CHALMERS
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Planning for Efficiency at Karlatornet

Master's Thesis in the Master's Programme Design and Construction Project Management

Oskar Andersson
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Karlatornet at Lindholmen, Gothenburg, (http://www.serneke.se/projekt/karlatornet/)
Department of Architecture and Civil Engineering, Göteborg, Sweden, 2017

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ABSTRACT

Construction of high-rise constructions has during past decades seen an incremental increase, which is now also evident in the Swedish market with the forthcoming construction of Karlatornet at Lindholmen in Gothenburg. When constructing high-rise constructions new constraints are imposed, connected to height and limited space at each floor, which calls for planning methods adapted for the challenges that emerges. However, present planning methods do not contribute sufficiently to value adding processes in regards to both production and logistics. Thereby, this master's thesis has been conducted to investigate how Lean Construction (LC) and Building Information Modeling (BIM) should be incorporated when planning for production and logistics, and further how to synchronise production and logistics at Karlatornet to attain a higher efficiency.

Research on LC and BIM is widespread, however commonly separated. This thesis aims to contribute in closing the gap between LC and BIM research in high-rise constructions. Further, the thesis intent to provide underlying barriers from both a theoretical and practical view to evaluate why implementation is lingering. In order to answer the research questions of this thesis, a qualitative research methodology was chosen, including a literature review followed by interviews from the industry regarding different planning methods. Focus has been directed towards planning methods within LC and how these can be combined with BIM, where Location-based Scheduling (LBS) and Location-based Management System (LBMS) has been applied to production. In regards to logistics, focus has been aimed towards Just In Time (JIT) which together with the LBS results in Location-based Planning (LBP).

It has been concluded that to incorporate LBP in the production planning at Karlatornet, focus must first and foremost be shifted towards creating organisational and technical alignment within the own organisation. This will in turn provide means for creating further alignment throughout the production chain. JIT should be incorporated in logistics planning to support production, as failure can lead to downtime and obstruction for production resulting in major costs. Therefore, risk is entailed due to the repetitive characteristics of high-rise construction, which can be found at Karlatornet, where the whole production chain can be affected. There is much to do regarding synchronised planning for production and logistics at Karlatornet. Alignment is yet to be reached within the perspectives separately, giving that it cannot be reached when combined. Workshops and meetings are required to create systems which can be used from subcontractor to supplier in all parts of construction.

Key words: Lean construction, High-rise construction, Push and pull, Location-based planning, Just in time, 4D BIM, and Virtual design and construction.

Planering för Effektiva Bygg- och Logistikprocesser vid Karlatornet

Examensarbete inom masterprogrammet Design and Construction Project Management

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SAMMANFATTNING

Byggnation av höga konstruktioner har under de senaste decennierna sett en successiv ökning, en trend som även den svenska marknaden blivit influerad av. Detta kan konkretiseras med den kommande byggnationen av Karlatornet på Lindholmen i Göteborg. Uppförandet av höga konstruktioner innebär nya utmaningar, kopplade till höjden på byggnaden och begränsad yta på varje våningsplan, därav måste planeringsmetoderna som används vara anpassade för att möta dessa utmaningar. Nuvarande planeringsmetoder bidrar emellertid inte i tillräcklig utsträckning till värdeskapande processer för produktion och logistik. Detta examensarbete har således genomförts för att undersöka hur Lean Construction (LC) och Building Information Modeling (BIM) kan implementeras vid planering av produktion och logistik. Vidare har arbetet undersökt hur synkronisering av produktion och logistik vid Karlatornet bör utföras för att uppnå en högre effektivitet.

Forskning om LC och BIM är vidsträckt men generellt sett separerad där detta examensarbete syftar till att minska klyftan mellan LC och BIM-forskning relaterat till höga konstruktioner. Arbetet avser även att påvisa barriärer ur både en teoretisk och praktisk syn för att utvärdera varför implementation i branschen varit långdragen. För att kunna ge svar på arbetets frågeställningar valdes en kvalitativ forskningsmetod, vilken inkluderade en litteraturgenomgång följt av intervjuer med representanter från branschen gällande olika planeringsmetoder. Fokus har riktats mot planeringsmetoder som ingår i LC och hur dessa kan kombineras med BIM, där Location-Based Scheduling (LBS) och Location-Based Management System (LBMS) har tillämpats på produktion. När det gäller logistik har JIT legat i fokus som tillsammans med LBS resulterar i Location-based Planning (LBP).

För att implementera LBP i produktionsplaneringen vid Karlatornet har arbetet konstaterat att fokus först och främst måste riktas mot att skapa en gemensam inriktning inom den egna organisationen. Detta för att skapa ytterligare förutsättningar för en projektövergripande tydlighet som inkluderar samtliga parter i kedjan. JIT bör implementeras i logistikplaneringen eftersom förseningar i produktionscyklerna kan leda till driftstopp och hinder för produktionen som medför stora kostnader. Mängden repetitiva arbeten vid höga konstruktioner, vilka kan härledas till Karlatornet, medför därför risker eftersom hela produktionskedjan påverkas. Det finns mycket att göra för att uppnå en synkroniserad planering för produktion och logistik vid Karlatornet. En gemensam inriktning är ännu inte uppnådd i varken produktion eller logistik, vilket ger att en gemensam inriktning inte heller kan nås när de kombineras.

Nyckelord: Lean construction, High-rise construction, Push and pull, Location-based planning, Just in time, 4D BIM, samt Virtual design and construction.

Contents

Preface

This master's thesis has been conducted at the Division of Construction Management at the Department Architecture and Civil Engineering at Chalmers University of Technology as a part of the M.Sc. Programme of Design and Construction Project Management of 120 ECTS. The study was performed during the spring semester from January to June 2017 and extends 30 ECTS. The case-study was carried out at the construction department at Serneke Group, where the work has benefitted from contribution from several persons that deserve acknowledgement.

We would first and foremost like to thank Christian Koch, Professor at Chalmers University of Technology, for inputs, ideas, and feedback during the course of this master's thesis. It has been of high value for the outcome of our work and thereby we would like to thank you for both your time and enthusiasm throughout the process. We would also like to thank Davor Sinik and Conny Segerdahl for giving us the opportunity to conduct our master's thesis at Karlatornet, and providing supervision during the process. Your time and knowledge input has been of high value both for us and the outcome of the thesis. Finally, we would like direct a great thanks to all participating interviewees for your willingness to allocate time and knowledge together with information and perceptions of the case with us. Your contribution has enabled us to conduct this master's thesis.

This master's thesis constitutes the final part of our education at Chalmers University of Technology. During the course of the thesis, we have gained extensive knowledge regarding complexities connected to construction and logistics planning that we will benefit greatly from in the future, as well as knowledge specifically connected to planning high-rise construction projects. Lastly, thank you to all involved in this master's thesis.

Göteborg, May 2017

Oskar Andersson
Simon Månsson

Notations

AB 04	Allmänna Bestämmelser för Utförandeentreprenader
ABT06	Allmänna Bestämmelser för Totalentreprenader
BIM	Building Information Modeling / Building Information Model
CPM	Critical Path Method
IGLC	International Group for Lean Construction
JIT	Just In Time
LBMS	Location-based Management System
LBP	Location-based Planning
LBS	Location-based Scheduling
LOB	Line of Balance
LPS	Last Planner System
VDC	Virtual Design and Construction
WBS	Work Breakdown Structure

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1 Introduction

Inefficiencies in construction have been highlighted in various research publications, stressing that present methods of planning do not contribute to value-adding processes during production (Barbosa et al., 2017, Josephson and Saukkoriipi, 2005). There are several reasons for these shortcomings, where literature points out one of them to be a mislead focus of trying to improve or refine current methods and techniques, rather than seeking for new solutions (Christiansen, 2012). Regarding planning, this includes incorporating float within and between activities, neglecting to recognise a collective approach, and software and systems which are difficult to synchronise (Lowe et al., 2012). Drawing upon research from the International Group of Lean Construction (IGLC), a trend towards planning more comprehensively through incorporating Lean Construction (LC) aspects with Building Information Modeling (BIM) can be found. Thereby, current practise is suggested to transform into integrated Virtual Design and Construction (VDC) systems, providing a new approach to planning and executing construction projects. These systems combine software and management systems to achieve improved visualisation, integration and automation. The trend can also be seen to improve focus towards solving problems during design and planning, and thus decrease errors and non-value adding activities at the construction sites.

Planning for efficiency can thus be found a continuously actual topic for research, with Barbosa et al. (2017) stating that the industry is in need of a revolution to catch up, as it currently is stagnating in efficiency. Specifically for high-rise construction, where production is highly repetitive, efficiency faces extensive risks in carrying out non-value adding activities repeatedly (Russell et al., 2009). In addition, the amount of high-rise constructions that are being constructed worldwide is incremental, giving that the total effect of inefficiencies increases with it (Kayvani, 2014). This further implies that the importance of planning consequently increases when constructing high-rise constructions, resulting in that there are great means for improvements.

1.1 Background

LC has been promoted since clear benefits were shown from implementing lean production in the manufacturing industry (Bertelsen and Koskela, 2004, Womack et al., 1990). It has gained governmental support from various countries where Egan (1998) explicitly presses the issue of enhancing efficiency through LC. The Swedish equivalent Gustavsson and Rupprecht Hjort (2009) support increased efficiency as it was deemed too low throughout the industry in Sweden. As late as in February 2017, McKinsey delivered a report stating that a revolution is required for the construction industry to change and become effective in its execution (Barbosa et al., 2017). Here, productivity was specifically evaluated, showing that Sweden was one of the countries where stagnation was most intrusive. However, it also showed that Sweden is one of the most prominent countries considering moving time spent from the production phase to the design phase to minimise non-value adding activities during production in advance. Parameters such as regulations, contract forms, supply chain management, improved on-site execution and increased use of technology were brought to surface as tools for change, giving that increased use of LC is vital.

LC places focus on improving both production and logistics, striving towards increasing pull based mechanisms for production to achieve better workflow and efficiency (Koskela, 1997). To focus on performing the right activity at the right time through delivering the right goods to the right place at the right time is pressed to minimise uncertainty, and thus facilitate efficient production. Several tools have been presented in LC research that could improve efficiency and facilitate both production and logistics. Location-based Scheduling (LBS) was introduced to enhance forecasting and achieve a location-based, rather than a conventional activity based, focus (Dave et al., 2016). It points out the importance of managing locations, in which the activities are to be performed, in order to evaluate activities in relation to each other. Location-based Management System (LBMS) is a system, which further embraces engaging in a social process of planning, promoting a collaborative planning process to reduce uncertainty, and decrease non-value adding activities. The location-based focus further highlights that increased efforts need to be aimed towards logistical issues in order to achieve adequate production efficiency, where Just In Time (JIT) is a frequently used LC tool (Seppänen and Peltokorpi, 2016). Moreover, issues related to logistics can result in substantial costs and obstruction of production workflow, giving incentives for increased focus on synchronising the two perspectives (Hulthén et al., 2015, Pérez et al., 2016). Hence, when constructing a high-rise building with limited space and time, synchronising production and logistics planning becomes vital, as both are highly dependent on each other (Lange and Schilling, 2015). It is thereby suggested that LBS and JIT, integrated, can provide substantial benefits in both production and logistical planning processes, resulting in Location-based Planning (LBP) (Seppänen and Peltokorpi, 2016).

Furthermore, moving towards LBP generates arguments for implementation of VDC, as it imposes combinations of software and systems to achieve integration and automation (Andersson et al., 2016). Building Information Modeling (BIM), is an important tool as it encompasses modelling the construction before production begins, while also enabling for enhanced production and logistics systems. Simultaneously, it provides means for efficiently plan in locations rather than only activities (Seppänen and Peltokorpi, 2016). They further argue that the construction industry would benefit from planning with BIM as it would provide means for increased efficiency, by connecting scheduling to the model and thus achieve 4D BIM. Yalcinkaya and Singh (2015) stress that there are deficiencies in research, as even though implementation practises of BIM was one of the most researched area out of 975 articles reviewed, only 9 of them were directly connected to what can be learnt from practical implementation. However, this area of research is argued to increase, which also can be seen with research topics connected to interoperability and standards in research between 2009 and 2014 (Yalcinkaya and Singh, 2015). The lack of practical reflections results in that there is no general method for implementation throughout the industry, but instead implementation varies between countries and companies, where each project utilises it differently (Gu and London, 2010, Lin et al., 2016). This can further be connected to developing VDC systems, which utilises different software and systems (Andersson et al., 2016).

Moreover, the thesis builds on previous research such as Sacks et al. (2009) where the interaction of LC and BIM is evaluated with addition on separate research from Seppänen et al. (2015) who elaborate on effects of implementation of LBS and LBMS, Seppänen and Peltokorpi (2016) who incorporate LBMS in BIM to create 4D BIM, and Bortolini et al. (2015) who apply 4D BIM to site logistics. This is further applied to high-rise construction, where a continuous workflow through phase scheduling is aimed for to create incremental effects (Russell et al., 2009, Seppänen et al., 2015). As both LC and BIM strive to produce only value adding processes, there is an alignment, which according to theory should raise efficiency and reduce production time through faster production cycles and increased visualisation. Although, it is important to note that understanding is key, as the tools of LC and BIM are merely means for the humans using them. Further, combining software and systems to create automation, and thus

1.2 Objectives

Research on LC and BIM is widespread, however commonly separated (Yalcinkaya and Singh, 2015). Both perspectives provide advantages to change the entire construction industry, and although the use of them is increasing, implementation in construction remains limited (Dave et al., 2016, Toledo et al., 2016). The objective of this thesis is therefore to contribute in closing the gap between LC and BIM research directed towards planning to present a VDC system for planning and synchronising production with logistics in high-rise constructions, as these are prominently used separately. Further, the thesis intends to provide underlying barriers from both a theoretical and practical view to evaluate why implementation is lingering.

1.3 Research questions

To concretise the objective, it can be broken down into three research questions applied to lean high-rise construction, namely:

- How should LBP be incorporated in production planning at Karlatornet?
- How should JIT be incorporated in logistics planning at Karlatornet?
- How should production and logistics planning be synchronised at Karlatornet?

1.4 Delimitations

The scope of the thesis is delimited to planning and scheduling of production and logistics through combining software and systems, based in LC, on high-rise constructions. Planning and scheduling is limited to the segment between design and production. Research question one and two specifically investigates how LBP and JIT can be incorporated to form a foundation for planning, while the third question investigates how to synchronise them. Only high-rise construction is evaluated as the thesis consist of one specific case study, Karlatornet, which is going to be constructed in Gothenburg, Sweden. This does however not exclude the conclusions and suggested methods from being used in other type of projects. The thesis further strives to investigate how goods are managed to be utilised at the construction site from suppliers to subcontractors, and does therefore not include producing goods or managing wastes created on the site. Instead, a focus of continuous value addition is implied to shine light on efficiency.

1.5 Thesis outline

The thesis is divided into 6 chapters, structured to give the reader insight to all the steps taken during the thesis, while also following the research design. The chapters are presented in the following order, containing the following:

Chapter 1 – *Introduction,* states the context within which the research has been conducted, introducing the subject and presenting the background. It also contains the objective, as well as a formulation of the research questions and the delimitations.

Chapter 2 – *Research Methodology,* covers the approach that has been used to gather information and achieve the objective of the thesis. The chapter presents the chosen research design, and method, together with the course of action when searching for literature and collection of data from empirical studies. It also entails a description of how ethical conduct and trustworthiness has been managed.

Chapter 3 – *Theoretical Framework,* provides the necessary knowledge as a foundation on which results, analysis, and conclusion has been developed. It is divided into three sections presenting current literature and research. The first section provides information on planning for production, the second is about planning for logistics, and the third and final concerns the synchronisation between production and logistics planning. In the end of the chapter, a theoretical summary is provided.

Chapter 4 – *Empirical Findings,* aims to interpret the information retrieved from interviews and data collection. The chapter follows a similar structure as presented in the theoretical framework, commencing with planning for production, followed by planning for logistics and finishing with synchronising production and logistics planning.

Chapter 5 – *Discussion*, contains the discussion which arises through synthesising the empirical findings and the theoretical framework. Thus, the research questions are investigated through both perspectives to provide suggestions on how to proceed with planning for achieving efficiency at Karlatornet.

Chapter 6 – *Conclusions*, presents the concluding remarks about each research question specifically, in summarised form. This chapter aims to give clarity on which questions that Serneke needs to work with while also acknowledging what is in line with the suggestions from the discussion.

2 Research Methodology

This chapter provides insight on the thesis methodology, which was developed to enable answering the research questions. It contains of the sections *Research design, Literature research, Ethical conduct, Data collection and analysis, and Trustworthiness*, aiming to describe how research was conducted for both the Theoretical framework and the Empirical findings and why specific methods were chosen. The chapter additionally discusses how validity was ensured during research, and how bias was avoided. Both authors contributed to all segments of this thesis, making it an even division of work.

2.1 Research design

Research was elaborated through an iterative process concerning both theoretical and empirical aspects, hence an abductive research strategy was chosen. The abductive strategy differs from inductive and deductive as it considers a combination of both empirical and theoretical findings, reinterpreting them as the research proceeds (Alvesson et al., 2011). Given the iterative process, new questions were expected to arise as research progressed resulting in changes in the theoretical framework, which the abductive strategy is supposed to manage better than deductive and inductive. This is supported by Dubois and Gadde (2014) who claim that the abductive strategy is suitable in research where there is a continuous interplay between theory and empirical findings. Suddaby (2006) further explains that the abductive strategy differs from induction and deduction as it implies reflection on the subject in order to provide new reasoning, an approach that was desired. Neither deductive or inductive strategy was therefore assessed to suit the objectives, as interpolating answers to the research questions through continuously balancing theory with empirical findings was deemed necessary in finding alignment for the specific case and existing research. Thus, an abductive strategy was to enable for making adjustments applicable for Serneke, specifically at Karlatornet.

As the objectives of the thesis were to investigate how production and logistics should be planned, and further how these should be synchronised, interviews were conducted with interviewees from both academia and practise. These were chosen based on both the interviewees own initiatives, due to their connection to research or the studied case project, and recommendations from connections and other interviewees. Due to having interviews as primary method for data collection, a qualitative research method was developed due to putting emphasis on words rather than numbers (Bryman and Bell, 2015). Moreover, qualitative method focuses on the importance of understanding a context, enabling for interpretations and development of new reasoning, which was assessed suitable for answering the research questions. Simultaneously, it is preferable for research of prescriptive and explanatory character, which were chosen due to the objectives of guiding the organisation in how to plan and synchronise production and logistics, and exploring new findings as well as barriers.

Moreover, the thesis was conducted as a single-case study, which is the research method that conforms to the qualitative method, as it according to Bryman and Bell (2015) enables for extensive and detailed data collection. However, conducting a single-case study brings the disadvantage of not being able to generalise findings. Conducting multiple case studies would have enabled for broader generalisations, as project specific findings could have been identified. However, as the time was limited, a single-case study was preferred due to providing the ability of performing an in-depth data collection. A multiple case study, in comparison, would have led to more shallow data collection and thus weaker answers to the research questions. In addition, connections could only grant access to information about the specific case study, Karlatornet, as comparable projects were few and widely spread across the country. Resulting in barriers both in accessing information and having substantial distance to similar projects.

2.2 Literature research

Before and parallel to the single case study, literature research was conducted to provide a theoretical framework giving the case findings a contextual meaning (Dubois and Gadde, 2014). In order to provide up to date literature research, conference papers from IGLC formed a base for further findings. Other sources for literature were scientific articles and books, found by both own searches and recommendations from interviewees. Specifically, the databases Scopus, Summon from Chalmers Library and Google Scholar were used to find complementary research. The search words used to find relevant articles include “Lean Construction”, “Location-based Management System”, “Location-based Scheduling”, “BIM Planning”, “BIM Execution Plan”, “Just In Time”, and “Virtual Design and Construction”. The relevance of the articles was estimated with regards to number of citations, number of hits for the specific search word, and actuality. The search words were also combined, both as whole and in parts, resulting in higher specificity in the searches.

