ballard, G. (2000). *The last planner system of production control*. The University of Birmingham.
- Ballard, G., & Howell, G. (1998). What Kind of Production Is Construction ? *Production*, 13, 15. Retrieved from <http://leanconstruction.org/pdf/BallardAndHowell.pdf>
- Ballard, G., & Howell, G. A. (2003). An update on last planner. In *Proc., 11th Annual Conf., International Group for Lean Construction, Blacksburg, VA*.
- Bergqvist, H., & Sköld, O. (2017). Analys av en issue-collaborator och dess användbarhet i byggbranschen.
- Berlo, L. A. H. M. van, & Natrop, M. (2015). BIM on the construction site: Providing hidden information on task specific drawings. *Journal of Information Technology in Construction (ITcon)*, 20(Special Issue: ECPPM 2014), 10.
- Bhatla, A., & Leite, F. (2012). Integration framework of bim with the last planner systemtm. In *IGLC 2012 - 20th Conference of the International Group for Lean Construction*. Retrieved from <http://www.scopus.com/inward/record.url?eid=2-s2.0-84874473993&partnerID=40&md5=f1d0a3125bc8391cba925390e71e2d1f>
- Birging, E., & Lindfors, N. (2014). *Integration of BIM in the construction phase - A study of a Swedish construction project based on interviews*. Department of Civil- and Environmental Engineering, Construction Management. Chalmers University of Technology, Göteborg.
- Bosch-Sijtsema, P. M., & Tjell, J. (2017). The concept of project space: Studying construction project teams from a spatial perspective. *International Journal of Project Management*.
- Brantitsa, E., & Norberg, R. (2018). *BIM Implementation in the Production Phase of Construction - Site Management Teams' Knowledge, Attitude and Needs*. Chalmers University of Technology.
- Bryde, D., Broquetas, M., & Volm, J. M. (2013). The project benefits of building information modelling (BIM). *International Journal of Project Management*, 31(7), 971–980. <https://doi.org/10.1016/j.ijproman.2012.12.001>
- Bryman, A., & Bell, E. (2011). *Business research methods 3e*. Oxford university press.
- Bröchner, J., Josephson, P.-E., & Kadefors, A. (2002). Swedish construction culture, management and collaborative quality practice. *Building Research & Information*, 30(6), 392–400. <https://doi.org/10.1080/09613210210159866>
- Büchmann-Slorup, R., & Andersson, N. (2010). BIM-based scheduling of Construction—A comparative analysis of prevailing and BIM-based scheduling processes. In *Proc., 27 th*

- Int. Conf. of the CIB W78* (pp. 113–123).
- Böregård, N., & Degerman, C. (2013). *Implementering av Virtual Design and Construction inom husproduktion*.
- Camara Jurado, M. (2012). Visual Planning in Lean Product Development.
- Carlsson, S. A., Henningsson, S., Hrastinski, S., & Keller, C. (2011). Socio-technical IS design science research: developing design theory for IS integration management. *Information Systems and E-Business Management*, 9(1), 109–131. <https://doi.org/10.1007/s10257-010-0140-6>
- Chidamber, S., & Kon, H. (1994). A Research Retrospective of Innovation Inception and Success: The Technology-Push Demand-Pull Question. *International Journal of Technology Management*, 53(9), 1689–1699. <https://doi.org/10.1017/CBO9781107415324.004>
- Chien, K. F., Wu, Z. H., & Huang, S. C. (2014). Identifying and assessing critical risk factors for BIM projects: Empirical study. *Automation in Construction*, 45, 1–15. <https://doi.org/10.1016/j.autcon.2014.04.012>
- Christiansen, F. (2012). *The Planning Process at a Construction Site*. Chalmers University of Technology.
- Dainty, A. R. J., Bryman, A., & Price, A. D. F. (2002). Empowerment within the UK construction sector. *Leadership & Organization Development Journal*, 23(6), 333–342.
- Dalman, C. (2005). *Visuell planering*. Peab AB.
- Daniel, E. I., Pasquire, C., & Dickens, G. (2014). Social perspective of planning in construction: The UK experience. In *30th Annual ARCOM Conference, Portsmouth, UK* (pp. 1355–1365).
- Daniel, E. I., Pasquire, C., & Dickens, G. (2015). Exploring the Implementation of the Last Planner® System Through Iglc Community: Twenty One Years of Experience. In: *ANNUAL CONFERENCE OF THE INTERNATIONAL GROUP FOR LEAN CONSTRUCTION*, (February 2016), 153–162. <https://doi.org/10.13140/RG.2.1.4777.2000>
- Daniel, E. I., Pasquire, C., Dickens, G., & Ballard, G. (2016). The relationship between the Last Planner® System and collaborative planning practice in UK construction. *Engineering, Construction and Architectural Management*, 407–425.