In order to obtain sufficient and applicable literature during the course of research, a three-phase iterative structure was developed for the literature research. These correspond with the main steps, shown in Figure 1, of a qualitative research method (Bryman and Bell, 2015, p. 395). The first phase was conducted to obtain broad knowledge on the subject, needed to define general research questions and select relevant subjects, while the process of interpretation and conceptualisation of data also was initiated. In addition, this phase was used as a foundation for developing the initial interview questions. The second research phase was designed to collect relevant data, interpret it, conceptualise it, and create a theoretical framework. Having done so, interpolation was conducted to comprehensively compare the findings. During the phase, the research questions were further specified which enabled for collection of increasingly specified data. This phase also correlated to the development of interview questions, as these further were refined to correspond to the research questions. Finally, the third phase of the literature research was conducted to, in depth, determine the findings and draw up conclusions. Compared to the main steps described by Bryman and Bell (2015, p. 395) findings were continuously written up and revised as the iterations progressed. Dividing it into three phases rather than six steps as shown in Figure 1, was done to effectively systematically combine theory with empirical findings and have an aligned structure between them.

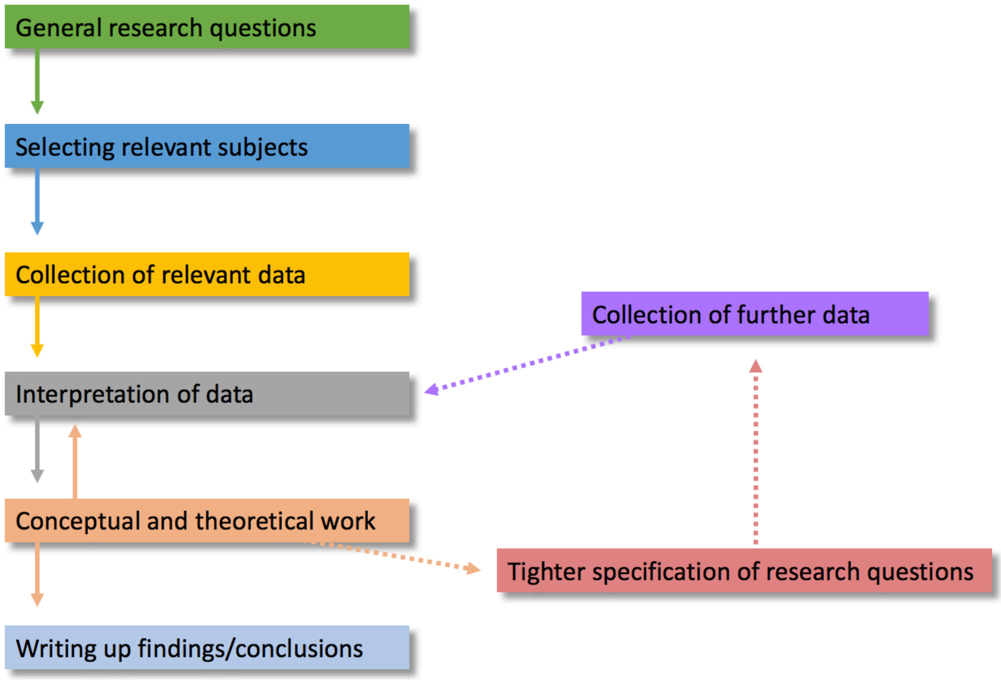


Figure 1 - The main steps of qualitative research, adapted from Bryman and Bell (2015, p. 395).

To acquire knowledge regarding the researched methods, world-wide literature was investigated. This was considered applicable, as documentation of Swedish implementation was found limited. Thereby, literature was interpreted and applied to the Swedish construction industry's point of view, as differences between national industries and companies does occasionally occur.

2.3 Ethical conduct

To ensure that research was ethically conducted, all interviewees were briefed regarding the scope of the thesis prior to each interview. An example of the brief that was sent to the interviewees can be found in Appendix A. Further information concerning the selection of interviewees invited to participate in the research, together with information on their respective contribution, was presented for each interviewee. It was also clarified that interview participation was voluntary, and that only their current position would be presented to give anonymity in the thesis regarding their answers and perceptions. This method was chosen in order for interviewees to elaborate and speak freely during the interviews. Positions of all participants are presented in Appendix B, together with a brief explanation of their insight to the project, working experience, and general background. Moreover, interviewees were asked if recordings of the interview could be conducted, where the unanimous answer was yes, which is perceived to increase the transparency of the interviews.

2.4 Data collection and analysis

The company Serneke was chosen due to three main reasons; they are going to construct the tallest building in Scandinavia, they are a young company with specific focus on efficiency, and they provided a possibility for further collaboration after previous commitments. Serneke was founded in 2002 by the current CEO, Ola Serneke, and Andreas Fagerberg where the latter chose to depart from the company in 2007 (Serneke, 2017). A core value in the company is to continuously encourage and strive for efficiency, and they aim to work as visionaries in the industry. The single case study is conducted on the project Karlatornet, which is a 72-storey building that is going to be constructed at Lindholmen, Gothenburg, in the coming years, estimated to commence in 2017. A high technical standard was aimed in the design phase, where BIM was to be used progressively in comparison to common practise in Sweden. The objective was to impose extensive use in both the planning and production phase. The company have set an aim to continue in this direction and were therefore interested in front-edge planning for both production and logistics, and further synchronisation between the perspectives, which made them aligned with the objectives of the thesis.

Data collection was conducted mainly through semi-structured interviews which were systematically combined with the theoretical framework throughout the process. Defining where theory and empirical findings correlated and were differentiated formed the foundation, on which conclusions could be drawn. This further corresponds to how an abductive research should be performed, described by Dubois and Gadde (2014). The semi-structured interviews were held with a progressive pattern, to continuously interpolate data. Initially, interviewees from academia were interviewed to provide direction on recent research, whereas interviewees from practise were interviewed in a sequence chosen to efficiently group arguments. The answers from the interviews were continuously interpreted and analysed by making comparisons between both different interviews and theory. When the empirical findings were considered to be complete, additional control interviews were held to ensure validity. In total, 15 interviews were held with interviewees both within and outside of Serneke's organisation to avoid bias. The duration of the interviews differed from 60 to 90 minutes. Complementary, Skype was used for two interviews due to restricted possibility of physical meetings. For each interview, an interview form, Appendix C, was used to give structure and ensure relevance.

An iterative process was used for the interviews. During the first phase, interviewees were chosen based on ability to provide guidance and assure scientific contribution. In the second phase, interviewees were directly connected or complementary to the studied case project. Finally, in the third phase, interviewees were chosen to control the outcomes both scientifically and practically. In regards to this, phase one consisted of interviewees from academia, phase two from practice whereas a mix was aimed for in phase three. Interviewees were also chosen by three attributes namely; experience from LC in regards to both science and practice regarding both production and logistics, connection to the case study Karlatornet and connection to comparable projects. Further, this iterative approach was used, as it entails the possibility of both creating an explorative approach and continuously imply control, while providing that analysis is incorporated throughout the process.

Interviews were held in three stages, commencing with stage 1 where the interviewees were briefed with formal information about the thesis together with information on the objective of the specific interview. Each interviewee was prompted to apply the questions to their area of expertise to provide relatable examples, connected to their respective competence. Stage 1 also included short presentations of the interviewers and their respective roles for the specific interview, which varied between the different interviews. The following stage 2 constituted the main part of the interview, where the interview forms were used as guidance. In this stage, the interviewees provided their views on the questions and were steered into discussions connected to the subject and relevant to their expertise. Finally, the interviewees were asked to summarise their perception of the discussed matters to avoid possible misunderstandings.

2.5 Trustworthiness

One of the difficulties of working with a qualitative method concerns bias from the authors (Bryman and Bell, 2015). Qualitative research does however provide a self-correcting function in its iterative form, where the researcher is able to pose additional questions during the interviews and review the work continuously (Morse et al., 2002). By doing so, conformity can be reached to deepen the understanding. As Alvesson et al. (2011) argue, it can also become a risk to work in this manner due to that underlying cultural values differ at different locations. Interviews were carried out in two different countries, which opens up for differing interpretations because of having different cultures and regulations. Although, Dubois and Gadde (2014) state that by systematically combining theory and data collection, a nonlinear process is created which implies objectivity. This should result in that empirical findings eventually matches reality, through interpolation. Therefore, iterative processes were used for both literature review and interviews in order to achieve an objective standpoint, and furthermore increase trustworthiness in this qualitative study.

Developing an early connection with the participating organisation could further provide means for deeper commitment and trustworthy data collection (Shenton, 2004). Thereby, extended engagement between the investigator and the participants contributes to establishing a relationship based on trust between the parties, and thus more elaborated answers leading to enhanced information supply. As previous collaboration with the company had been performed, a good relationship was already developed before initiating the thesis. This enabled for a well-developed commitment from all involved parties. It was however recognised that previous commitments may result in increased positivism, which was managed through triangulation of interviewees. Merriam and Tisdell (2015) describes that triangulation increases trustworthiness of data collection, where interviewees from different organisations both connected and disconnected to the project can be chosen to decrease positivism.

Participation in the investigation was held voluntary to ensure that only genuinely interested participants were included (Merriam and Tisdell, 2015, Shenton, 2004). However, an already established interest in the subject may imply a risk as preconceptions can exist. Although, as all of the respondents chose to participate, nuancing was maximised. Furthermore, participants were informed prior to each interview that no right answers to the questions existed. This corresponds with the tactics to ensure honesty presented by Merriam and Tisdell (2015) and helped to ensure well elaborated and personal answers to the questions. During interviews, an iterative structure was present, where the final stage of the interview was used to return to previous discussed matters of the interview in order to detect perceptions and possible contradictions from the interview.

3 Theoretical Framework

This chapter presents a theoretical framework on the research questions, provided to give insight on software and systems used for planning high-rise constructions. The chapter is divided into four sections, commencing with *Planning for production* which includes *Push and pull in production, Flow through activities or locations, Location-based planning, BIM for production,* and *Coordinating production.* The second section is called *Planning for logistics* and contains *Push and pull in logistics, Supply logistics, Just in time, BIM for logistics* and *Coordinating logistics.* The third section is named *Synchronising production and logistics planning* and includes *Push and pull, Integrating LBP and JIT, Virtual design and construction,* and *Coordination.* The fourth and final section is called *Theoretical summary* and contains a summary of the essential aspects of the investigated theory.

3.1 Planning for production

Planning in the construction industry is generally associated with uncertainty and risks, which in turn hinders efficiency in production (Daniel et al., 2014). Hence, developing an effective plan with minimised risk is ultimately the goal of present planning methods. Moving from activity-based planning to LBP is considered to provide more comprehensive planning, as activities are related to each other to detect clashes and minimise float within and between activities (Christiansen, 2012, Seppänen et al., 2010). Furthermore, Gledson and Greenwood (2014) argues that conventional activity-based planning relies merely on experience of the individual planner where the plan originates from a set sequence of activities, not recognising the importance of managing the locations in which these are going to be performed. LBP does however consider the importance of location-based aspects, identifying the fact that locations link activities together which highlights collaboration between different parties.

To minimise float within and between activities, and thus achieve increased pull for production, visualisation must be improved (Murguía et al., 2016). For all participants to fully understand the importance of increasing pull requires increased commitment, and that collaboration between parties working close to each other is high. Korb and Sacks (2016) also address the importance of committed participants, as the construction industry is generally associated by each participant trying to maximise their own profits resulting in decreased overall production efficiency. Implementing a BIM-based planning tool will according to Büchmann-Slorup and Andersson (2010) ensure sufficient information flow along with increased visualisation and communication possibilities. Thereby, BIM is thought to have potential for enabling an efficient planning process that will facilitate increased pull for production.

Planning is conventionally conducted in two phases where the responsible party, usually the main contractor, produces a master schedule (Lange and Schilling, 2015). After this, each subcontractor plan their work to match the times that are set in the master schedule in the second phase. In this scenario, the plan of each subcontractor respectively is not related to each other, but rather create a long line of activities when combined by the contractor. The master schedule is thus only revised by the contractor, neglecting to include those who perform the activities resulting in subcontractors being pushed to perform accordingly. Planning should according to Seppänen et al. (2015) be conducted collective, implying that those who perform the work can provide input and further relate activities to each other. By doing so, float is minimised within and between activities. LBS is thought to promote this approach as focuses on planning specific locations where the work conducted by the different subcontractors are interrelated and thus aims to minimise float (Lowe et al., 2012). Thus, activities are rather pulled to specific locations when they are needed instead of being pushed by the master schedule. This further results in that information is put into the plan when uncertainty is minimised to a greater extent, as those who have the best competence on when to perform a specific task are those who are going to do it.

3.1.1 Push and pull in production

Planning conventionally implies extensive push for production, as the master schedule is used to schedule deliveries which production must cope with, to avoid having materials obstructing production (Kalsaas et al., 2015). Subcontractors rarely get the opportunity to give input on the master schedule, resulting in that they are pushed to perform certain tasks at certain times (Dallasega et al., 2016). However, as a delivery schedule is set, it can be argued to pull production giving that logistics is superior to production. Pull for production focuses on carrying out the right activity at the right time, providing that deliveries should be coordinated to when production is ready for them to avoid obstruction. According to Ballard (2000), the traditional Critical Path Method (CPM) only releases information or goods based on preassigned dates, neglecting to recognise the actual demand for production. By finding the critical line of activities before commencing production, the demand of production is set in advance rather than being evaluated continuously, and thus providing less opportunity for production to pull information or goods. Increased pull on the other hand aims to pull information from the production teams in order to minimise float, which conventionally is incorporated in master schedule to reduce risk (Kalsaas et al., 2015). It is thereby characterised by production pushing information to logistics in order to avoid obstruction, enabling for enhanced workflow compared to the pushing production with a master schedule. When pull is increased for production, actual demand at site is evaluated instead of relying on estimations made. Uncertainty is thus decreased, as accuracy can be improved as illustrated in Figure 2. According to Kalsaas et al. (2015), increased pull for production should result in more flexibility, higher delivery reliability, and higher production quality, as well as decreased variation of demand and changeover time. This is due to having the right goods delivered to the right place at the right time to for each specific activity. Moving to a solely pull based approach is however a complex task, as suppliers commonly have long lead times for delivering goods (Ballard, 2000). This results in having to balance push and pull rather than only adapting to one side, whereafter different activities and materials must be prioritised for each side depending on preferences in the specific project.

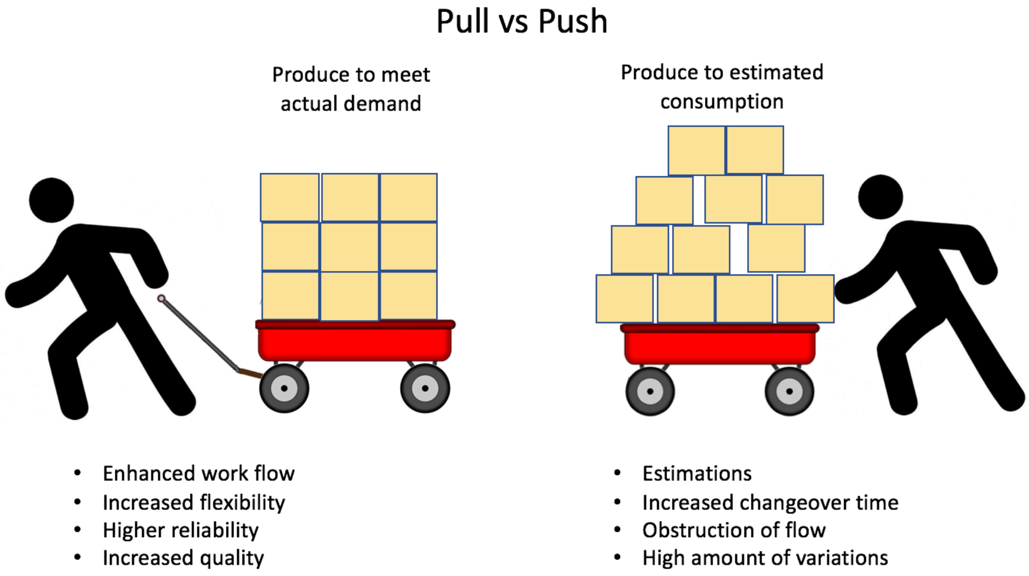


Figure 2 - Pull vs Push.

Increasing pull in production requires better control systems, with exact measurements rather than estimations, as to ensure decreased push demands extensive information from production (Kalsaas et al., 2015). Estimations, which the master schedule commonly is based on, can be minimised by measuring actual demand in production. This gives that push is increased for logistics, as there is need of an increased flexibility from suppliers. Kalsaas et al. (2015) further argues that the Kanban system, where notes are used to visualise actual demand for production, and thus provide clear information on what is needed at what time, can help to achieve better workflow in production as it focuses on production flow without affecting excessive push in logistics. Dallasega et al. (2016) builds on this argument, stating that an IT-based delivery system where all deliveries are organised to meet actual demand is crucial for increasing pull for production. This system can further be applied to LBP, establishing pull signals of demand from different locations (Kalsaas et al., 2015). Applied to high-rise construction where repetition is implied, this can have beneficial effects as pushing deliveries may result in obstructing production, and hence failure in the production cycle (Russell et al., 2009). However, it is still important to establish estimations of what activities that are to be performed, similar to what is done in a push system, in order to determine the timeframe needed for each subcontractor in each specific location (Ballard, 2000). Combined push and pull is thereby a necessity, although the coordination between production and logistics become central in optimising workflow in production, as there are limitations to what degree pull can be achieved. For production specifically, activities should be evaluated to decide on whether to be push or pull logistics.

Minimising float in production should according to Daniel et al. (2016b) be done through collaborative planning, where the subcontractors engage in the planning process, resulting in better estimations and improved communication. By doing so, activities are evaluated in relation to each other, and float can thereby be minimised in production scheduling. This further results in an increased demand of control, as decreased float implies a higher risk of clashes between different working teams. The Last Planner System (LPS) is described by Daniel et al. (2016b) to manage this as the working teams engages in a social process, which should imply better collaboration and communication. Clashes are expected to be detected during planning as it is conducted collectively and therefore acknowledges the interaction between activities as well as between those who perform them. LPS further stresses that decisions should be made when uncertainty is minimised to ensure that non-value adding activities are avoided, moving the planning process closer to production, when more information is available. On the other hand, the system provides that logistics need to be flexible in order to continuously meet the demand at the site for the right activity to be performed at the right time resulting in excessive push for logistics (Russell et al., 2009).

3.1.2 Flow through activities or locations

In contrast to industrial production, where a product flows through different locations where different activities are conducted until finished, construction production is performed at a set location with activities flowing through them respectively (Seppänen et al., 2010). This makes the location of assembly static and not shifting, as in industrial production, resulting in an issue where those who are to perform different activities may clash, as they wish to perform work at the same location. When planning production, Work Breakdown Structure (WBS) and CPM has conventionally been used, resulting in focus on activities as both methods aim to break down production and find the critical activities in the production chain (Christiansen, 2012). With influences from industrial production, LC has during the last decades resulted in development of new planning methods moving from activity-based planning to methods emphasising the importance of locations (Büchmann-Slorup and Andersson, 2010). Thus, recent research on LC promotes focus on locations to optimise production efficiency and reduce float, which is considered non-value adding.

When assessing the different methods for planning, visualisation becomes an important factor where traditional planning provides a critical line, giving the full sequence of the activities (Freeman and Seppänen, 2014). Having focus on specific activities in the master schedule, and not breaking them down into specific locations, is thought to give measurements on the amount of work for each respective subcontractor, however the work relatively other subcontractors is neglected (Seppänen et al., 2010). To achieve this, coordination is needed between the contractor and the subcontractors, and the subcontractors respectively. By planning with a location-based method, subcontractors are forced to adhere to a collective mind-set as their work becomes related to others, giving that a more comprehensive plan is developed (Seppänen et al., 2015). The process is further thought to give better accuracy on measurements on the specific activities as opportunities and barriers are evaluated more extensively. Having focus on locations does however imply decreased control of the total workload and instead increased control of the specific activities within the planned location (Lowe et al., 2012). Visualisation is therefore limited to specific locations within the master schedule, giving that the method is connected to planning in phases rather than focusing on total workload. To track the total workload, there is thus need for back-tracking the location plan when conducted, to ensure that the master schedule is not affected but rather improved.

3.1.3 Location-based planning

Planning in locations has been subject for research for over a decade, originating from a combination of linear scheduling and CPM, however practical documentation has been limited (Kenley, 2004, Lowe et al., 2012). LBS was found beneficial in projects with a high degree of repetition where the first documented implementation dates back to the construction of Empire State Building in 1929 (Kenley and Seppänen, 2010, Lowe et al., 2012). Its repetitive character implied that phases could easily be formed, in which work could be conducted efficiently. At first, LBS was however primarily used as a tool for visualising and controlling production in locations rather than mere sequences of activities, neglecting to recognise the social process of collaboration in the construction industry. This resulted in the development of LBMS, where planning and scheduling further aims attention towards the knowledge and expertise possessed by those who are to perform the activities (Kenley and Seppänen, 2010, Lowe et al., 2012). LBMS is a management system, where LBP planning is implied through using LBS and further incorporating those who are to perform the activities in the planning process to increase alignment and minimise uncertainty. Further it should be noted that as LBMS originates from, CPM many similarities do occur, however the former has the advantage of providing answers to both what activities that should be included in the schedule, and where they are to be performed (Christiansen, 2012, Lowe et al., 2012, Murguía et al., 2016). Thus, while LBS is directed to software and scheduling, LBMS aims to connect scheduling to those who are to perform the work. In this way, clashes can be detected in advance, and phase scheduling can be done more accurately.

The main goal of both LBS and LBMS is to facilitate planning and give continuous production flow by dividing a project into locations, which preferably consists of equal amount of work (Kenley and Seppänen, 2010). Having an even amount of work is claimed advantageous, as it simplifies execution by creating repetition. This is further aligned with Freeman and Seppänen (2014) who state "*The focus of LBMS is on continuous flow of resources, completing locations in sequence and synchronizing the production rates of crews"* (p. 1133). Creating production cycles with a continuous flow of resources is extensively beneficial when constructing high-rise buildings as they often already consist of repetitive work (Sacks and Goldin, 2007). This is supported by (Russell et al., 2009) who state that the repetition between different floors entails natural production cycles. Thereby, it is noted in Sacks and Goldin (2007) that construction of high-rise might benefit from implementing the Line-of-Balance (LOB) method, which is used to manage projects with high repetition by defining relationships between unit completed and rate of production. However, it is stated by Lowe et al. (2012) that LOB assumes that each work unit is identical to the previous, making it inefficient for the changing context of the construction industry even if repetition is perceived high. Thus, LBS and LBMS can help in streamlining production and developing a production cycle with continuous workflow as they aim to optimise each location respectively.

Additionally, LBS has become progressively popular in the construction industry as it emphasises the importance of locations as a dimension in the production process, where activities are linked together (Lowe et al., 2012, Murguía et al., 2016). LBS is stressed to enable for improved visualisation of how activities affect each other, and where they are to be carried out, compared to traditional activity based CPM (Büchmann-Slorup and Andersson, 2010, Christiansen, 2012). Connected to the construction industry, where activities have set locations, it is therefore claimed to be more suitable. LBS produces a flowline chart that effectives visualisation in planning as illustrated in Figure 3, showing what activities that are planned and how they proceed through different locations (Lowe et al., 2012). As the flowline chart also take locations into consideration, resulting in a view on activities that may falter in effectiveness. In comparison, the conventional usage of a Gantt chart to visualise planning provides an insight to timing of activities, as well as their sequence and durations (Christiansen, 2012). However, as Gantt charts are not able to visualise where activities are to be performed, neglecting to recognise the physical location of different work crews, effectiveness may be obstructed. Therefore, planning in activities does not consider nor identifies activities that could be performed simultaneously in each location. This has resulted in that the increased visualization provided by LBS has been argued to raise understanding of how activity delays impact the totality in a project, and how activities interact with each other (Lowe et al., 2012, Lucko et al., 2014).

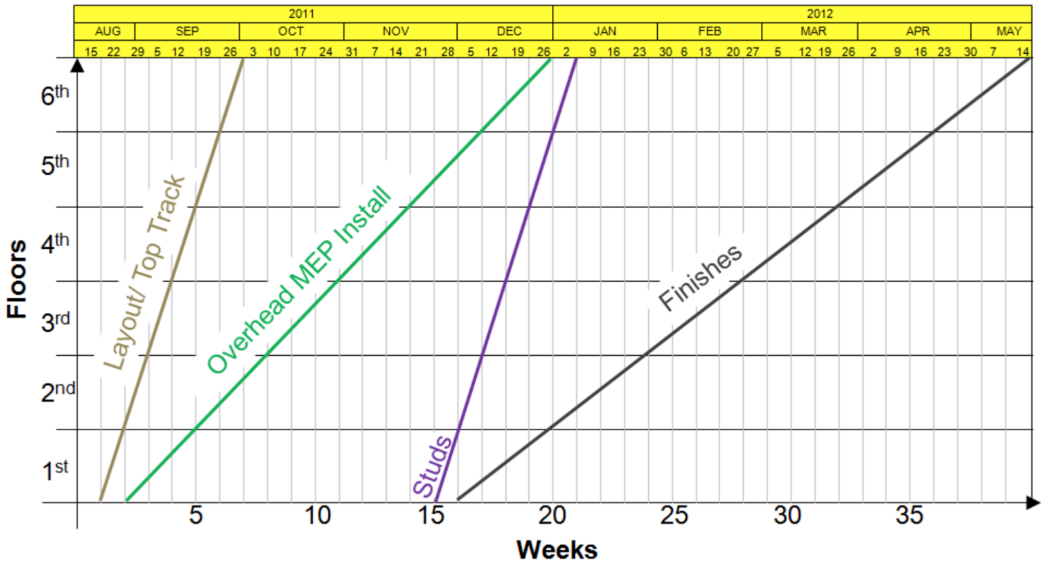


Figure 3 - Flowline chart prior to optimisation (Lowe et al., 2012).

Planning with LBS focuses on achieving a continuous flow where interruptions between activities are kept to a minimum (Lowe et al., 2012). This means that the start of a task should be delayed until work can be guaranteed to proceed continuously from location to location without interruptions to increase workflow. In order to do so, Seppänen et al. (2015) suggest that the planning process is divided in master- and phase scheduling. Master scheduling consists of important project milestones with long lead times including main trades and tasks that should be carried out, together with a location breakdown structure (Dave et al., 2016, Freeman and Seppänen, 2014). The location breakdown structure should further in LBMS, compared to in LBS, be conducted collectively with those who are to perform the work within each location to create alignment and enhance collaboration (Seppänen et al., 2010). Locations are set to be equal in workload and possibly size to produce continuous production cycles which can be divided in phase schedules. However, it is noted by Christiansen (2012) that dividing certain parts of production in locations is a rather complex task, and not always perceived efficient among those who are to perform the activities. It is mentioned that some wide-ranging activities such as concrete formwork may be separated into different locations when the location breakdown structure is done, resulting in an inefficient division of locations in regards to production. This is exemplified by a case studied by Christiansen (2012) where production supervisors opposed the site manager's division of locations, suggesting that certain activities were merged over the location boundaries in order to increase the efficiency in production. Hence, even if Christiansen (2012) promotes a LBP method, it is argued that problems may arise connected to how the locations are divided and executed in production. In this case, usage of a traditional activity-based CPM would have implied that merging large activities could have had beneficial outcomes as it effectively shows which activities that needs to be finished to remain within the timeframe. Therefore, it also suggests that a combination of traditional CPM and LBS could be beneficial in striving for increased efficiency in production.

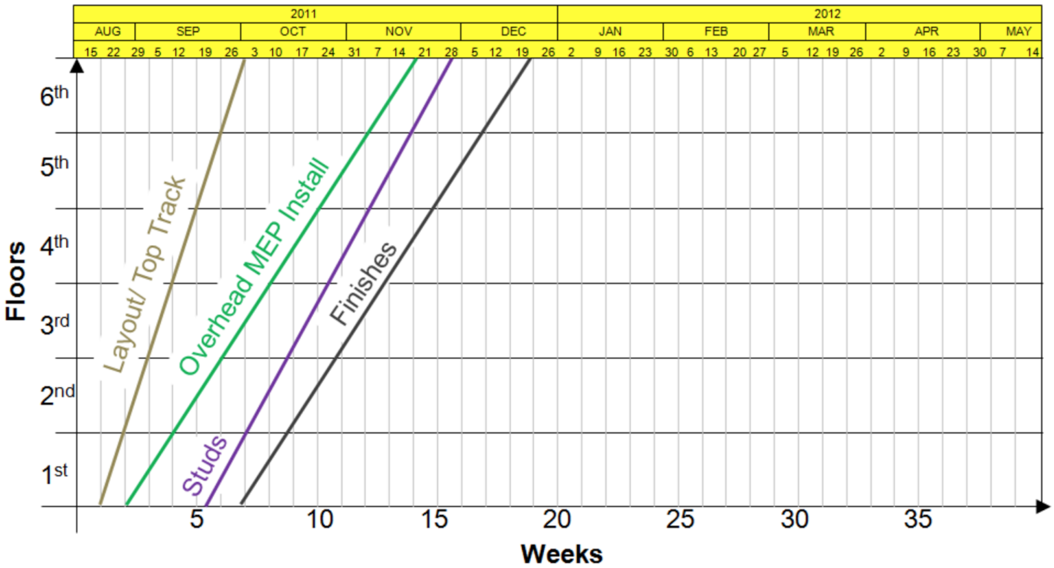


Figure 4 - Flowline chart after optimisation (Lowe et al., 2012).

Furthermore, when division of locations has been done through a location breakdown structure, the process moves into phase scheduling and schedule optimisation (Seppänen et al., 2015). Here, all involved parties jointly develop a logical sequence of work, and based on this develops a phase schedule. Generally, further optimisation is needed if the schedule exceeds the milestones of the master schedule. Optimisation is done collectively, where all involved parties discuss how to improve efficiency and productivity in the phase schedule to minimise float and increase workflow (Frandson et al., 2015). This is done by changing the production rates, attempting to align the inclinations, see Figure 4, of each task in the flowline chart to be as close to parallel as possible (Lowe et al., 2012). Production rates are adjusted by changing the amount resources requested for a specific task, increasing or decreasing the number of workers from different crews until the inclination of the task is similar to its prior task. Rearranging the order of activities can also help in minimising float, as some activities are less affected by changing the amount of resources. They further argue that by identifying bottlenecks, it is possible to evaluate whether to increase working speed for specific activities by adding resources or decreasing tempo for other activities to create continuous workflow. If done properly, the outcome should be a flowline schedule that finishes earlier than the initial end date and within all the participants' satisfaction (Seppänen et al., 2015). Thus, it aims to minimise float both within and between activities to increase efficiency in production.

3.1.4 BIM for production

Including planning in a 3D model by adding time and thus making it possible to visualise the different stages of production is usually known as introducing the fourth dimension, creating 4D BIM (Sacks et al., 2010, Sacks et al., 2009). Russell et al. (2009) state that 4D BIM provides a basis for planning as it visualises production in different stages, making it easier to create a logical sequence of activities. Sacks et al. (2009) also stress that improving visualisation would entail a greater flexibility towards the changing character of the construction industry. This comes from visualisation enabling for increased understanding regarding project execution. Thereby it is suggested that BIM facilitates decision making and increases understanding, as the relationship between different activities becomes increasingly prominent. Further, the limitations of BIM are considered to be few as it for example can incorporate costs, environment, quality and facility management (Sacks et al., 2010). Although, VDC has become a prominent research area, claiming to incorporate a wider range of activities and information compared to BIM due to combining different systems and software to achieve integration and automation (Andersson et al., 2016). Thus, it rather implies a hybrid practise compared to BIM, where having all information gathered in the same system is prioritised.

Developing a 4D BIM model provides a virtual environment in which production processes and operations can be viewed and evaluated, giving opportunity to identify time related resource conflicts (Harty and Whyte, 2009). In turn, this provides means for enhancing efficiency and reducing risk, as well as improving production flow. However, as pointed out by Jongeling and Olofsson (2007) going from 3D to 4D in regards to planning workflow requires additional information to be included in the model. This is supported by Andersson et al. (2016) who also press the importance of regular updates in order to ensure the reliance of the model. Generally, 3D models are restricted to only incorporate building components and does not include space as a resource. This will be needed if a proper workflow plan is to be established. Hence it is argued by Jongeling and Olofsson (2007) that BIM combined with other planning methods that recognize the importance of space and locations could facilitate workflow, resulting in the implementation of VDC to the industry. In this scenario, BIM is merely a software used to support and be combined with other software and systems, although a significant one.

Korb and Sacks (2016) argue that the level of development in construction is specific for each project as different terms are provided. Thus, to set the appropriate level of development for each project should be based in the terms of the project. To be able to model each project in advance, getting the opportunity to build it before production begins, gives a chance to find clashes and plan activities ahead (Redmond et al., 2012). To become a value adding process, it must however be ensured that this is achieved, as the process is not of value if it does not provide means for enhancing production and improving integration. BIM does however imply a risk of increased non-value adding activities as it promotes testing before construction, which may result in excessive testing compared to what is necessary. This mainly comes down to the level of development in the model, which decides what information that should be in the model, alongside the level of development, which decides when a certain level of development should be reached in the process (Lin et al., 2016).

Gledson and Greenwood (2014) stress that some of the main problems in construction are related to inadequate communication and competence among project participants. Thus, it is suggested that implementing BIM as an integrated model would address and resolve these issues, which in turn would enable and improve interaction and collaboration between involved parties (Tallgren, 2015, Toledo et al., 2016). Furthermore, Tallgren (2015) acknowledge the possibility to reduce uncertainty connected to lack of appropriate information when using an integrated BIM model, as all of the information will be stored at the same place. However, it should be further noted that defining and ensuring that all involved parties are aware of responsibilities associated with the BIM model is essential in order to reduce uncertainty and gain efficiency when using BIM (Gu and London, 2010, Lin et al., 2016). Having an integrated model, instead of managing information separately, implies a collective mind-set where the involved parties provide an understanding about the big picture on the specific project or location within the project, instead of sub-optimising each activity (Redmond et al., 2012). This is supported by Andersson et al. (2016) who argue that having an integrated model provides a context where all project participants can access information from a central VDC information hub, resulting in increased compliance among participants. It is however stressed that the amount of information easily can become overwhelming, and that having the right information on the right place should be prioritised (Redmond et al., 2012). Having excessive information in the model can therefore also result in losing focus and further lower visualisation rather than enhancing it if managed insufficiently. Working in separate software and system can also be preferred due to excessive fragmentation in the industry, having broad variation of competence and ability in adapting to new methods.

In order to establish clear instructions regarding execution and stipulate who will be responsible for what information, it is important to develop a BIM execution plan at the early stages of implementation (Lin et al., 2016). The BIM execution plan states responsibilities, defines appropriate times for specific level of development, and includes a detailed description of how BIM is used in the project. The execution plan should constitute a basis for alignment between all involved parties and ensure sufficient commitment from all participants as it divides the responsibilities. There is according to (Lin et al., 2016) no standard execution plan applicable to all projects today, however they see advantages in developing one in order to streamline the use of BIM and avoid double work between different projects.

3.1.5 Coordinating production

The aspect of making planning into a social process where the subcontractors, that are to perform the activities, are included differs from conventional planning (Daniel et al., 2014). By engaging the subcontractors in a social planning process, it is suggested that alignment and increased commitment is achieved. Murguía et al. (2016) support this and stresses that the social process in planning results in better cooperation, as the parties who are to work side by side on the site get to know each other. It is also suggested to imply better understanding on each subcontractor's respective work. When assessing key drivers for the subcontractors regarding commitment, Murguía et al. (2016) do however argue that the contracts act as base. Planning workshops can here be considered a barrier if seen as excessive to projects where conventional planning is used. Subcontractors cannot be expected to take part in collaborative meetings apart from what is standard, as this according to AB04/ABT06 should result in extra costs (Byggtjänst, 2011). Thus, extensive meetings must be regulated in the contracts to avoid later charges, and thereby avoid hampering efficiency. To engage the whole production team in a social process and plan collectively must therefore be planned for at an early stage to have the whole production team aligned.

Further, to create alignment throughout the supply chain, Daniel et al. (2016b) argue that a physical meeting place, where the participants are able to work together, is a critical factor applying to the whole process. When considering transfer of information, the physical meeting place provides means for a social process where parties can plan their work jointly. It is suggested by Daniel et al. (2016b) that there are gaps between subcontractors within the production team, resulting in faltering efficiency due to creating float between activities. To change this, Dallasega et al. (2016) claim that planning workshops, where the contractor and the subcontractors should plan the work jointly. Another benefit of collaborative planning is that risks can be derived to the party with the best competence to manage it, while also avoiding double work through having open communication. Involving the subcontractors in the planning process can thus give more accurate planning as they possess the best competence on how to solve issues within their field of expertise. This is supported by Seppänen et al. (2010) who stress that by including those who are to perform the work in the planning process, uncertainty can be decreased. Tallgren (2015) concretise this by giving an example from a project where a three-stage workshop was used when planning, resulting in efficient information transfers. Firstly, the production team was involved with the design team to walk through the construction. Secondly work was distributed where each party was to estimate and plan their own work. Thirdly, the specific work was planned collaboratively, where the result was a phase schedule which all subcontractors were committed to. A post stage was later used where the plan was controlled and evaluated to decide on whether to proceed or if changes are necessary.

3.2 Planning for logistics

Achieving workflow reliability and labour productivity are key measures in LC (Seppänen and Peltokorpi, 2016). Pérez et al. (2016) claim that construction logistics is a cornerstone in achieving productivity, as problems can result in downtime and have major effects on time and cost. The densification of cities provides dense construction sites, which creates complicated logistics, as goods rarely can be stored on site (Hulthén et al., 2015, Said and El-Rayes, 2013). Thus having the right material on the right place at the right time according JIT deliveries becomes increasingly important to efficiently manage time and costs. Seppänen and Peltokorpi (2016) elaborates on this by stating that focus from the contractors is on lowering costs of logistics, however without losing out on efficiency on site where workers commonly must spend time on searching for the right material. This creates a catch 22, where investments are not made before they can be proved to give better results instantly.

For logistics to promote efficient production, the supply chain must be managed to avoid obstructions without resulting in substantial costs. 4D BIM is thought to provide means for comprehensive planning, as it incorporates scheduling into the model, and thus visualises the conditions of different stages (Bortolini et al., 2015). Cheng and Kumar (2015) also stress the important of integrated planning, by pressing the importance of closely coordinating goods to be delivered to the right place at the right time to avoid non-value adding activities such as waiting times, double work and downtime. Software and systems must therefore be combined to develop one, aligned, system to support production rather than having separate systems which requires extensive and manual management.

3.2.1 Push and pull in logistics

Logistics are generally scheduled to meet the demands of a predetermined master schedule rather than the actual demand on site (Hulthén et al., 2015). Thus, for deliveries to meet demand, production must match the master schedule. This implies that logistics pushes production to continuously meet the master schedule, which is based on estimations instead of focusing on delivering the right material to the right place at the right time. An increased flexibility is requested, as changes in the master schedule are common, resulting in that the delivery schedule becomes desynchronised with the production schedule (Seppänen and Peltokorpi, 2016). Increasing flexibility does however imply push for logistics as suppliers commonly are contracted long before deliveries due to having long lead times (Ballard, 2000). This puts increased pressure on suppliers, who are dependent on other customers, giving that flexibility also is limited. Push is required, to manage long lead times, however not desired as it does not imply supporting production by meeting the actual demand on site.

Push from logistics is further promoted by suppliers providing rebates on big orders, fees for truckloads that are not filled, and extra costs for on time deliveries (Benton and McHenry, 2010). Thus, delivering the right materials to the right place at the right time commonly implies increased costs, compared to delivering full truckloads of specific materials on times that can be fitted to their supplier´s delivery schedule. As efficiency is connected to the total economy of the project, these costs must be derived to decreased costs in production to be motivated (Benton and McHenry, 2010). Thereby, deliveries should be coordinated to be optimised in regards to the efficiency of the specific delivery and its total economy and therefore, materials should be divided accordingly. In addition, when planning for efficiency, the alternatives must be balanced for each type of goods to find the best alternative for the specific project.