- Dave, B., Koskela, L., Kagioglou, M., & Bertelsen, S. (2008). A critical look at integrating people, process and information systems within the construction sector. *Proceedings for the 16th Annual Conference of the International Group for Lean Construction*, 795–807.
- Davies, R., Crespín-Mazet, F., Linne, A., Pardo, C., Havenvid, M. I., Harty, C., ... Salle, R. (2015). BIM in Europe: innovation networks in the construction sectors of Sweden, France and the UK. In *31st Annual ARCOM Conference, Lincoln, UK* (p. 1135–1144). Lincoln.
- Davies, R., & Harty, C. (2013). Measurement and exploration of individual beliefs about the consequences of building information modelling use. *Construction Management and Economics*, 31(11), 1110–1127. <https://doi.org/10.1080/01446193.2013.848994>
- Dix, A. (2017). Human–computer interaction, foundations and new paradigms. *Journal of Visual Languages and Computing*, 42, 122–134. <https://doi.org/10.1016/j.jvlc.2016.04.001>

- Dix, A., Finlay, J., Abowd, G. D., & Beale, R. (2004). *Human-Computer Interaction* (3rd ed.). UK: Pearson Education Limited.
- Dvir, D., Raz, T., & Shenhar, A. J. (2003). An empirical analysis of the relationship between project planning and project success. *International Journal of Project Management*, 21(2), 89–95.
- Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*. John Wiley & Sons.
- Edwards, J. (2011). A Process View of Knowledge Management : It Ain ' t What you do , it ' s the way That you do it. *Electronic Journal of Knowledge Management*, 9(4), 297–306. <https://doi.org/10.1080/07294360.2015.1011087>
- Faniran, O. O., Oluwoye, J. O., & Lenard, D. (1994). Effective construction planning. *Construction Management and Economics*, 12(6), 485–499.
- Friblick, F., & Olsson, V. (2009). *Planering i byggproduktion*. Sveriges byggindustrier.
- Ghaffarianhoseini, A., Tookey, J., Ghaffarianhoseini, A., Naismith, N., Azhar, S., Efimova, O., & Raahemifar, K. (2017). Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges. *Renewable and Sustainable Energy Reviews*, 75(December 2016), 1046–1053. <https://doi.org/10.1016/j.rser.2016.11.083>
- Gidado, K. (2004). Enhancing the prime contractor's pre-construction planning. *Journal of Construction Research*, 5(01), 87–106.
- Goulding, J. S., & Lou, E. C. W. (2013). E-readiness in construction: an incongruous paradigm of variables. *Architectural Engineering and Design Management*, 9(4), 265–280.
- Gregor, S., & Hevner, A. R. (2013). Positioning and presenting design science research for maximum impact. *MIS Quarterly*, 37(2), 337–355.
- Hansson, B., Olander, S., Landin, A., Aulin, R., Persson, M., & Persson, U. (2017). *Byggedning - Produktion*. Lund: Studentlitteratur AB.
- Hartmann, T., Van Meerveld, H., Vosseveld, N., & Adriaanse, A. (2012). Aligning building information model tools and construction management methods. *Automation in Construction*, 22, 605–613. <https://doi.org/10.1016/j.autcon.2011.12.011>
- Harty, C. (2005). Innovation in construction: A sociology of technology approach. *Building Research and Information*, 33(6), 512–522. <https://doi.org/10.1080/09613210500288605>
- Hevner, A. R. (2007). A Three Cycle View of Design Science Research. *Scandinavian Journal of Information Systems*, 19(2), 87–92. <https://doi.org/http://aisel.aisnet.org/sjis/vol19/iss2/4>
- Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design science in information systems research. *MIS Quarterly*, 28(1), 75–105.
- Howell, G. A. (1999). What is lean construction-1999. In *Proceedings IGLC* (Vol. 7, p. 1). Citeseer.
- Isikdag, U., Underwood, J., Kuruoglu, M., Goulding, J., & Acikalin, U. (2009). Construction informatics in Turkey: Strategic role of ICT and future research directions. *Electronic Journal of Information Technology in Construction*, 14, 412–428.
- Johannesson, P., & Perjons, E. (2014). *An introduction to design science*. Springer.

- Jongeling, R., & Olofsson, T. (2007). A method for planning of work-flow by combined use of location-based scheduling and 4D CAD. *Automation in Construction*, 16(2), 189–198.