Constructing high-rise constructions in dense environments requires both a well-planned and yet flexible logistics solution, suggesting that increased pull in production can be beneficial for achieving enhanced workflow (Russell et al., 2009). Sweden is not traditionally characterised by being dense, however the construction sites are incrementally densifying as the cities grow and become denser (Boverket, 2012). High-rise constructions entails density not only on the construction site, but also on each level as the height implies complexity in transporting materials inside the construction (Russell et al., 2009). Making sure that the right material is delivered to the right place at the right time is therefore of increased value in this type of projects. This further puts increased pressure on developing a system where push and pull is balanced to optimise workflow throughout the chain. However, there are reasons for increasing flexibility in logistics when constructing high-rise constructions, and thereby putting extra pressure on suppliers, as these advantages can be found in the repetitions that are implied.

3.2.2 Supply logistics

Cheng and Kumar (2015) press the issue of having deliveries at the right time as overcrowding the workspace is considered a major risk. Incorrect deliveries should be directly avoided, which demands carefully planned logistics. It is however not only important to have a detailed plan, where logistics is synchronised with production; the plan must also be flexible to unforeseen events resulting in changes in the delivery schedule. Having the right material on the right place at the right time should therefore be central for logistics planning, as it otherwise may directly obstruct production (Lange and Schilling, 2015).

According to Seppänen and Peltokorpi (2016), the question of how material is stored impacts workflow reliability, as on site storage decreases available space on site and can be an obstacle for work that is to be carried out. On the other hand, off site storage can imply a risk for deliveries due to having less float for transportation. Material should according to them be stored close to where it is needed without interfering with production or risking to lower productivity. Hamzeh et al. (2007) claim that a consolidation centre can provide several benefits for construction projects as the projects become central for deliveries giving higher reliability. Hence, a lean signal system can be developed where production orders the goods, and thus ensure that the right materials are delivered to the right place at the right time. This can also be connected to modifications in the production schedule where the logistics schedule must be adjusted to become synchronised. This gives that off-site storage implies a higher tolerance to variations compared to on site storage (Cheng and Kumar, 2015). For example, a superintendent need to be able to change a delivery when it is obvious that the material no longer will arrive at the right time to create a lean process, regardless whether the delivery needs to be accelerated or postponed.

Using a consolidation centre with intermediate and temporary storage would according to Kalsaas et al. (2015) facilitate JIT deliveries to the construction site, and thereby enable for the construction site to increase pull for production. The use of consolidation centres provides that logistics are kept in accordance with a pushing logistics, resulting in increased flexibility as goods can be coordinated before being delivered to the site. Simultaneously, it gives that big orders and full truckloads can be guaranteed to the consolidation centre while on time deliveries become redundant (Sullivan et al., 2010). This could according to Sullivan et al. (2010) also decrease the amount of goods damages and wrong deliveries, ensuring that production does not get obstructed. A consolidation centre could further be combined with an IT-based control system to synchronise supply and demand between the construction site and the supply chain (Dallasega et al., 2016). It is implied that this would facilitate increased pull for production, focusing on ordering goods when a demand arises at the construction site and thereby provide a JIT material supply. Deliveries do however increase in amount, resulting in more truckloads and extended coordination, which implies extra costs compared to delivering full truckloads to the site directly from the supplier (Cheng and Kumar, 2015). This is visualised in Figure 5, where conventional supply logistics are compared to having coordinated deliveries through using a consolidation centre.

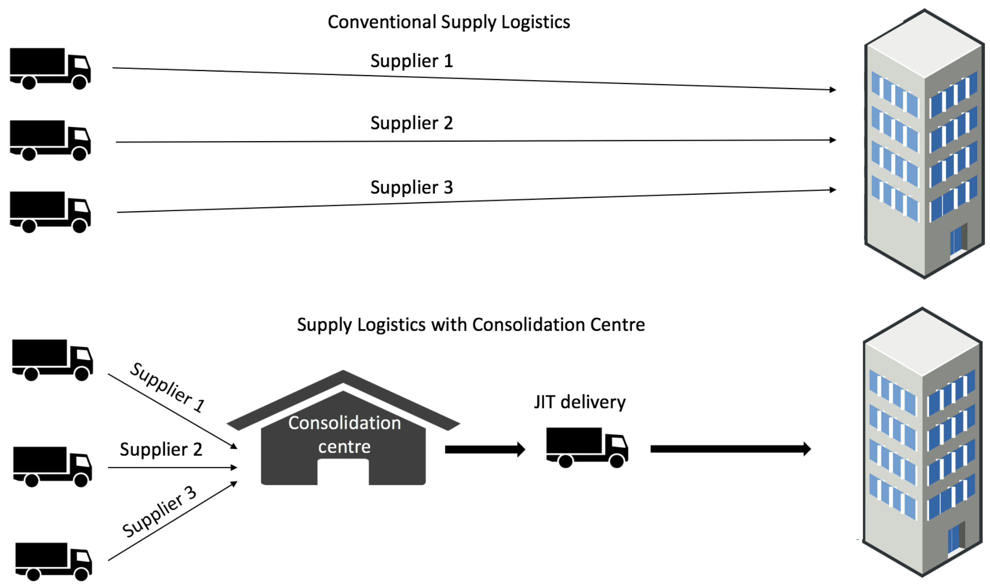


Figure 5 - Conventional supply logistics vs supply logistics with consolidation centre.

Furthermore, when using a consolidation centre, logistics coordination is moved away from the construction site resulting in need for well-established collaboration with one party off site rather than having to coordinate with several different parties from the site (Seppänen and Peltokorpi, 2016). By moving this process off site, extra costs are implied for the coordination which traditionally is made by production (Cheng and Kumar, 2015). If these costs however can be covered by the risks that otherwise are implied in production, there are advantages to find.

3.2.3 Just in time

Delivering materials JIT, the right goods in the right place at the right time, has been increasingly common due to densification of cities where goods cannot be stored on site and later be distributed when needed (Said and El-Rayes, 2013). Even though space is a less common limitation in Sweden compared to more closely populated countries, the space for on-site storage is commonly limited due to having tight construction sites (Boverket, 2012). Therefore, focus has shifted to not deliver material before it is needed on site so it can be delivered to match actual demand to the place where it is needed on the site directly, without obstructing productivity. The approach puts high demands on suppliers, as a delivery that runs late risk obstruct the entire production cycle. Lange and Schilling (2015) argue that when each subcontractor manages their own delivery by truckload, the system is at risk as control over coordination is lost. Instead, optimisation through full truck deliveries with minimised distance is suggested by Seppänen and Peltokorpi (2016) in order to achieve JIT deliveries. This approach can be connected to LBS where deliveries are directed to specific locations to coordinate between different subcontractor trades. To do this, goods needs to be coordinated before arriving to the site resulting in excessive management. It does however provide better means to have full truck deliveries and having a system where the right goods is delivered at the right place in the right time (Sullivan et al., 2010).

An issue with JIT deliveries is scheduling, where BIM often have been suggested to act as a supportive tool (Bortolini et al., 2015, Cheng and Kumar, 2015, Seppänen and Peltokorpi, 2016). The competence required is commonly missing in the production team which has created a market for separate logistics companies and an increased focus on prefabricated building components in order to decrease work and waste on site. Skjelbred et al. (2015) argue that the production flow should never be harmed by lack of materials but materials should neither be stacked on site as they will become an obstacle for production. To achieve this, scheduling is critical as it implies a balance between the two measurements. To find a useful tool and arrange who is responsible for synchronisation between logistics and production will thus depend on the competence that is required in the specific project giving that logistically complex projects have higher demands on coordination than less complex projects.

3.2.4 BIM for logistics

Given that BIM is under constant development, logistics planning is thought to be one of the major benefits providing simulations and clash control services for deliveries to ensure that they arrive to the right place at the right time (Pérez et al., 2016). Cheng and Kumar (2015) argue that through synchronising logistics planning and production planning in BIM models, visualisation can be improved compared to traditional planning. It is moreover stated by Andersson et al. (2016) that using information models to improve logistics is something that will increase as the proliferation of future research and implementation of VDC increases. However, there are limitations to the system as it requires a high level of development for the model, it needs to be constantly synchronised with production, and it does not consider the presence of buffer locations (Gu and London, 2010, Pérez et al., 2016). In addition to this, the supplier needs to be active in updating when goods are ready for dispatch and when it has been dispatched for the system to stay updated. Bortolini et al. (2015) support this and add that synchronisation between the level of development of the model and level of development in the construction schedule is key in achieving high accuracy in logistics. This requires extra administrative work which results in extensive planning costs giving that the savings from the benefits must be weighed against them.

Bortolini et al. (2015) describe a case where a 4D model was used to support planning. The system was used in meetings to show sequences on how work was to be conducted giving that clashes were easier to discover. Storage locations were identified to minimise transportation and increase production flow. By visualising the building in the sequences, it was possible to plan where material was supposed to be at what time and thus minimise waste. The simulation was governed by a coordinator, having those affected by the specific simulation involved in the decision-making process and thus creating a collaborative approach. Having 4D BIM implied an interactive process where the different parties planned the logistics jointly. A similar solution was presented by Russell et al. (2009) where linear scheduling was applied to a high-rise construction project, and further incorporated in the 3D model, taking it to 4D. By including time as a parameter in the model, planning was enhanced due to having better control of the sequences in the production cycle.

A BIM model can easily be divided into segments or locations that are going to be conducted simultaneously, which gives what deliveries of goods that risk to clash (Bortolini et al., 2015). By having improved visualisation, the logistics becomes easier to manage which implies less risk of having the wrong material delivered to the wrong place at the wrong time. As high-rise construction entails repetition of locations in form of floors, commonly with similar floor plans, BIM can thus provide means for enhanced planning (Russell et al., 2009). This results in a delivery schedule which is connected to the production schedule, where the use of BIM can be used to visualise the logical sequence of activities within each respective zone.

3.2.5 Coordinating logistics

Another core aspect of logistics planning is how information is transferred from production to suppliers, and who is responsible for which delivery. Cheng and Kumar (2015) claim that information can be extracted from BIM, as long as the level of development is high enough, meaning that suppliers can retrieve information on what goods that should be delivered to which place at what time. In this scenario, the model must be trusted to be correct and include all the materials needed for the specific segment or location which the material is going to be delivered to. More commonly, separated software is used, resulting in the deliveries are planned based on the master- or phase schedule. Cheng and Kumar (2015) further admit that it is tedious to have an updated model, where control of every single building component is included. However successful management of this process it thought to enhance production as material is delivered according to JIT and wastes are reduced.

Moreover, using an efficient planning software for coordination is key in increasing pull for production (Dallasega et al., 2016). By using software to plan and manage deliveries, collaboration is enhanced throughout the supply chain, as information is easily distributed compared to having one party who distributes all information to each respective party. To further integrate the software with the production system to meet actual demand means that automation is achieved. This also implies extended flexibility in deliveries, as all parties can be made aware of changes by notifications from the software. As shown in Figure 6, information is gathered in the software and then distributed to the suppliers, thereafter each supplier can follow it to see when their respective delivery is to take place.

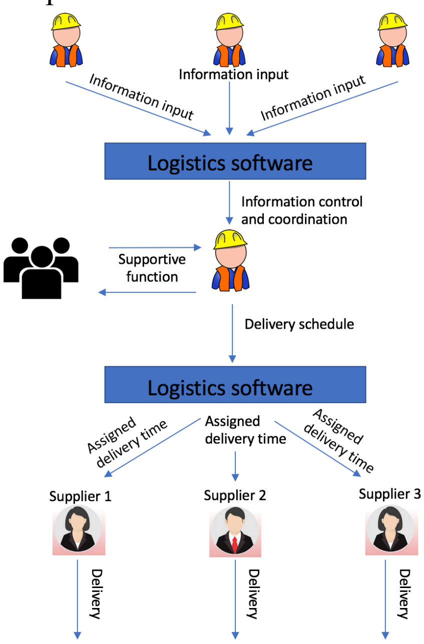


Figure 6 - Example of logistics information flow.

Traditionally, each subcontractor is responsible for the material connected to their work (Lange and Schilling, 2015). However, in complex projects where logistics demand extra attention, there is need for more careful planning to avoid clashes. When constructing high-rise constructions, the height becomes an obstacle, providing that extensive communication and coordination is necessary. To govern this process, logistic companies can be hired as expertise to bring specific competence to the project (Lange and Schilling, 2015). Where subcontractors on logistically low complex projects can bring their own goods or have it coordinated by a superintendent, high complex projects provide that logistics planning require higher competence and extra attention to not obstruct, but rather promote, efficiency. Complexity connected to logistics can have several reasons, both related and unrelated to production complexities, such as density on and around the site, amount of parties involved in the supply chain and height or location of the place where the material is supposed to be delivered (Pérez et al., 2016, Said and El-Rayes, 2013). However, by having an integrated software, subcontractors can still order their own material but have it governed by the contractor.

3.3 Synchronising production and logistics planning

Traditional construction planning implies a high level of uncertainty, as it commonly is carried out by the contractor and thus not including those who are to perform the work, making it a game of assumptions rather than an accurate plan (Bortolini et al., 2015, Daniel et al., 2014). By focusing on locations rather than activities, and planning collectively, estimations become more accurate while risks also can be distributed to be managed by the party possessing the best competence to manage it (Seppänen and Peltokorpi, 2016). Additionally, to ensure flow from suppliers to subcontractors, 4D BIM can be utilised to facilitate efficient risk management both in production and logistics (Cheng and Kumar, 2015). Separately however, production and logistics planning can hardly promote workflow significantly as their value comes when integrated properly. Both aspects build on the other working without interruption, implying high demands on the synchronisation between them (Hulthén et al., 2015). In order for one to run smoothly, the other must flow and vice versa providing a situation where focus often is lost for one of the aspects. Thus, planning for efficient synchronisation becomes vital in producing a system where flow is implied from suppliers to subcontractors.

3.3.1 Push and pull

Production and logistics scheduling are highly dependent on each other, giving that changes in one is likely to affect the other (Lange and Schilling, 2015). This results in a situation where flexibility is key, as risks cannot be removed. For example, if suppliers cannot guarantee that deliveries will be on time for a specific activity or zone, it cannot be done before the delivery is made. In contrast, if a delivery arrives before it is necessary due to changes in the production plan it is likely that non-value activities will be generated in form of obstruction on the site. Planning is however commonly carried out separately, implying that synchronisation is a risk (Bortolini et al., 2015). Therefore, managing information is of utmost importance in creating flow throughout the chain, from suppliers to subcontractors, as changes in either production or logistics must imply reaction in the other.

Contractors rarely include logistics management in their organisation resulting in that specific competence needs to be hired for projects where it is deemed necessary (Hulthén et al., 2015, Said and El-Rayes, 2013). Hence, a situation in logistically complex projects occur where there are two separate parties planning production and logistics, which results in a situation where synchronisation between the schedules to promote workflow is essential. Separate planning implies sub-optimisation, which is a common mean for poor flow in the otherwise fragmented construction industry. As both production and logistics planning promotes a social process in planning of specific locations, activities, assembly points or deliveries, synchronising should include both a top-down and bottom up approach, implying a balance for push and pull (Seppänen and Peltokorpi, 2016). This results in that a close collaboration is required between production and logistics planners to avoid clashes. The bottom up approach implies specific planning while the top-down approach provides look-ahead planning. Developing systems for how to work with both production and logistics is therefore also central to enhance the information flow from suppliers to subcontractors and vice versa, to promote the balance of push and pull that is chosen. Consequently, alignment must exist both within production and logistics separately but also when being combined.

The repetition implied in high-rise construction further presses for increased pull for production, as the benefits become incremental due to streamlining the process for every round in the production cycle that is completed (Russell et al., 2009). The master schedule, which conventionally is the subcontractor's liability to fulfil towards the contractor, should therefore decrease in value providing decreased push while push for logistics is increased to ensure that the right material is delivered, enabling for the right activity to be performed at the right time (Said and El-Rayes, 2013, Sullivan et al., 2010). Engaging the subcontractors in a social process through planning collectively further supports an incremental pace in the production cycle, resulting in a higher efficiency. It must however be ensured that logistics can cope with the increased pace, as downtime otherwise is increased in production. When constructing high-rise construction, it therefore becomes clear that increased pressure on accurate planning is implied, and that balancing push and pull between production and logistics is central to ensure continuous workflow. The height must specifically be taken into consideration, as the production pace for each cycle increases while the logistics cycle stagnates due to longer transportation routes (Sacks and Goldin, 2007). The combination of incremental pace for production and stagnating pace for logistics entails that planning should be done in phases to cope with the conditions of each stage of construction.

3.3.2 Integrating LBS and JIT

To break down production planning in locations, aiming to create an optimised sequence of activities within each location should according to Seppänen et al. (2015) increase workflow for production. Applied to JIT, goods should be delivered to the right place at the right time, making location-based deliveries synchronised with the workflow within each location. This is supported by Dave et al. (2016) who stress that planning with LBS is rather about finding the optimal production cycle through phase scheduling than planning every activity in detail. JIT correlates to this as it is about finding the right time to deliver the right goods to the right place, which if synchronised properly can enhance production flow by increasing pull in production through efficient production and logistics planning.

LBP is directed towards phase scheduling and developing production cycles, giving that it has weaknesses in look-ahead planning and planning of specific activities (Dave et al., 2016). It is thereby suggested to be combined with a system for collaboration in production, such as LPS, to create a comprehensive approach. However, as subcontractors should be included in the planning process when using for example LBMS, there are means for accurate planning (Freeman and Seppänen, 2014). This approach could be applied to logistics planning by including the different suppliers in the process making it a collaborative process. However, even if the systems complement each other, it should be noted that implementing LBP and JIT to logistics, integrated, requires planning comprehensively to achieve flow in deliveries (Seppänen et al., 2010). It is therefore stressed by Hamzeh et al. (2007) that using a logistics centre can facilitate the challenges that implementation evokes, resulting in reduced lead time of deliveries. This is stressed necessary to manage the increased amount of deliveries needed to sustain a sufficient level of JIT. Therefore, to synchronise LBP and JIT and further develop an efficient production system, may require extra push in either production or logistics.

Moreover, in order to ensure flow in the production cycle, uncertainty must be minimised both in the production and logistics schedule (Daniel et al., 2016a). Finding a logical sequence for how work is to be conducted, and further incorporating those who are performing the work in planning to increase accuracy can thus facilitate development of a production system from suppliers to subcontractors. Software can be used for scheduling, which further can be optimised collaboratively with those who have the best competence on the specific activity, where bottlenecks can be identified to be managed in advance. To do so, planning workshops can be conducted in stages where the collaborative approach is take to minimise float between activities and where the ones who are to perform the activities may plan them to minimise float within them.

3.3.3 Virtual design and construction

Creating integrated systems and striving for automation has been subject for research recently, giving that BIM which mainly provides benefits regarding visualisation, is perceived as too narrow (Sacks et al., 2010; Andersson et al., 2016; Kunz and Fischer, 2009). BIM can be seen to fail in incorporating all the activities and workflows connected to the implementation of information models to the construction industry. Instead, VDC is claimed to provide a comprehensive model, by combining both software and systems and thus create a hybrid production system. When applied to LBP, and a system such as LBMS, the model can be divided into locations rather than activities providing means for combining software and system. The model clearly provide benefits concerning visualisation, both for production and logistics, as simulations can be used to illustrate conditions for different stages in construction (Bortolini et al., 2015). This does however also imply need of combining software and system, as the software merely provide the information based on the input. A system where planning is conducted collectively can therefore provide that clashes are avoided to a greater extent as input can become increasingly accurate. Besides, the model can be used for picking the logical order for deliveries when being combined with a production system, creating a bridge between production and logistics planning. Henceforth, there is a correlation in the use of information models between production and logistics where they are dependent on each other, giving means for a well-developed VDC implementation (Andersson et al., 2016).

It is further argued by Gledson and Greenwood (2014) that incorporating time to the BIM model, thus achieving 4D, enables for a wider practical implementation as it would have incremental effects on how to benefit from BIM. To incorporate time in the model gives extended visualisation regarding proceedings of production, giving basis for increased certainty for the planning process (Tallgren, 2015). This is moreover supported in VDC where Andersson et al. (2016) press that in recent years 4D BIM have gone through extensive development, resulting in incremental change of how complex projects are planned and executed. Applying 4D BIM to the planning process of for example LBMS would facilitate understanding among participants, enabling for production processes and operations to be viewed and evaluated, and simultaneously provide opportunity for identification of time related resource conflicts (Davies and Harty, 2013). Additionally, it is argued by Gledson (2016) that 4D BIM have the possibility to increase communication of project participants, which will be a crucial element for managing the challenge of synchronising production and logistics.

In order to efficiently use BIM, Lin et al. (2016) argue that the right conditions must be set from the start, making the BIM execution plan an essential tool for efficient planning. By deciding the level of detail at specific times, and thus the level of development, responsibilities become clear and alignment is achieved. Further, in order to fully implement information models to the industry Andersson et al. (2016) argue that involving modellers to the project team should be considered a key measure. It is stressed that by having modellers integrated in the team, practical understanding increases. This should further result in higher quality of the information model, as modellers become aware of what information to include in the model. This applies both to production and logistics planning as the level of development decides the possibilities for 4D BIM (Russell et al., 2009). By setting the right conditions from the start and incorporating the right criteria in the contracts, the use of 4D BIM can thus be enhanced.

4D BIM and VDC does however experience similar issues regarding implementation both in production and logistics planning, where the costs of incorporating every building component or delivery in the model requires a high level of detail (Lin et al., 2016). Apart from this, there is a resistance towards change where hard value benefits must be shown before implementation in order to motivate the change, which hampers implementation (Redmond et al., 2012). In addition to this, competence is considered a major issue for implementation where education is regarded as a barrier. Thus, a catch 22 is created where hard value benefits cannot be shown as the competence is missing due to lack of education, as investments are needed. There are however indications on that the benefits are becoming prominent, resulting in an increased use of 4D BIM for both production and logistics (Bortolini et al., 2015, Tallgren, 2015). As the use becomes widespread, it is also thought that it will increase in efficiency resulting in new and improved ways of 4D BIM. So forth, it is argued by Andersson et al. (2016) that as implementation of BIM proceeds it will develop into VDC in order to generate a greater benefit for the industry than what is possible from mere model visualisation. It is claimed that to successfully implement and benefit from the information models provided by BIM a combination with management tools and methods are required, which would constitute a new way to execute construction projects that is not covered by BIM alone. To have production and logistics systems in place, where coordination of suppliers and subcontractors is included, is essential in planning comprehensively giving that taking the step towards VDC achieving integrating and automation is an objective to strive for.

3.3.4 Coordination

The synchronisation process requires focus on demarcations and clarifying who is responsible for what (Lange and Schilling, 2015). For logistically complex projects the risk for clashes in logistics increase, giving that the traditional method of having each subcontractor responsible for supplying their own goods becomes risky. Cheng and Kumar (2015) stress that the bridge between subcontractors and suppliers is essential in coordinating logistics, especially when changes occur. This can be connected to the complexity of the project, as changes are more common to occur in complex projects. Developing an integrated system, where software can be connected to the production and logistics systems, is thus of importance to efficiently manage information from suppliers to subcontractors. Further, by having software which continuously synchronises the delivery and production schedule provides that pull can be increased as actual demand can be measured and delivered, rather than basing deliveries on estimations (Dallasega et al., 2016). When changes occur in either schedule, it is important that there is a response in the other schedule as the production cycle otherwise may be obstructed. This does however raise the question about who is responsible for what, which makes it essential to be clear and concise in the contracts, as these form the base of every collaboration (Lange and Schilling, 2015).

To incorporate a social process, both for production and logistics coordination, can help to improve collaboration and create a collective mind-set (Dave et al., 2016, Lange and Schilling, 2015). By planning jointly, and thus use the competence of those who are to perform the work, alignment is created throughout the chain giving that an understanding is developed between parties who are to cooperate. When applied to high-rise construction, it can be of extra interest to have a collective mind-set as it implies repetition of work where the involved parties are working together continuously in the same sequence (Ibrahim and Hamzeh, 2015, Seppänen et al., 2015). To have the same issue with a party throughout the process is therefore increasingly troublesome, and can result in poor collaboration. Planning workshops, where the interrelation of activities is evaluated, will provide that collaboration is imposed and float between activities performed by different parties is minimised. In addition, alignment can be created throughout the production chain, giving that responsibilities are divided early in the process. When the activities further are performed, the information flow from subcontractor to supplier can be enhanced as the parties are aligned regarding how to report and communicate. However, the contractor must set the conditions from the beginning to ensure that alignment is achieved, as information otherwise becomes fragmented resulting in sub-optimisations rather than focusing on total efficiency and further failing to create integrated and automated systems.

3.4 Theoretical summary

Taking the next step towards synchronising production and logistics planning contains developing a balanced push and pull system, which is supported by combining software and management systems. Further, to focus on creating alignment throughout the chain from suppliers to subcontractors, and have a system where actual demand can be measured and sent from subcontractors to suppliers becomes vital as high-rise construction largely depends on achieving efficiency in the production cycle. Engaging in a social process, where planning also is conducted collectively, therefore also provides excessive benefits compared to other types of projects, as minimising float both within and between activities gives optimised phase scheduling. This gives that increased pull for production should be prioritised, due to increased consequences from obstruction, resulting in extra push for logistics.

To connect LBP to JIT further provides that logistics become integrated with the production cycle, resulting in automated synchronisation where changes in production implies changes in logistics. Using software where production can report of time reductions and delays, which directly affects deliveries of goods to the next location provides that downtime and obstruction is minimised in production. The locations should preferably be adjusted after how much goods that can be used in production without obstructing, while also resulting in that resources can be distributed between the subcontractors to have an even pace and thus an optimal workflow. Planning collaboratively is a central part in achieving minimised float as those who are to perform the work have the best competence on how to perform it, while it also provides that collaborations begin before construction commences. For production, a system such as LBMS could be used to increase commitment throughout the chain, simplifying the flow of information. For logistics, JIT deliveries becomes vital due to the constraints that high-rise construction entails. By delivering the right goods to the right place at the right time, the right activity can be performed at the right time. Software can thus be used to communicate actual demand, as production can report changes, compared to the phase schedule which the delivery system is based on, to logistics. A LBP system can thus be developed, where information from subcontractors to suppliers, and vice versa, is implied.

Furthermore, extensive use of 4D BIM facilitates enhanced planning, as it enables for running simulations and increased visualisation, as well as providing means for integration of systems and automating synchronisation. Developing a VDC system, structured to suit the company, can therefore be beneficial as it implies combining BIM with lean tools. This imposes focus on efficiency through increased use of technology, where clash controls can be done both for production and logistics before commencing work while also giving the advantage to report progression during construction. The system can be used from subcontractors to suppliers, resulting in increased pull for production and enhanced workflow, ultimately providing higher efficiency. Applied to high-rise construction, it can be used to evaluate the different stages, where different conditions are implied for both production and logistics as one is incremental in pace and the other is regressive. Synchronised coordination can thus be implied in the system as transfer of information is automated. However, for production and logistics respectively, alignment throughout the chain should be focused resulting in that coordination will be required. As long as humans are carrying out the work, information must reach those who are to perform it, both for subcontractors and suppliers, giving that collaboration is inevitable. Engaging in a social process where those who have the best expertise are those who provide input to the system will therefore provide the best outcomes.

Combining different systems and software further requires that all parties using them needs to be aligned. This considers both technical alignment where the same software not only must be used, but must be used similarly, and organisational alignment, where there should be one combination of software and systems in place rather than several different. Having dispersed combinations implies higher demands on competence, as solutions become one-off rather than standardised. Having alignment is therefore essential for developing a comprehensive plan for both production and logistics, and further how to synchronise them.

Finally, to develop a comprehensive system which covers both different software for different purpose and different logistics and production system implies that competence must follow. Educating staff and create alignment in how software and systems are used is necessary to create alignment, and further avoid non-value activities in form of fragmented understanding. To merely provide tools is therefore not the solution, as to efficiently use them encompasses providing the right input. This further craves for investments, which commonly cannot be shown to provide better financial results instantly as optimising use demands time, while it also requires personal investments from those who are to use it as they must step away from old methods. The situation results in an inertia, where efficiency is hampered. Developing a VDC system compatible with the specific organisation is therefore of importance, however taking time to develop it right is essential to optimise its use when implemented.

4 Empirical Findings and Analysis

This section aims to interpret information retrieved from the interviews and data collection on how to plan for production and logistics, and further synchronise them, to provide guidance on how to proceed with planning at Karlatornet. It contains of the sections *Karlatornet, Planning for production, Planning for logistics,* and *Synchronising production and logistics planning.* The first section is about the case study, Karlatornet, to provide its specific conditions. The second section includes the subchapters *Push and pull in production, Flow through activities or locations, Location-based planning, BIM for production,* and *Coordinating production,* and the third section concerns *Push and pull in logistics, Supply logistics, Just in time, BIM for logistics, and Coordinating logistics* while the final section includes the subchapters *Push and pull, Integrating LBP and JIT, Virtual design and construction,* and *Coordination.* The chapter aims to provide practical insight on the research questions to further be compared with the Theoretical framework in the coming chapter, *Discussion.*

4.1 Karlatornet

Serneke aims to have obtained a building permit for what is to be the tallest building in Scandinavia during 2017. It will be located at Lindholmen, Göteborg, only 10 minutes from the city centre by car or public transportation. The tower will have 72 floors, and contain mainly of residential apartments, besides common areas such as a lobby, spa, gym, and a viewpoint just below the apartments in the top. Its base is a 31,7m times 31,7m square, which from floor 48 to 68 will contain of a twist resulting in a slight variation of the floor plans. Apart from this, there are substantial similarities in the floor plans, and the amount of work that is to be conducted on each floor respectively. This is visualised in Figure 7 and Figure 8 below, which illustrate early blueprints of floor 25 and 38.

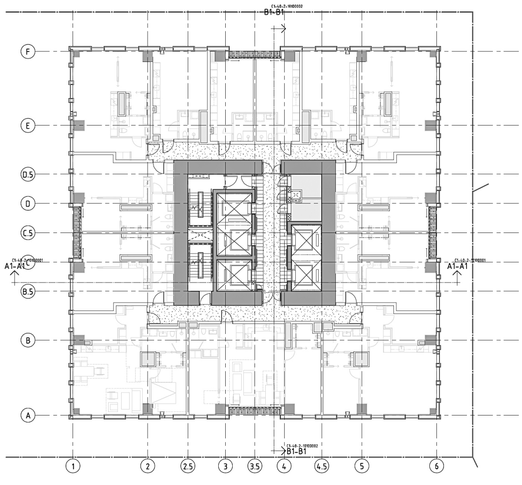


Figure 7 - Floor 25 at Karlatornet.

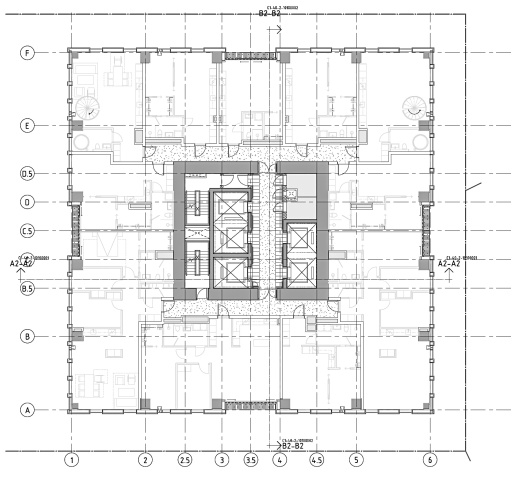


Figure 8 - Floor 38 at Karlatornet.

Even though there will exist a variation where the tower has its twist, it can still be seen that work will be largely repetitive. Internal works will mostly be of the same character, as the building to a high extent will consist of residential apartments. Therefore, the sequence of which activities are being performed will also be the same throughout construction as the locations will stay similar. Constructing residential apartments includes work from several subcontractor trades, giving that production and logistics management will be vital for achieving efficient workflow. Further, production is divided in three sections namely; structural works, installations, and internal works. The relation between these will decide the optimised production speed, as clashes between them otherwise will occur. By finding the bottleneck, the others can be adapted and production speed can be optimised.

Regarding logistics, Karlatornet will face challenges in its central location as the possibility of storing goods on site will be limited. It will also imply difficulties in managing transportations to the site, as the surrounding transportation routes often are highly trafficked. In addition, the time for transporting goods on site and inside the building will also be restricted as the goods required for each floor cannot be fitted in the floor in advance without obstructing production. Thus, the surroundings both around the site and on site results in that logistics must be closely planned to ensure that obstruction and downtime is avoided. The characteristics for logistics are specific for high-rise constructions as they entail density in height, giving that there are extensive risks at Karlatornet compared to other projects.

4.2 Planning for production

There is a general opinion among the interviewees that planning methodology needs to improve to achieve higher efficiency in production. Conventional planning methods can however still be useful according to project manager A and B, as they imply low uncertainty in regards to execution. As crews are already experienced with the ways of working, there is little need for education. The calculations manager further builds on this reasoning, stating that change must imply direct benefits for the specific project to be motivated. At Karlatornet, project manager A investigated whether to use the LBP system VICO or not. It was concluded that the system was too complex due to having limited experience of VICO among the participants, and it was therefore not implemented even though possible long-term effects were acknowledged. Planning will however be carried out location-based, although not with integrated systems. The question of incorporating planning in the BIM model has also been discussed. Nonetheless, it was considered preferable to have separated systems as combining the systems requires an excessive level of detail in the model according to project manager A. This is supported by the BIM coordinator, who adds that planning will not be fully incorporated in the model, however sequences of the schedule will be used to visualise production and thereby enhance planning. Thus, 4D BIM will not be used to its full potential at Karlatornet, although steps are taken away from conventional planning methodology towards new methods where LBP and BIM are used to achieve higher efficiency.

Project manager B states that planning is conducted in stages with different level of detail, commencing with an overview where the initial calculations are incorporated to get a grip on the total amount of time needed for each specific milestone in the project. As Karlatornet is an in-house project, the calculations manager has been able to work closely to those who are to conduct the production planning, which has simplified the transfer of information. The calculations have been incorporated in the master schedule, which is broken down into milestones and divided by structural works, installations and internal works. Project manager A stresses that having flexibility between the milestones is key in creating successful scheduling in the coming stage, as there are changes in production along the way. Hence, the milestones are set by times that cannot be changed, such as receiving a building permit and having the final inspection, while planning between them is conducted to optimise production efficiency in relation to costs.

Further, there is a disagreement on how to proceed with planning where project manager B claims that planning in locations is done in every project to find the logical sequence of activities, where after it is up to each party to ensure that they can cope with the schedule. The installations coordinator on the other hand presses the importance of planning in locations as it provides the relation of work between different parties, making it easier to adjust the schedule and optimise resource utilisation. This implies a significant difference where focus is shifted from push to pull in production by optimising resources in planning instead of locking the activities within the schedule. The retired senior director claims that by locking the activities within the schedule, making it up to each party to deliver what is promised by their contract, usually leads to a push system where the contractor gets to blame those who do not cope. Instead, a collective mind-set can be created in the planning process where resource utilisation can be optimised before commencing the actual work. In addition, project manager A lifts that planning in locations is advantageous specifically for repetitive projects, such as Karlatornet, where the internal works will be divided in two halves for each floor over 18 floors. Repetitive work does according to him provide means for phase scheduling conducted in locations to create efficient production cycles where the team eventually becomes an oiled-up machinery. Besides, he also presses the importance of knowing the relation of work between different parties to achieve efficient workflow throughout the production cycle, where collaboration between the involved parties is a key aspect.

For detailed planning where the specific activity is to be planned, the interviewees agree on that the party who is to perform the activity possesses the best competence to plan for it. Thus, float can be minimised within each activity respectively, provided that those who are to perform the activities strive towards optimisation. In this scenario, there is however no relation between the works respectively as it considers the execution of specific activities connected to specific trades. To achieve this, collaborative planning where activities are set in relation to each other is required in order to also minimise float between the activities in the schedule.

4.2.1 Push and pull in production

The purchasing manager claims that when a master schedule has been set, it is usually pushed to production and each subcontractor to execute. He claims that by asking the right questions when procuring subcontractors, the right services will be delivered. Therefore, it is also considered equally important to not provide the wrong information. This gives that different subcontractors should be procured at different times, as the right information becomes available to them at different times in the process. To include each subcontractor in the planning process can therefore be found tedious in some cases, as it may not be the right time to procure them. This also implies constraints to what activities that can be pushed and pulled respectively, making it important to evaluate which subcontractors that are crucial to include early in the project. At Karlatornet, several subcontractors have contracts of intent, as the project is yet to receive a building permit. This method has been used as there is need of competence within specific areas to achieve increased pull for production and avoid times from being pushed for production to execute without the opportunity of giving input. Despite this ambition, a language barrier is expected to exist at the construction site and among the different subcontractors, which is thought to imply difficulties for collective planning and later production control.

Project manager B claims that Serneke, as the contractor, must be able to trust that the subcontractors perform what is written in their contracts, and that push therefore is required. According to him, the master schedule will define what has to be done by each subcontractor every week. The installations coordinator on the other hand stresses the importance of avoiding clashes between different working teams, naming input from those who are to perform related activities fundamental in creating efficient workflow. He claims that it becomes essential to conduct the right activity at the right time when constructing high-rise constructions, as breaking the production cycle have greater effects than in other types of projects, as high-rise constructions imply extensive repetition. Thereby, having increased pull in production is also preferred at Karlatornet due to its large extent of repetition. A clean pull system is however not desired as it would imply less control of the total progress, and difficulties in deriving responsibility to each respective subcontractor. Thus, a suitable combination must be found to achieve efficient workflow.

The control system that is to be used for internal works at Karlatornet is also yet to be formed according to project manager A. He further presses that it must be developed to avoid clashes and obstruction of materials as much as possible to reduce non-value adding activities. To achieve this, production must be superior to logistics and therefore push logistics rather than having deliveries pushing production, which can result in obstruction. The BIM coordinator have a vision of using a control system where each activity is checked off in the model when conducted to decide on where to progress. This could according to several interviewees be combined with a system like LPS, where reporting is done continuously from those who carry out the work where after the information is gathered in the model. The master schedule will ultimately act as base in planning, however flexibility in resources is required to optimise workflow and create an even flow between different subcontractors to avoid clashes, resulting in a balanced push and pull in production. There is however a clash in opinions, where the master schedule according to project manager B should be governing while increased pull is strived for according to project manager A, giving that the balance is yet to reach organisational alignment. The latter alternative requires that the schedule is revised as construction proceeds to match the actual pace. According to the installations manager, this is however a process which continuously is being worked with, as organisational alignment is key in achieving good collaborations.

4.2.2 Flow through activities or locations

The LPS lecturer presses that moving from flow through activities to flow through locations, implying a collaborative process rather than an individual, is the main point in planning production. To have all affected subcontractors involved when planning the work in a location instead of pushing each respective subcontractor to carry out specific activities is stressed to help in achieving efficient workflow. Planning in separate activities, forming a long line of activities, is expressed to reduce focus on how the activities are related to each other and how to reduce float. It is argued by project manager A that initially an activity-based working method might be preferable as it allows for easy connection to the production time schedule. However, as planning proceeds, activities will be connected to the locations where they are to be performed. The installations coordinator adds to this and presses that by dividing planning into different locations subcontractors can work on the same floor without interfere with each other. This results in increased efficiency as utilisation of the available space is increased. Thereby it is suggested that the location-based method will enable for an effective view of how much work that is carried out at each given time and location in comparison to the traditional CPM. Both project manager A and the installations coordinator argue that activities commonly are directed to specific locations with input from each respective subcontractor, however the coordination should according to them be carried out by one responsible party, suggestively the contractor. The installations coordinator argues that having input from those who are to perform specific tasks is essential as they have the best competence to plan the activity they are to carry out, however having one responsible party is considered essential as the responsibility otherwise may be difficult to derive.