- Kang, J. H., Anderson, S. D., & Clayton, M. J. (2007). Empirical study on the merit of web-based 4D visualization in collaborative construction planning and scheduling. *Journal of Construction Engineering and Management*, 133(6), 447–461.
- Karlsson, D. (2009). *Effektivare byggproduktion med virtuellt byggande*. Lunds tekniska högskola. Elektroniska källor.
- Kelsey, J. M., Winch, G. M., & Penn, A. (2001). Understanding the project planning process: requirements capture for the virtual construction site.
- Kenley, R., & Harfield, T. (2014). Location Breakdown Structure (LBS): a solution for construction project management data redundancy. In *Proceedings of the International Conference on Construction in a Changing World* (pp. 4–7).
- Kenley, R., & Seppänen, O. (2006). *Location-based Management System for Construction: Planning, Scheduling and Control*. Routledge.
- Kenley, R., & Seppänen, O. (2009). Location-based management of construction projects: part of a new typology for project scheduling methodologies. In *Winter Simulation Conference* (pp. 2563–2570). Winter Simulation Conference.
- Khanzode, A., Fischer, M., Reed, D., & Ballard, G. (2006). A guide to applying the principles of virtual design & construction (VDC) to the lean project delivery process. *CIFE, Stanford University, Palo Alto, CA*.
- Koo, B., & Fischer, M. (2000). Feasibility study of 4D CAD in commercial construction. *Journal of Construction Engineering and Management*, 126(4), 251–260.
- Koskela, L. (1992). *Application of the new production philosophy to construction*. Stanford university Stanford, CA.
- Koskela, L., Howell, G., Pikas, E., & Dave, B. (2014). If CPM is so bad, why have we been using it so long?
- Kvale, S. (1996). *InterViews: An Introduction to Qualitative Research Interviewing*. *InterViews: An Introduction to Qualitative Research Interviewing*. SAGE Publications.
- Lagos, C. I., Herrera, R. F., & Alarcón, L. F. (2017). Contributions of Information Technologies to Last Planner System implementation. In *Proc. Lean & Computing in Construction Congress (LC3)* (Vol. 1).
- Laufer, A. (1992). A micro view of the project planning process. *Construction Management and Economics*, 10(1), 31–43.
- Laufer, A., & Tucker, R. L. (1988). Competence and timing dilemma in construction planning. *Construction Management and Economics*, 6(4), 339–355.
- Laufer, A., Tucker, R. L., Shapira, A., & Shenhar, A. J. (1994). The multiplicity concept in construction project planning. *Construction Management and Economics*, 12(1), 53–65.
- Liker, J. K. (2005). *The toyota way, 14 management Principles from the world's greatest manufacturer*. Esensi.
- Linderoth, H. (2013). *BIM i byggproduktionen: organisatoriska hinder och drivkrafter*. Centrum för management i byggsektorn (CMB).

- Lindholm, T. (2014). *Lean in Construction Projects: Is lean suitable for all construction projects?*
- Liu, Y., Van Nederveen, S., & Hertogh, M. (2017). Understanding effects of BIM on collaborative design and construction: An empirical study in China. *International Journal of Project Management*, 35(4), 686–698.
- Löfgren, A. (2007). Towards Mobile Lean Communication for Production Management. *Proceedings of CIB-W78, Bringing ICT Knowledge to Work, Maribor, Slovenia*, 541–548.
- Mann, D. (2005). *Creating a lean culture: tools to sustain lean conversions*. CRC Press.
- March, S. T., & Smith, G. F. (1995). Design and natural science research on information technology. *Decision Support Systems*, 15(4), 251–266.
- Merschbrock, C., & Erik Munkvold, B. (2012). A research review on building information modeling in construction-an area ripe for is research. *Communications of the Association for Information Systems*, 31(1), 207–228.
- Nepal, M. P., & Staub-French, S. (2016). Supporting knowledge-intensive construction management tasks in BIM. *Journal of Information Technology in Construction (ITcon)*, 21, 13–38.
- Persson, K. M., & Gårdelöv, L. (2017). *Digitala hjälpmedel i byggproduktionen En studie av programvaran Dalux Field*.
- Persson, M. (2012). *Planering och beredning av bygg-och anläggningsprojekt*. Studentlitteratur.
- Prodan, M., Prodan, A., & Purcarea, A. A. (2015). Three New Dimensions to People, Process, Technology Improvement Model. In *New Contributions in Information Systems and Technologies* (pp. 481–490). Springer.
- Sackey, E., Tuuli, M., & Dainty, A. (2014). Sociotechnical systems approach to BIM implementation in a multidisciplinary construction context. *Journal of Management in Engineering*, 31(1), A4014005.