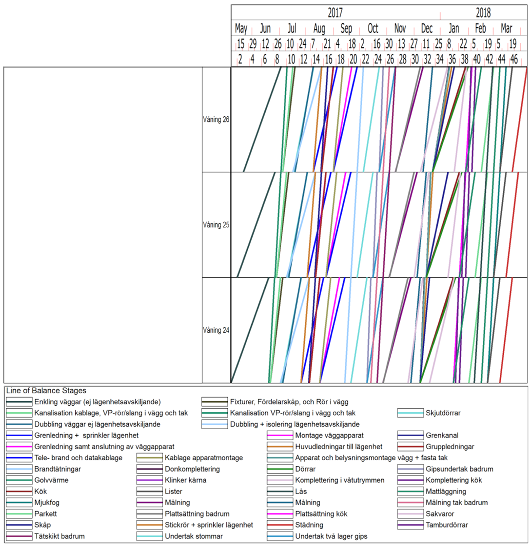
At Karlatornet, PowerProject is used as scheduling software. It contains the advantages of both being able to carry out conventional planning where each activity is visualised and LBP where the activities within a location are related to each other. This gives that when the times for each activity have been estimated, their respective inclinations can be compared to evaluate where resources need to be redistributed. The installations coordinator uses this programme extensively and claims that he rarely needs to present further arguments than the outcomes from the software when communicating with those who are performing the activities regarding whether they need to increase or decrease resources. As the software can adhere to both types of planning, it is also very flexible in giving the user power over the tool, and thereby technical alignment is created within the project as the planners are using the same tool. However, as competence regarding utilisation differs, the outcomes also differ. The possibility of using different types of scheduling within the same software does however imply that the user can choose how to work with the software, and also compare the different ways of using it. This further gives that even though technical alignment exists, organisational alignment is not necessarily achieved.

4.2.3 Location-based planning

Utilisation of LBS is considered to be a more convenient way of planning according to the research engineer, who states that dividing planning in locations rather than activities gives a comprehensive view on the actual work. Additionally, the retired senior director claims that LBS can be majorly beneficial for repetitive work, which is connected to high-rise construction. As LBS aims to produce production cycles with a constant amount of work to improve flow, the efficiency can be incremental in high-rise construction as repetitive work already is implied. This is further supported by the BIM coordinator who stresses that planning in locations can be connected easily to the technical development within the industry, giving advantages in visualising different sequences. This is a function which will be used at Karlatornet to create a common understanding on how to proceed in production as avoiding clashes is considered essential in optimising the production cycle. Project manager A further claims that the production system must be aligned with the software to create efficiency in production as LBP not only is about scheduling but also about production.

In order to ensure production flow, the installations coordinator uses locations which are less sensitive to changes in the production schedule. He claims that there will always be uncertainty involved in production, providing that planning with buffer locations is necessary. In high-rise construction, there is however little possibility to create buffer locations as the majority of the work is repetitive and conducted with limited space. Having a continuous use of resources is however something he claims to be easily achieved when planning in locations, as they provide a logical sequence where activities are illustrated effectively. In addition, if the production cycle becomes out of phase, it is easier to find the deficiency. Having buffer locations instead of buffer times incorporated in the schedule gives the advantage of less float, which conventionally is built into the schedule. Buffer locations can according to the installations coordinator be carried out almost at any time, giving that production is increasingly flexible while avoiding that different subcontractors have to wait for others to begin with their work. Project manager A however expresses that by using LBS, the schedule becomes increasingly sensitive to outer impacts such as harsh weather conditions or sickness of staff, which therefore is a risk. Having minimised float is considered to optimise production flow when everyone is working and logistics is synchronised, although it is pressed that this rarely is the case. Although, developing a system where LBP is implied is prioritised, and outer impacts must be managed through adapting the affected crew.

As PowerProject has the function of creating flowline charts from Gantt charts, taking CPM to LBS, a location-based focus is increased through the use of software. The retired senior director however claims that using software cannot give the full benefits of LC as the tools do not take soft values into account. By creating a collective approach to planning where the production cycle is revised jointly to create understanding for each other's respective work should instead be prioritised, as it still is humans that are doing the work. In these regards, a management system such as LBMS is considered helpful in creating a collective approach. Nonetheless, he sees that having sophisticated software also can provide means for extensive understanding among the participants as tools for increased visualisation are emerging. It gives means for both hard and soft management, as it implies collaboration to minimise float while also showing the bottlenecks, in which extra efforts are required compared to the initial plan. PowerProject is thought to have this impact for planning at Karlatornet, as it provides arguments for resource optimisation to enhance workflow. As seen in Figure 9, the initial plan, without resource optimisation, resulted in a broad variety of inclinations, while Figure 10 shows the production cycle after resource optimisation by using a flowline chart results in almost parallel lines and thus increased optimisation.



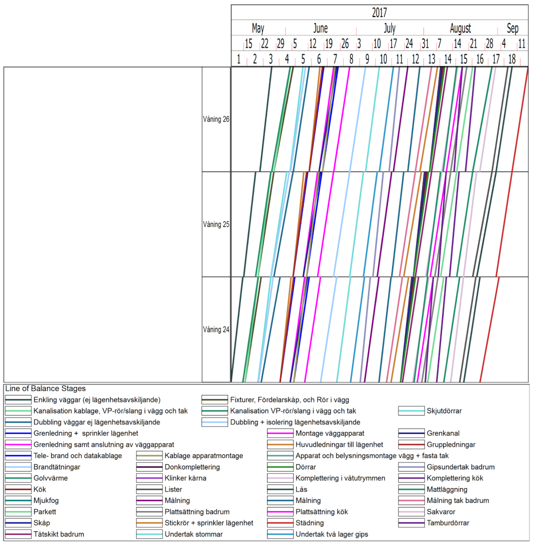


Figure 9 - Flowline chart with initial inputs at Karlatornet.

Figure 10 -Flowline chart after optimisation at Karlatornet.

Another advantage with LBS stressed by the installations coordinator is improved visualisation of how resources are distributed. He states: *"When I present a location-based schedule, it becomes easier to see who needs to accelerate or slow down to enhance workflow."* Thereby, the software can be used as argument for optimising workflow and helping to distribute resources. However, as with any other software the information that is inserted defines the outcome. Creating a LBP system that is suitable for Serneke is considered vital for a successful implementation. Even though the system includes great potential for increasing efficiency, implementation can be complex as there are no standard implementation plan that suits every organisation. Instead, by gradually implementing and adjusting the system to the organisations own needs it is believed to achieve a higher commitment and efficient utilisation.

4.2.4 BIM for production

When assessing BIM, the research engineer and the programme leader are troubled to find any negative sides, whereas for example the calculations manager claims it to be time consuming and costly apart from also being very technical and thus competence demanding. The main benefit, which is generally stressed by the interviewees, is the visualisation process where a 3D model have clear advantages over 2D blueprints. By enabling for sequences to be tested and clashes to be identified through simulations, it is thought to decrease non-value adding processes in production. The VDC coordinator expresses that 4D planning in BIM can enhance planning as connecting time to the model implies the possibility to try different sequences, giving the constraints for each specific sequence and thus constructing the project virtually before physically. According to him, this entails easier decision making in the planning process resulting in more comprehensive planning. This is supported by the BIM coordinator who claims that technology now starts to enable for extensive use of the model, giving it a higher value. It is further noted by the VDC coordinator that for BIM to generate a higher value for the industry there is a need of developing BIM into an integrated approach that does not merely incorporate the information model. Instead there should be a combination of the increased visualisation provided by BIM with other management tools from LC to fully exploit the benefits. The essence is to create a system where integration and automation is achieved through combining software and systems. At Karlatornet, one step is taken towards integrated 4D planning, as sequences will be picked out from the model to visualise how different locations are going to be constructed. By doing so, it is expected that understanding is improved among the participants and clashes are detected earlier in the process.

Project manager B describes that he did his own dissertation on BIM in 1999 and that he is puzzled that it has not come farther. He stresses that there are several reasons to inertia in implementation stating that the general competence is the most pressing one. Technical development, the variation of software and being reluctant to change are described as other barriers apart from the costs that change implies. The calculations manager also expresses that there are juridical difficulties with implementation as the model is yet to receive liability making it reliant on pull from the industry. The BIM coordinator opposes that the model lacks liability, referring to that it is up to the client to incorporate the right conditions in the contracts. This can however also be considered being required to rely on pull from the industry. Besides this, the calculations manager claims that the competence required to take the model to the level of development required for full use is more expensive than conducting the same measurements with conventional measurements software. The model at Karlatornet is therefore not perceived to be suitable for containing every single construction component from an economic standpoint, making its main application in planning visualisation.

There are however areas where exact measurements are desired, such as the structure, according to the structural engineer and the structural model manager. They claim that by having a level of detail in the model for the structure where every building component is included in the model to base purchases from suppliers on, the model can indeed be beneficial as this gives opportunity to also include planning in the model. When having this level of detail, it is argued that every component can be derived to a certain position in a sequence, which further can be shown in a simulation to support production planning. This simulation is further shown to those who are responsible for the work and those who are to perform it, and hence they can get a grip of the work before executing it. However, the costs implied by the level of detail needed are also acknowledged giving that it may not be suitable for all types of works or all projects. The structure however is considered to consist of work by fewer subcontractors and with less material variation which makes it more suitable for inclusion of every building component. As there is less variation of elements making it more suitable for being of exact measurements as it compared to conventional measuring is considered economically favourable.

According to the structural BIM manager, there is need of an extensive BIM execution plan where demarcations are clearly shown to ensure that BIM is used similarly by all parties to achieve technical alignment. It is expressed that non-value adding processes are created when the different parties are not synchronised as late changes often create secondary faults forcing double work on a single activity. To get the right information from the beginning is considered key in creating efficient processes. This is also stressed by the calculations manager who claims that measurements in the model commonly exist twice as different parties put in the same information and thus make the model unusable for making purchases or measuring time or cost. This is also something that is expressed to hamper the use of BIM in production as its correctness depends on the level of development, where the necessary level in many cases is costlier than making conventional measurements. The BIM coordinator, who closely to the calculations manager have developed the BIM execution plan at Karlatornet, states that standards are being developed where a level appropriate to the project must be decided early on to improve the use of the model. Thus, merely relying on BIM and including all elements in the model is considered excessive, giving that a hybrid practise is created where different software and systems are combined to reach integration.

4.2.5 Coordinating production

According to the LPS lecturer, focus on creating social processes in planning is insufficient, resulting in poor planning with activities being desynchronised. He further claims that to have a continuous workflow where subcontractors, that are to carry out their work in relation to each other, need to engage in the process to understand each respective work. This should result in better collaboration, giving that time waste can be reduced as the different parties can assist each other and thus create a project focus. Hence, everyone involved should strive towards a common goal. The retired senior director supports this and adds that it is to have everyone involved and sharing a lean thinking that does the difference. Both claim that benefits are to be found when implementing lean tools, however not as substantial as if the thinking is implemented fully. The purchasing manager opposes this by stating that each party will perform what is concluded in their contract and that pressure therefore should be on giving the right conditions from the start. Cooperation should according to him be based in what has been agreed during the procurement rather than being expected to happen at the site. The Swedish regulations are however expressed to be obstructive to new working methods as excessive meetings to what is considered standard can be charged for by subcontractors. Thus, by laying extensive focus on planning where subcontractors are expected to join collective planning meetings, extra costs must be motivated. To include subcontractors in production planning and embark on the social process is however something that Serneke has chosen to do at Karlatornet. The amount of repetition is considered a vital factor that serves as reason for extended focus on planning a production cycle where uncertainty is minimised. Therefore, it is concluded by project manager A that the competence from the subcontractors is necessary when planning the production cycle.

Planning workshops are regarded as necessary by the interviewees, where the programme leader explains that they lay grounds for cooperation in production. The workshops are meant to visualise the constraints by each respective party giving a totality focus on how the specific location or activity is going to be performed. This is further argued by both logistics manager A and the installations coordinator to be vital parts in the process of creating organisational alignment between subcontractors, and by doing so increase the means for collaboration. The workshops are further claimed to provide that possible clashes between the subcontractors are detected before they occur, which gives that they can be prevented. Thus, float can be minimised between the respective activities, giving that pull for production is increased.

4.3 Planning for logistics

The general opinion among the interviewees is that logistics have major impact on workflow in production, and thus also project performance. It is specifically stressed that when constructing high-rise buildings, density becomes a vital constraint as the space on each level must be considered. Logistics manager A gives the following explanation "*if the building had been lying down, the logistics would have been far less complicated. However, as it is standing up, there is also density in height*". In addition to this, Karlatornet is going to be placed close to the city centre, making traffic an important constraint for deliveries. To decrease pressure on site, JIT deliveries will be strived for resulting in an increased focus on planning and setting the right conditions in the contracts.

4.3.1 Push and pull in logistics

Logistics manager A argues that extensive focus at Karlatornet lies on achieving pull for production, specifically with JIT as driving approach being incorporated in the contracts. There will be three different types of deliveries depending on what they contain; direct deliveries from suppliers, deliveries via a consolidation centre and deliveries for storage at site. These are visualised in figure 11. Option one is for materials which can fill a truckload and be distributed directly at the site, option two for materials that need to be distributed before coming to site to fill a truckload and option three is for materials with high consumption. By optimising each type of delivery, it is thought that logistics will help to enhance production instead of obstructing it. Project manager A expresses that letting logistics pull production commonly leads to obstruction at the site which can hinder the production cycle, and further argues that having the right material delivered to the right place at the right time is central for creating efficient workflow. In order to reduce uncertainty regarding deliveries, both the BIM coordinator and the VDC coordinator promotes making simulations of deliveries in the different construction stages. By doing so, clashes can be detected beforehand and thus, it becomes easier to plan how to manage deliveries of different materials at different stages. The balance between push and pull can thus be evaluated continuously in production, giving an optimised workflow and making it possible to determine the bottlenecks for logistics in different stages of production.

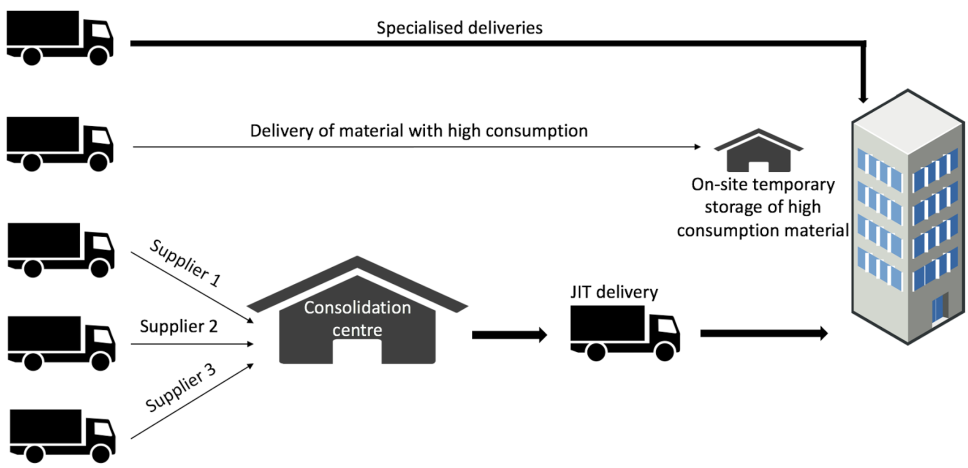


Figure 11 - Delivery methods at Karlatornet.

By having a consolidation centre where deliveries are coordinated to suit demand of materials at specific times, flexibility is implied in the delivery system. This is stressed by several interviewees to be essential as changes in production must create reaction in logistics as it otherwise may result in downtime if deliveries are slower than production and obstruction if deliveries are pushed to the site. Flexibility is also required as there will be different times for transportation at the site depending on which floor the materials are going to be delivered to. The hoist times will be significantly lower during the first stages of production, incrementally increasing as the works are proceeding to the higher floors. Deliveries will therefore mainly be outside of production hours to facilitate efficient logistics and low downtime. Thus, logistics are pushed to be flexible and adapt to production.

A strict system for deliveries where every material is marked with a delivery time and location will according to the logistics coordinator help to ensure JIT deliveries. Every delivery can be checked upon arrival and coordinated to its assigned location, where both time and location can be adapted to the actual demand on site based on production control. Coordination is however expressed to be a major challenge for logistics to maintain flexibility in the delivery system, based on changes in production. An IT-based booking system will therefore be used for deliveries. Once again, the solution implies excessive push for logistics, as it is strictly governed to match actual demand resulting in that flexibility must be high for deliveries. This is however deemed necessary by the logistics coordinator, as the implications connected to the characteristics of high-rise construction are great if logistics pushes production.

4.3.2 Supply logistics

As three options for deliveries have been chosen, supply logistics are managed differently depending on what material it regards and who is responsible for the material. Materials which are hefty and possible to deliver in larger amounts without obstructing production will be delivered directly from suppliers, while smaller materials and materials that only is needed in smaller amounts will be distributed at the consolidation centre before being delivered to the site. Finally, materials with high consumption will be delivered and stored at the site to ensure its availability. The logistics manager claims that the density around and inside Karlatornet entails that different solutions are required for different materials as storage on site is extremely limited. Storing materials on each floor can be done to a low extent, giving that a JIT approach is demanded for deliveries. According to project manager A, as much material as possible will be prefabricated to decrease transportations and waste on site. This is supported by the installations coordinator who claims that if materials can be assembled in advance, there will be less coordination between logistics and production.

Moreover, the consolidation centre does not only provide benefits as it implies a substantial investment. According to logistics manager A, new crew needs to be hired and systems need to be set up apart from renting a location suitable for deliveries to Karlatornet. To motivate the costs of this investments, savings must be done in other ends such as simplified production or decreased costs of logistics at site. According to the logistics manager, there are however many costs which can be reduced through the use of a consolidation centre which are difficult to show. Having improved order on site is one of the costs that are difficult to calculate as estimations on how much goods that needs to be moved around on the site or inside the building before being ready for production are vague. It largely depends on those who are working with logistics and how well they distribute the materials on site, making it differ between different parties and goods. Instead, a consolidation centre is thought to entail better order on site, and thus improving the situation for all involved parties. According to the purchasing manager, this is also something that will be shown when procuring subcontractors as better circumstances on the site entails better tenders.

To manage a signal system where deliveries are communicated from subcontractors to the contractor and further to the suppliers or the consolidation centre, an IT-based software called Myloc will be used. Myloc provides a service where deliveries are scheduled to the construction site in the cloud for all parties to see. Each subcontractor will use the system to book the respective delivery. The system will be managed by the logistics manager who administers the dates of deliveries for types of goods to ensure that goods are delivered to the right place at the right time. As a material is ready for being called to the site, a notification is sent to the supplier or the consolidation centre depending on what type of material it considers. When the deliveries arrive to the construction site, they are distributed to their respective delivery zone wherefrom teams responsible for on-site distribution takes over to deliver the material to the right location within the building. This is ensured by using BEAst, a system for marking goods, which shows delivery zone, right location, responsible party, what goods the delivery considers and time. Combined with JIT deliveries arranged after actual demand on site, the right materials are delivered to the right place at the right time.

4.3.3 Just in time

As storing material remains a limited option at Karlatornet, JIT is incorporated systematically. When each subcontractor is contracted, they receive information on how logistics are managed according to JIT, both regarding supply logistics and logistics on site, in order to create organisational alignment. Besides this, efforts are made towards simplifying JIT deliveries as prefabrication is going to be conducted to a high extent. Further, deliveries for internal works will mainly be after production hours to optimise logistics workflow and minimise obstruction on site giving that repetition of deliveries can be created. According to logistics manager A, deliveries from the consolidation centre will be divided into zones to suit the production schedule. As production incorporates LBP, deliveries can be adapted to follow the same schematic to achieve a JIT approach throughout.

JIT does however imply a risk as it may result in downtime due to production running out of materials. The VDC coordinator claims that clash detection can be done if the time schedule is incorporated in the model, however unforeseen events are not included in this process. Changing weather conditions and sickness in staff are considered the two major unforeseen risks that are built in when using JIT. In Sweden, where the weather conditions during winter tend to vary, transportation risks to be affected resulting in delays in the delivery schedule. The same goes with sickness in staff, as if all material cannot be delivered to a certain place at a certain time will give that logistics fall behind. The logistics manager claims that these types of risks will be estimated during the planning process to minimise the effects.

The main issue with JIT deliveries is that they tend to be costly, compared to deliveries which are adapted to the supplier. It is therefore important that suppliers are held accountable for possible fees that arise if deliveries are late, does not arrive on the set date, or does not include the right goods for example. The same applies to subcontractors if they manage to schedule deliveries so that production is obstructed by hampering logistics. Therefore, it is also a necessity that contracts are formed to impose JIT.