- 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, 172–187.
- Simon, H. A. (1996). *The sciences of the artificial, (third edition)*. *Computers & Mathematics with Applications* (3rd ed., Vol. 33). MIT press. [https://doi.org/10.1016/S0898-1221\(97\)82941-0](https://doi.org/10.1016/S0898-1221(97)82941-0)
- Simonsen, R. (2007). *Et ledelseskoncept i politiske arenaer-Lean Construction i dansk byggeri*. Technical University of Denmark Danmarks Tekniske Universitet, Department of Civil Engineering Institut for Byggeri og Anlæg, Section for Planning and Management of Building Processes Sektionen for Planlægning og Ledelse af Byggeprocesser.
- Styhre, A., & Josephson, P. (2006). Revisiting site manager work: stuck in the middle? *Construction Management and Economics*, 24(5), 521–528.
- Succar, B., & Kassem, M. (2015). Macro-BIM adoption: Conceptual structures. *Automation in Construction*, 57, 64–79. <https://doi.org/10.1016/j.autcon.2015.04.018>
- Sunke, N. (2009). Planning of construction projects: a managerial approach. *A PhD Thesis, University of Siegen, German*.

- Svalestuen, F., Knotten, V., & Laedre, O. (2017). Using Building Information Model (Bim) Devices To Improve Information Flow and Collaboration on Construction Sites. *Journal of Information Technology in Construction (ITcon)*, 22(22), 204–219. Retrieved from <http://www.itcon.org/2017/11>
- Tezel, B. A., Koskela, L. J., & Tzortzopoulos, P. (2009). Visual management—A general overview.
- Tjell, J. (2016). *The constructed space of a construction design team*. Chalmers University of Technology.
- Tulenheimo, R. (2015). Challenges of Implementing New Technologies in the World of BIM – Case Study from Construction Engineering Industry in Finland. *Procedia Economics and Finance*, 21(Henttinen 2012), 469–477. [https://doi.org/10.1016/S2212-5671\(15\)00201-4](https://doi.org/10.1016/S2212-5671(15)00201-4)
- Turk, Ž. (2006). Construction informatics: Definition and ontology. *Advanced Engineering Informatics*, 20(2), 187–199. <https://doi.org/https://doi.org/10.1016/j.aei.2005.10.002>
- Turk, Ž. (2007). Construction Informatics in European Research: Topics and Agendas. *Journal of Computing in Civil Engineering*, 21(3), 211–219. [https://doi.org/10.1061/\(ASCE\)0887-3801\(2007\)21:3\(211\)](https://doi.org/10.1061/(ASCE)0887-3801(2007)21:3(211))
- Urbina Velasco, A. (2013). Assessment of 4D BIM applications for project management functions.
- Van Berlo, L. A. H. M., & Natrop, M. (2015). BIM on the construction site: Providing hidden information on task specific drawings. *Journal of Information Technology in Construction*, 20(November 2014), 97–106. Retrieved from <http://www.scopus.com/inward/record.url?eid=2-s2.0-84921685621&partnerID=tZOtx3y1>
- Verheij, H., & Augenbroe, G. (2006). Collaborative planning of AEC projects and partnerships. *Automation in Construction*, 15(4), 428–437. <https://doi.org/10.1016/j.autcon.2005.06.011>
- Viklund Tallgren, M., Roupé, M., & Johansson, M. (2015). An empowered collaborative planning method in a Swedish construction company - A case study. In *31st annual ARCOM Conference* (pp. 793–802). Association of Researchers in Construction Management.
- Waly, A. F., & Thabet, W. Y. (2003). A virtual construction environment for preconstruction planning. *Automation in Construction*, 12(2), 139–154.
- Weldu, Y. W., & Knapp, G. M. (2012). Automated generation of 4D building information models through spatial reasoning. In *Construction Research Congress 2012: Construction Challenges in a Flat World, Proceedings of the 2012 Construction Research Congress* (pp. 612–621). Retrieved from <http://www.scopus.com/inward/record.url?eid=2-s2.0-84866241826&partnerID=40&md5=fba9fd011231164d3e0001ef4c18972f>
- Winch, G. M. (2010). *Managing construction projects*. John Wiley & Sons.
- Winch, G. M., & Kelsey, J. (2005). What do construction project planners do? *International Journal of Project Management*, 23(2), 141–149.
- Xue, X., Shen, Q., Fan, H., Li, H., & Fan, S. (2012). IT supported collaborative work in A/E/C projects: A ten-year review. *Automation in Construction*, 21, 1–9.