4.3.4 BIM for logistics

There is a general conception among the interviewees that BIM has yet to reach its full potential regarding planning. The BIM coordinator explains that the inertia towards implementation largely depend on that neither the systems or the humans working with them have been able to manage the amount of information necessary for effective use. Instead, information is stored separately and managed by different software where production scheduling is done in PowerProject, logistics scheduling in Myloc, calculations in MAP whereas the model mainly is used for visualisation and simulation of specific segments. For logistics, the VDC coordinator stresses that simulations in specific stages enables for clash detection before delivering. This can be done both for supply logistics where the surroundings for the construction site changes between different phases, having different amount of cranes in different stages of production, and for logistics at site where material needs to be directed to specific places on each floor. By running simulations, visualisation over which activities that may clash become clear compared to trying to synchronise the schedule with a 2D blueprint. Besides, this can be connected to the LBP system that will be used in production where BIM models can help in dividing the locations to derive what goods to deliver where in the sequence. According to the both the programme leader and logistics manager A, this will help in creating efficient delivery schedules as the model shows when material is needed where.

Furthermore, the calculations manager argues that the demarcations, which are set in the BIM execution plan, define the usefulness of the model. If the right conditions are set from the beginning, it becomes easier to work with the model making it value adding throughout the process. The structural engineer and structural BIM manger agree with this and state that for the model to be useful in production, a high level of detail is necessary. According to them, this can be achieved through including the necessary parties in the process early as this provides less changes later in the process. Having competence to make the right decision from the beginning is thought to lower the total costs, as their opinion is that the major cost overruns comes from changes made late in the process. BIM does however needs to be combined with other software, and also with systems, to reach its full potential. By doing so, software and systems become integrated providing means for automation.

4.3.5 Coordinating logistics

There is little focus on creating a social process in logistics coordination according to logistics manager A. Instead, suppliers easily become disconnected as they do not carry out any work at the construction site, but only deliver material to the site. However, logistics manager A also argues that on dense worksites where storage opportunities are limited, extensive coordination between different suppliers is invoked. The VDC coordinator supports this and further claims that deliveries must be coordinated strictly not to obstruct production. Having workshops for suppliers, as for subcontractors in production, is considered overwhelming by several interviewees while others mean that it in fact may be necessary to coordinate logistics collectively.

At Karlatornet, the logistics manager will be responsible for coordination with assist from both within and outside of the organisation. Myloc will be used to distribute delivery times to suppliers and locations to the logistic crew at the site, however it is up to each subcontractor to book their deliveries in the system. As deliveries will be largely repetitive, a delivery cycle will form a base after which the remaining deliveries will be scheduled separately. Whether deliveries come directly from the suppliers or via the consolidation centre will therefore not make a difference, as the system manages deliveries only as incoming and outgoing making each delivery connected to a specific zone and time slot in the schedule. Coordination with the consolidation does however result in excessive communication compared to projects where a consolidation centre is not used as it implies one delivery to the centre, coordination of material to fill a truckload and then a delivery to the construction site. Here, it is expected that close communication between the logistics manager and the team at site and the team at the consolidation centre will ensure that the right material is delivered to the right place at the right time. This information is also distributed through Myloc, where each delivery is planned.

The structure for deliveries should according to logistics manager A should optimise a pull flow for logistics at Karlatornet. As there are several steps in the supply chain, with deliveries being coordinated at the consolidation centre, there is also a risk in delivery times resulting in that ordering must be done well in advance to ensure that deliveries are on time. This implies extensive planning and making early purchases, however deliveries remain flexible as if reported in advance goods can be held at the suppliers or consolidation centre to avoid push on the site.

4.4 Synchronising production and logistics planning

Production and logistics planning can be optimised separately, however all interviewees stress that the synchronisation is crucial for achieving efficient workflow. Even though the complexity in Karlastaden requires planning separately and not having production managing logistics, the flow in production should not be harmed but rather streamlined as extra focus is laid on logistics.

4.4.1 Push and pull

In order to achieve increased pull throughout the chain from subcontractors to suppliers, there is need of breaking the conventional approach according to the programme leader. He claims that a signal system where materials are called for when needed in production rather than being delivered based on a schedule implies the lowest amount of downtime and thus the most efficient workflow, as it represents actual time for demand instead of estimated time. This does however imply extensive flexibility in deliveries and the possibility to make changes in the plan from day to day. At Karlatornet, where internal works will be conducted at 18 different floors at the same time, the risk for clashes becomes considerable. Planning is therefore conducted separately to begin with, and later combined to detect possible clashes. The amount of goods that is going to be delivered to each floor for one cycle is measured and further distributed over the floors to be matched with the production cycle. By doing so, constraints in both the production and delivery schedule are shown after which a balance between push and pull in production and logistics is found. The master schedule will thus act as anchor pushing production, while pull is achieved through collaborative planning and extensive control combined with the three different delivery systems, specifically designed for different type of goods. Retaining push through the master schedule is considered inevitable as subcontractors must be held liable for their respective work.

Furthermore, avoiding clashes both in production and logistics is deemed essential in containing increased pull in production, as downtime in either of them can result in obstructing the other. The retired senior director expresses that there are major benefits to find in the repetitiveness given by similar floor plan in high-rise construction. Efficient workflow is thought to be achieved as the production cycle is set and the teams have got the chance to optimise their work. Project manager A states that "*we initially plan a production cycle, which is streamlined together with those who are to perform the work to ensure that everyone is aligned".* At the same time, it does however imply a substantial risk as buffer times are eliminated when planning with minimised float, as teams are working closer to each other´s activities. The installations coordinator uses buffer locations when planning production to ensure that work is continuous and downtime is minimised, however expresses that it is difficult to find suitable locations when constructing high-rise buildings. By dividing production in locations over activities, it is also thought that production can push logistics to the location needed to create a continuous workflow. To support this system, JIT deliveries are focused to pull production. The consolidation centre will enable for coordinated deliveries where materials are distributed to specific locations directly, rather than having to move materials around on the site, while direct deliveries only will consist of materials that can be stored right next to the site and where it is to be used on each specific floor. Thus, increased pull for production is strived for resulting in a demand of extensive flexibility in logistics to enable efficient workflow throughout the chain.

There is however a long way to go regarding synchronised planning for production and logistics according to the installations manager. At the stage of the interview, planning was conducted separately resulting in differences in opinions and systems. When asked about the process of creating organisational alignment, the installations coordinator answered "*We should probably start off with talking to each other"* giving that an initial plan was missing. This could also be seen through differences in opinions of the interviewees, where project manager B states that push through the master schedule is required while project manager A presses the importance of close collaborations and inclusion of those who are to perform the work in the production planning process. This can according to the logistics coordinator imply a risk, as varying balance between different types of activities provides different conditions for logistics.

4.4.2 Integrating LBS and JIT

To have continuous flow from suppliers to subcontractors throughout construction is considered essential at Karlatornet. The density at the site, combined with a strive towards enhanced workflow has led to an integrated model of LBS and JIT. Deliveries are going to be done to locations where work is ready to commence, increasing pull for production. The use of a LBP system from suppliers to subcontractors is thought to simplify for deliveries, as a supply cycle can be created to match the production cycle that is implied by using LBS. As production proceeds, it is however expressed by project manager A that the production rate will increase resulting in that logistics must be able to cope with a higher tempo. Logistics manager A presents an example of where the hoist times increase incrementally as the building rises, although approximately the same amount of material must be delivered to each floor. Thus, as the production tempo increases, the logistics tempo risks to stagnate. Logistics manager A therefore uses a mean value when estimating times, which later will be used to divide the building into sections where the delivery times are optimised. This must also continuously be managed in the LBP system, to not result in obstruction due to the varying pace.

To have an integrated system is pressed to be costly according to the calculations manager, as having deliveries coordinated to specific locations instead of delivering full truckloads of the same material for each delivery is more expensive. Logistics manager A however stresses that for Karlatornet, it will be a necessity to coordinate deliveries before they arrive at site to ensure that full truckloads can be delivered due to the lack of space. The use of a consolidation centre will make it easier to coordinate materials to locations, as each delivery can be assembled at the centre also entailing that full truckloads are ensured. Simultaneously, the consolidation centre implies having increased control over deliveries as it is a supportive function to the project. Thus can be compared to having suppliers which have other commitments. Thus, the consolidation centre promotes the use of JIT deliveries integrated in LBS as it lowers uncertainty in deliveries and enables coordination of materials before being delivered to the site.

As the building is divided in halves over 18 floors, where each half represents one location in production, deliveries are planned to be divided similarly for logistics. Project manager A claims that having a synchronised planning system will tie production and logistics closer to each other, making the collaboration better. This is further thought to decrease uncertainty as communication is expressed to be commonly problematic when synchronising production and logistics. An integrated system, where the parties are working closely is therefore deemed more flexible to changes. The division by halves is further stressed to be preliminary, as an optimised solution suitable for both production and logistics is to be developed as planning proceeds, similarly to how planning is done in LBMS. As having buffer zones is expressed by the installations to be vital for continuous workflow, it does however mean that the locations must be divided to suit this structure. The same thinking is applied to logistics where preliminary investigations involved having one or two floors at different stages as material supply inside the building. This idea was however scrambled as it would entail issues with moving materials inside the building. To incorporate buffer zones instead of float between activities is nonetheless chosen to decrease downtime, and further increase continuous workflow.

The BIM coordinator explains that an integrated production system called Serneke VDC is being developed, to create alignment from suppliers to subcontractors in future projects. Logistics manager A builds on this reasoning, adding that having one aligned system is a key aspect at Karlatornet. All parties must be aligned with how processes will be managed to ensure that uncertainty is minimised. As scheduling is conducted with PowerProject for production and Myloc for logistics, synchronisation between the software is necessary. The BIM coordinator gives an example, stating that when an activity or location is completed it can be checked off in the BIM software and further communicated to the logistics system. The production and logistics schedules are controlled and adapted to actual status for deliveries to meet actual demand. The process does however imply that a comprehensively developed production system is in place, as all participants must be aligned with how it is working. Thus, there is a high demand of competence for the system to be implemented fully, as well as having a planning system in place. Both the BIM coordinator and logistics manager A are positive towards forming the system based on LBP, as they see advantages in creating efficient production cycles where float is minimised both between and within activities. In Figure 12, the initial plan for how the production system at Karlatornet is visualised, where it can be seen that LBP is implied both for production and logistics.

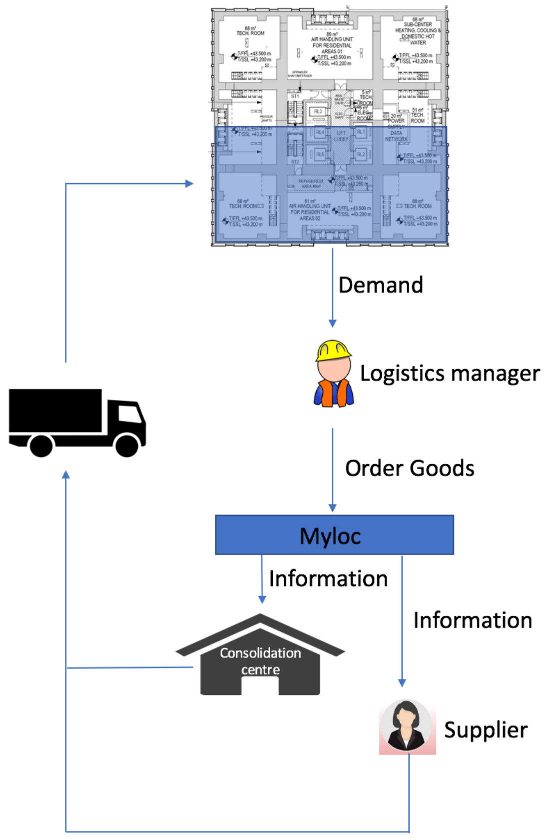


Figure 12 - Information and material flow from synchronised LBP and JIT at Karlatornet.

4.4.3 Virtual design and construction

BIM can according to the programme leader facilitate enhanced visualisation, where synchronisation between production and logistics planning can benefit from early clash detection and the possibility of constructing the building before construction begins. This is supported by the BIM coordinator who explains that sequences from the production schedule will be incorporated in the model to create simulations, and thus provide enhanced visualisations compared to having the schedule and 2D blueprints. Project manager B presses that this process must be conducted stepwise as full-scale implementation implies information heavy change, and therefore a substantial risk. Project manager A supports this, referring to the investigation on the software VICO which was considered overwhelming. Instead, striving towards what VDC encompasses where conventional tools is merged with new software, such as the production schedule incorporated in BIM to simulate sequences, uncertainty is argued to be reduced. By gradually moving towards an integrated VDC system, which further can move to cloud-based BIM models having all participants working online in the same model, education among participants in the industry have time to catch up.

Revolutionising the industry, as suggested by McKinsey (2017), is considered problematic as it would entail extreme short-term losses throughout the industry. This would imply devastating effects as the industry is fragmented and largely contains of small businesses.

Moving from 3D to 4D is however expected to explode throughout the industry when benefits can be shown in production according to the VDC coordinator. He describes a project in Stockholm where logistics are of utmost importance due to having several construction sites directly connected and centrally located. In the project, simulations were used to detect clashes in logistics before delivering, and thus ensuring minimised push. Because of this, a pull flow could be initiated from production, giving that obstruction was reduced and workflow was enhanced. He further claims that there is a lack of understanding for reading 2D blueprints, giving that new methods for visualisation is required to enhance planning. By simulating sequences where production and logistics are combined, the whole chain from supplier to subcontractor can be planned for each location. He means that this gives incentives for implementation of the fourth dimension as it is valuable for production to be able to conduct clash detections. The BIM coordinator agrees with this and further claims that the process of sequential clash detection recently have started and will be refined as planning proceeds.

The level of development is described to be crucial for 4D planning regarding production, as several of the interviewees experience that every building component needs to be included in the information model to get the sequences correct. Logistics, on the other hand, is expressed to need a less detailed model, as to decide on where to place materials only requires information on the approximate surroundings. It is however pressed by logistics manager A that each type of material needs to be assigned to an exact delivery spot to minimise obstruction for production. This gives that having a high level of development is not as necessary for logistics as for production when considering simulations and using the model to decide the logical sequence of activities for production. Therefore, it is according to the calculations manager essential to decide on a level appropriate to the specific project, which have to be matched with the ambition for the model. As 4D planning is only conducted in sequences at Karlatornet, having a high level of detail when planning production is only required for specific locations, or activities, where a simulation is to be created. To ensure that an appropriate level of development is reached at set milestones, the BIM execution plan is incorporated in the contracts for each member of the design team and subcontractors. The purchasing manager concludes this, stating that it comes down to the specifications that are set when procuring designers and subcontractors. As the ambition for Karlatornet is to be able to simulate sequences of both production and logistics in order to facilitate planning, the level of development at specific times is incorporated in the contracts to achieve this.

4.4.4 Coordination

To synchronise production and logistics coordination imposes major challenges, as both consist of extensive information management. Project manager A claims that having all participants aligned will be vital for the workflow as work will be conducted on 18 floors simultaneously, only for internal works. Adding that installations and structural works are conducted at the same time above the internal works gives that the production cycle is very long. This further impacts logistics, as material supply must match the demand of each floor, giving that strict management is required according to the logistics manager. Each subcontractor must be able to deliver a specific amount of work to keep up with the production cycle and the suppliers must be able to satisfy the material demand for the work that is going to be conducted.

By dividing the building in locations, in which resources are distributed to create a continuous workflow by using flowline charts, it is believed that production coordination is simplified. When a subcontractor has conducted their work within a location, this is reported, whereafter they move to the next location. As a location contains of several different activities performed by several different parties, an even and continuous workflow is considered key to achieve efficient production. The installations coordinator presses that the parties that are performing the work must have an understanding for each other, and that workshops and collective planning can provide that the organisation becomes aligned. By including those who are to perform the actual work in the planning process and thus engaging in a social process is thought to both provide more competence to the planning process and increase understanding among the production team. By conducting workshops and using BIM to facilitate understanding on the logical sequence of activities within each location, a production cycle can be tested before being conducted which entails focus on optimisation. Applied to logistics, where suppliers either deliver directly to site or to the consolidation centre and a logistics team further deliver materials to the right place at the right time on the site, and understanding throughout the supply chain is critical. At Karlatornet, where Myloc is going to be used to coordinate deliveries both on and off site, it is thought that information will be distributed to ensure that deliveries arrive on time and to the right place. To synchronise production and logistics will therefore largely depend on communication between production control and the logistics system, Myloc. A signal system, striving to achieve pull flow, is thus developed where production is controlled and if the rate is slower or faster than planned, logistics can be steered to match the actual rate. Simultaneously, it is described that production rates can be steered to match logistics. As the schedules are compared, the constraining factors are evaluated to find the optimised solution from suppliers to subcontractors.

Having two separate systems for production and logistics coordination is deemed necessary at Karlatornet, due to its complexity in both aspects. It is however stressed by project manager A and logistics manager A that the systems need to correlate and be similar to be easily synchronised. This will according to them also imply improved communication between the responsible parties, which for internal works production will be project manager A and logistics manager A for the logistics. They are responsible for scheduling the respective task, making synchronisation of internal works production and material deliveries to these activities their common responsibility.

5 Discussion

The objectives of this thesis were to evaluate the planning processes for both production and logistics, and further synchronisation between the two perspectives, at Karlatornet. These were broken down into three research questions, which were examined through interviewing and retrieving information from key personnel on the project. In this chapter, the Theoretical framework is synthesised with the Empirical findings and analysis to combine and compare the investigated theory with findings from the studied case.

The project organisation at Karlatornet is yet to reach alignment on how to plan production, and further synchronise production planning with logistics. Clear objectives exist from the company, imposed from the top of the organisation, however there is a broad variation in how planning is conducted and how tools are being used. Conventional ways of planning are continuously utilised as they provide less uncertainty for the user, which can be ascribed to a lack of competence often mentioned by the interviewees themselves. The tools for both efficient planning and planning for efficient construction exist, however there are several aspects which are subject for not only improvements but also change.

5.1 Incorporating LBP at Karlatornet

In short, there is need of alignment regarding how to work with LBP at Karlatornet. There is neither technical alignment on how to use software nor organisational alignment in form of a production system, resulting in that a complete management system such as LBMS is not in place. However, the implementation of LBS is incremental, where education and actual work with it is required to improve efficiency and understanding on how to efficiently manage the software. The same applies to managing those who are performing the activities, as including them in planning and thus engaging in a social process to increase commitment will only be done partly at Karlatornet. In this aspect, language is considered a difficult barrier to overcome, as several different languages are expected to occur at the site, possibly resulting in obstructing organisational alignment. However, the development of Serneke VDC hints of creating means for increased alignment as it implies both technical and organisational alignment to achieve an integrated and automated system. Further, to adhere to LBP will help to find the logical sequence of activities, and minimise float both within and between activities.

Increasing pull for production, compared to conventional construction, is highly prioritised due to the risk of downtime being significantly higher than in other types of construction. High-rise construction is characterised by repetition of a production cycle where breaking the cycle results in that the following parties cannot proceed, which applies to Karlatornet due to a high resemblance between the floors. Conducting the right activity at the right time is therefore of utmost importance when planning production. This gives that inclusion of subcontractors in the planning process is essential for achieving a comprehensive reporting system where logistics can be steered to match the actual demand of production. To develop a common understanding among those who are performing the work already during the planning phase will decrease uncertainty in production, giving that engaging in a social process can provide increased pull. This does not necessarily interfere with planning in different stages, where the first stage solely is based on estimations and simple calculations. It is rather the process placed in between when subcontractors are contracted and production begins that needs to be refined to have all parties aligned with the production cycle. Increasing pull for production will therefore largely depend on coordination, making it central to have a comprehensively developed plan which all included parties adhere to. It is however important to understand that total efficiency is strived for, making a combination between push and pull inevitable as there are milestones within the master schedule and lead times for logistics which production must be adapted to. To efficiently incorporate this at Karlatornet, LBP should be included in the contracts to have the conditions set from the beginning. By doing so, it can be stated how the master and phase schedule will be used to hold subcontractors reliable, which results in that the desired balance between push and pull is reached.

A production system based on LBS is yet to be fully implemented, as there are differences in how production is to be planned between different segments of construction. For example, LBS will be used extensively for installations and internal works, however structural works will mainly be planned conventionally and manually resource equalised. PowerProject is used by all parties working with scheduling, however knowledge of the software differs resulting in different approaches to it. Utilising it to enhance implementation of LBP is thus partial, which further entails that integration with a connected delivery system is obstructed. To focus on creating alignment in how work is planned and how software is used would facilitate more efficient integration with the whole production chain as well as with logistics. As LBMS also contains engaging the participants in the planning process, and thus deriving every activity to be planned by the one with the best competence, resulting in that estimations are minimised and scheduling become more comprehensive. Planning will however be done cyclically giving that it, even if done in activities, will be done with respect to locations as the production cycle for internal works is based in conducting 18 floors simultaneously. Dividing each level in halves further provides that a location is set for each subcontractor every week, giving that LBS is used in production. To achieve efficient use of LBP, Serneke needs to develop their own system which is suitable to the competence within their organisation. As LBP is only used partially, and not for all segments, it cannot reach its full potential but rather increase uncertainty as several systems are used simultaneously.

When considering the use of BIM, Karlatornet is used as a flagship for the company, having invested heavily in developing a solid model usable in production. This facilitates improved visualisation where sequences can be simulated to find the most efficient route of activities. A reporting system where progress is recognised and further sent to synchronise logistics is yet to be implemented, but instead a traditional system is going to be used where progress is reported directly to the logistics coordinator via Myloc if changes are made in relation to the preliminary delivery schedule. Automatisation is thus lacking, and the usage of BIM can thereby be seen to not fully reach integration and automation in regards to production but kept to what now has become conventional apart from the simulations. Developing a system where production progress is reported through BIM will facilitate going from using BIM to combining software and systems, to apply VDC. By extensive use of BIM at Karlatornet, Serneke however have the possibility to set a standard for how they are going to use it in coming projects, and thereby achieve incremental efficiency in planning.

The most crucial barrier for basing planning in locations, instead of only activities, can be considered competence as it hinders alignment both technically and organisationally. As it varies among the participant, and directives are not clear, there is a situation where each participant uses their own experience with the tools that have been provided. This is not in line with lean thinking, which is about decreasing the number of non-value adding activities by streamlining processes, as thinking becomes dispersed between the participants. Competence is considered hampering implementation of BIM and further integration and automation between different systems, as the participants prefer to work as they are used to be working. This results in that to incorporate LBP as the central concept of planning, it requires education and clear directives on not only which software and systems that should be used, but also instructions on how to use them.

5.2 Incorporating JIT at Karlatornet

The outline which have been set for logistics at Karlatornet is in line with what is suggested in the Theoretical framework. Managing deliveries depending on the actual demand at site will imply that JIT deliveries are promoted heavily. Lowering costs for logistics can however be deemed complicated as investing in a consolidation centre and designing a new delivery system with an increased amount of deliveries is costly compared to conventional deliveries, where full truckloads are delivered directly to site from the suppliers. Although, this is expected to be balanced by smoother production, and assessed to be necessary as storage on site is impossible due to the height constraint.

Deliveries will initially be planned conventionally, with a delivery schedule being developed based on the master schedule. It will however be revised after the production cycle has been set, and continuously updated as production proceeds to meet actual demands on site, by having the logistics coordinator managing the booking system. This results in increased pull for production, giving increased push for logistics compared to conventional construction. Logistics is further pushed by using a consolidation centre, where extensive information must be managed compared to having deliveries directly to site. Flexibility is however reached through this delivery route, as deliveries can be coordinated to meet the actual demand at site resulting in that the right goods can be delivered to the right place at the right time extensively.

So forth, having JIT incorporated in the contracts, and thus forcing subcontractors to continuously schedule their deliveries based on actual demand, provides that uncertainty is decreased. Subcontractors are held liable for reporting their deliveries, resulting in that control is generally improved for logistics. Having all deliveries booked and arranged in Myloc ensures that clashes are avoided and that goods only are delivered at the right time. Incorporating fees for not delivering on time and delivering the wrong materials will further ensure that costs are controlled. Additionally, the BEAst system gives that a delivery location is assigned before the delivery, and that deliveries can be connected to locations rather than to specific goods. Goods will therefore be delivered assembled to suit the demand of a specific location, giving that the risk of obstruction decreases.

The use of Myloc will enable for an automated system where changes occurring on site, which are reported to the logistics coordinator, will result in changes in the delivery schedule to adapt to the actual demand. Further, integration is achieved through running simulations on logistics at different stages of construction to detect possible clashes and possibilities that can be connected to specific times. Myloc and BIM will also provide that visualisation is improved, as Myloc shows what goods are arriving at what time to which place and BIM shows the constraints through simulations, however the systems are not integrated as deliveries are not based on measurements in BIM. Even though integration and automation is enabled through the use of software such as Myloc and BIM, giving means for JIT deliveries, they are not used to their full potential.

Coordinating logistics will be central in avoiding downtime and obstruction, making a comprehensively developed plan vital. Having strict forms adapted to JIT incorporated in the contracts, together with a software such as Myloc and the use of a consolidation centre, will ensure that more flexibility is reached for logistics. The challenge of stagnating logistics pace due to the height of Karlatornet will require extensive planning, as it otherwise may result in consequences for the production cycle and additionally prevent JIT deliveries. To optimise logistics based on each stage of production, to continuously meet actual demand at site, is therefore vital in achieving flow throughout the chain. Automatisation will thereby play a key role in the process, as changes in production must be included in logistics, implying that synchronisation between production and logistics is essential in achieving efficiency.

5.3 Synchronising planning at Karlatornet

Increasing pull for production, and thus increasing demands and push for logistics, is deemed necessary at Karlatornet due to constraining density at site. Developing a system where production and logistics are synchronised to minimise clashes and create flow from subcontractors to suppliers, while continuously managing changes to enable for JIT deliveries based on actual demand will thus be key for efficient production. Not reaching organisational and technical alignment in how production is planned will likely form a barrier for synchronisation as this affects logistics planning. Working with one system, where the chain from subcontractor to suppliers is the same for both structural works, installations and internal works, would decrease uncertainty and the amount of non-value adding processes due to reaching uniformity. Comprehensive planning is thereby required throughout the project, together with education of staff and extensive focus on collaborations.

Furthermore, reaching alignment is part of planning as it contains creating a common understanding of a problem and how to solve it. It can thus be seen to be part in a social process, where all participants gather information on how to proceed with their work. Attention thereby needs to be drawn towards collaboration and how work is to be conducted relative to each other to avoid clashes and non-value adding processes. This must primarily be done within production and logistics separately to ensure that there are no clashes in how either production and logistics are planned to be carried out. Further, production and logistics must be synchronised to be working with one system rather than creating one-off solutions to each part of production. As this has been done, information can be communicated to subcontractors and suppliers to create alignment throughout the whole chain but as it is yet to be reached, the risk of sending out the wrong information increases. Apart from the increased risk, it implies extra costs to manage several systems instead of having one integrated system for all synchronisation. Workshops and meetings will thereby play central roles in creating organisational alignment both vertically and horizontally in the project organisation, together with education to even out competence in the different organisational levels. Workshops for synchronising production and logistics must first and foremost be conducted to ensure that the right information is distributed in the respective chain.

Engaging subcontractors in the planning process, as well as reporting during production, will enable for deriving planning specific activities to those who have the best competence to do it, while actual demand can be measured continuously at site. Serneke still holds responsibility as the contractor, and each subcontractor is still held liable towards their contract, however optimisation of the production schedule thus requires extensive collaboration. Planning the activities in locations, and thus evaluating them in relation to each other implies that the float can be minimised and the production pace maximised. When connected to logistics, this results in having deliveries coordinated to meet the demand at the specific location instead of being connected to specific goods. Reporting at the site will thereby result in that suppliers are made aware of changes through Myloc, giving that an automated system is achieved where actual demand at the site is delivered to the right place at the right time. The initial plan will be based in the master schedule, and further the production schedule as it has been set, which gives milestones to when goods need to be delivered approximately. The use of a consolidation centre will further provide flexibility in deliveries, making it easier to adjust for actual demand. Deliveries can therefore be made from suppliers to the consolidation centre in advance to ensure that downtime is minimised, as Serneke controls it. To include suppliers in logistics planning would further give the opportunity to increase accuracy as suppliers use different systems, resulting in that deliveries will vary. As the consolidation centre is specifically installed for Karlatornet, there is need of extensive focus on creating alignment and common understanding about how to use systems such as Myloc, and further how to arrange deliveries. For example, reassuring that the assembly of deliveries is carried out to support the production system is central to avoid clashes.

Using BIM to support synchronisation by earlier clash detection and increased visualisation is planned to be done at Karlatornet, as well as partial integration in form of simulations where production and logistics are set relative to each other. Automation between different systems is however lost as reporting will not be done through BIM and further connected to Myloc but instead done manually. Changes in the production and logistics schedule will also be done in segments, as the objective only is to control and compare sequences rather than every detail. The level of detail chosen can therefore be considered adequate for visualisation, and partly considering integration however non-existent regarding automation. As Serneke VDC is being developed, this process is something that needs attention to create seamless solutions that have systems that are integrated and thus communicating with each other. The most important factor for implementation, recognised in this thesis, is competence within the industry where fragmentation in the industry is deemed a great barrier. Alignment is considered a cornerstone in achieving efficient processes, making a common understanding and thereby increased competence a requirement. This can be achieved through extensive education and clear communication, as having the tools to do it merely results in varying quality due to differing user capacity. For synchronised planning at Karlatornet, this means that the competence on the systems and software that are being used must be scaled to meet the demands of each specific role, as alignment is necessary both vertically and horizontally in the project organisation.

Informing subcontractors and suppliers already when procuring them will increase understanding and promote organisational alignment. Similar to how JIT is going to be incorporated in the contracts, subcontractors could be made aware of what production systems that is going to be used and how planning will be conducted. Having extensive collaboration in the planning phase does not imply that the liability in the contracts is lost, which must be clearly expressed. A cost driven focus can be remained, and milestones which have been set in early planning stages where only a master schedule have been available can be used as cornerstone for functioning production. Optimisations is however lost as times in this scenario are estimated, making it important to press in the contracts that the production cycle that has been set during the planning process will be superior to the master schedule. Obviously, the production cycle must be planned to meet milestones in the master schedule to not jeopardise finishing too late. Further, this provides that collaboration is implied in planning, as optimisation requires those with the best competence to plan each respective activity. To synchronise with logistics efficiently, the same structure regarding deliveries should apply to all subcontractors leading to alignment throughout the chain. The conditions for logistics must therefore be incorporated already in the subcontractor contracts, as well as the system that is to be used in production. This will create alignment in the chain and further promote an integrated system for synchronising production and logistics. As there are several new systems in place at Karlatornet, while the construction itself carries uncertainties as few high-rise constructions have been built in Sweden, control throughout the chain becomes increasingly vital. The constraints are very specific, having increased pull and thereby striving to have JIT deliveries to a high degree. Therefore, contracts must be used to promote synchronisation of production and logistics.

Adapting to new systems requires organisational changes, which implies run-in periods. As constructing a high-rise construction is new to most of the participants working at Karlatornet, change is inevitable. However, setting up an entirely new system for logistics, containing of a consolidation centre and optimisation of routes through three types of deliveries entails shaping a new organisation. The same applies to using location based scheduling, where conventional methods adhering to activity based scheduling previously has dominated among the planners. To integrate these systems and have them run efficiently requires comprehensive planning, but also education about how the systems are built and how they work. As competence is named the most critical factor in creating inertia in the industry, it must be prevented from being insufficient in these new systems when they are started. All participants must be able to carry out the work they are assigned to, making it a necessity to instruct subcontractors on how to use Myloc for example. The same applies to the use of LBP, where the production cycle adhering to specific locations needs close coordination and a well-developed collaboration to be synchronised with logistics.

5.4 Contribution and emerging questions

This thesis contributes to research by evaluating combinations of systems used for planning high-rise construction. The combination of push and pull, rather than pressing for one or the other, is extensively discussed with regards to practical implementation in high-rise construction. Combining different software and systems to achieve an integrated production system is also investigated, resulting in findings regarding opportunities and barriers. Specifically; BIM, PowerProject, and Myloc are studied and combined with production and logistics systems to assess how visualisation, integration and automation is managed, and further how the processes can be improved.

New software and systems for production and logistics are continuously being developed, where construction companies strive to find their own approach, using their own solutions and combinations. This is also presented in this thesis, where it is recognised that Serneke during the time was developing Serneke VDC. Combining different software and systems to enhance visualisation, integration and automation, and thereby decreasing the amount of non-value adding activities is therefore assessed to be a topic for further research. Another aspect subject for further research, which highlighted in this thesis, is the discussion on high-rise construction characteristics and what differences that can be found compared to constructing lower buildings.

For Serneke, this thesis acts as guidance in how to proceed with planning as it identifies strengths and weaknesses of current practise at Karlatornet. Simultaneously, it provides suggestions on how to progress with developing Serneke VDC due to pinpointing where the barriers lie in the software and systems which were being used at the time. It raises the question of financially measure between different project how production, logistics and synchronisation should be managed to optimise efficiency for each project. Finally, the thesis provides a status report on how the project organisation, as well those belonging to Serneke as consultants, interpret current utilisation of software and systems resulting in revision of how work is conducted at Karlatornet.

6 Conclusion

The concluding remarks specifically aims to answer the research questions in summarised form to synthesise the theoretical framework and empirical findings and thereby provide suggestions for Serneke on how to proceed with planning at Karlatornet.

How should LBP be incorporated in production planning at Karlatornet?

To conclude how LBP should be incorporated in production planning at Karlatornet, it can be stated that focus first and foremost must be shifted towards creating organisational and technical alignment within the own organisation to provide means for creating further alignment throughout the chain from suppliers to subcontractors. If the own organisation is not aligned, synchronisation will be obstructed as different segments will end up using the same software and systems differently ultimately resulting in increased uncertainty and decreased understanding among the participants. Using the same tools merely gives the possibility of alignment, however to reach it competence must be levelled. To increase pull for production by managing deliveries after actual demand provides that the right activity can be carried out at the right time. This is supported by LBP, as reporting can be done in regards to location, which easily can be communicated and synchronised with logistics. However, to optimise the production cycle by minimising float both within and between activities is the key to provoke collaboration, as it implies planning collectively. Division in locations rather than activities provides that activities are set in relation to each other, forcing those who are to conduct them to collaborate in order to efficiently progress in production. To set up workshops, engaging the participants in a social process, is therefore important, as minimising float entails close collaborations. Software such as PowerProject and BIM should thus also be used to enhance visualisation and integration with the production system to help in measuring actual demand and to efficiently manage clash detection. For Karlatornet, there are clear advantages to be found in its repetitive character, providing that comprehensive planning in locations can result in optimised production cycles. It does however imply that each supplier and subcontractor have the right conditions set from the beginning, as changes implies excessive costs and risks in form of non-value adding activities. Therefore, finding a combination of software and systems to facilitate LBP is considered vital in planning for efficiency.

How should JIT be incorporated in logistics planning at Karlatornet?

JIT should be incorporated in logistics planning to support production, as failure can lead to downtime and obstruction for production resulting in major cost overruns. The repetitive characteristics of Karlatornet entails risks as the whole production cycle is affected. In addition, the height constraint where only a limited amount of goods can be stored at each level, together with the limited space for storage on the site around the tower itself, provides that JIT deliveries are demanded. The three logistics routes should further be coordinated to optimise every delivery and promote efficiency in regards to workflow and total costs. BEAst will also be a vital part of fully using JIT deliveries at the site, as all goods can be derived to specific locations resulting in simplified management at the site and ensuring that the right goods are delivered to the right place. Using Myloc is a step towards having an automated system as information is gathered and changes are direct, however dependant on extensive reporting from production. It will however ensure that the right goods are delivered at the right time if managed properly, as changes in production must be manually reported to the logistics manager. Integrated JIT would imply that logistics are coordinated and automated after actual demand on site based on reporting through connected systems. To take it so far would mean integrating Myloc with BIM in a VDC system, where status of all activities continuously is updated in the model to measure actual demand, which further is communicated to Myloc. Simulations will however be conducted to detect clashes in different stages of production, giving that the issue of stagnating pace in logistics at site is managed. Overall, logistics can be found to synthesise well with theory at Karlatornet, providing that the project should have good expectations provided that the plan is realised.

How should production and logistics planning be synchronised at Karlatornet?
There is much to do regarding synchronised planning for production and logistics at Karlatornet. Alignment is yet to be reached separately, giving that it neither cannot be reached when combined. Workshops and meetings are required to create a combination of software and systems which can be used from suppliers to subcontractors in all segments, however as the building permit is not yet obtained, there is time to create alignment which further can be communicated throughout the chain. A high technical standard has been set, which results in high demand on the users and hence making competence vital. There are several new systems in place, together with new software, making synchronisation central in creating integration between the different systems and software. Information is however rarely automated, giving that manual work for integration will be carried out extensively. Serneke should continue focusing on creating systems that simplifies for synchronisation as using different systems will obstruct synchronisation and increase uncertainty. Having systems which can be integrated will further imply that automatisation is enabled, giving that the right information reaches the right person.

LC is all about minimising non-value adding activities, which also means that every workshop, meeting, and working opportunity should add value to the final product. It is here up to the project organisation to evaluate what software and systems that can be used to ensure that efficiency is optimised relative to the competence within the organisation. In this respect, it is not possible to do more than what the organisation is capable of, even if the tools provided have functions implying that more can be done. For Karlatornet, it is due to lack of experience in constructing high-rise construction a complex task to set an appropriate level to optimise efficiency. Therefore, when planning for efficiency at Karlatornet, Serneke must primarily focus on creating alignment throughout the organisation to create a common understanding on the systems that are going to be used, avoiding to neglect a varying competence. Otherwise, uncertainty will arise and the risk of having goods delivered at the wrong place and at the wrong time, obstructing for activities to be carried out in the right sequence, will increase. In this scenario, efficiency can be majorly harmed as the repetitiveness entailed by high-rise construction results in chain-reactions in the production cycle. This can ultimately lead to costs which easily go out of control, due to having a long chain between suppliers and subcontractors resulting in that planning is the best tool to prevent it from happening.

Final suggestion for Serneke
Planning for efficiency at Karlatornet will largely depend on organisational and technical alignment, as to plan and synchronise production and logistics according to this study requires competence. Working dispersedly with software and systems, and

further when combining them, will result in non-value activities as it requires understanding on several one-off solutions rather than one standardised form. To have technical alignment, where the participants use the same software, and organisational alignment, where the participants use the software and systems similarly is therefore preferable. This can further be connected to the characteristics of the project Karlatornet, which will depend on developing an efficient production cycle. Repetitiveness has in this study been acknowledged to provide means for comprehensive planning, as the opportunities with an optimised production cycle are many while the risks of failure through obstruction simultaneously are extensive. Specifically, production and logistics must be aligned separately first, to further be synchronised to form one united direction. Karlatornet is one house, and although it will have 72 floors and contain of different segments of production having several teams working on it during construction, only one house is going to be built. To plan for efficiency at Karlatornet thus requires alignment, and a shared lean thinking, rather than merely using the same tools.

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8 Appendix

Appendix A

Förberedande information inför intervju

Arbetet syftar till att utreda hur produktion och logistik effektivt kan synkroniseras i byggande av höga konstruktioner. Studien har fokus på koncepten Location-based Management System (LBMS) och Just in Time (JIT), båda hämtade ur Lean i byggindustrin. I detta studeras även hur BIM kan användas som hjälpmedel. Arbetet utförs för att ge styrning i produktions- och logistikplaneringen, där förutsättningarna vid Karlatornet är speciella för svenskt byggande. Dels hålls en hög teknisk standard i projekteringen, och dels är det Sveriges blott andra skyskrapa.

Förklaringar följer nedan under produktion och kan tillämpas på övriga punkter.
Gällande produktion undersöker vi:

- Tryck- och dragsystem: avser styrning och om information trycks till eller dras från produktion för att hantera leveranser och nästkommande moment.
- Zon- och aktivitetsbaserad planering: avser olika typer av planering där moment antingen planeras i zoner eller i aktiviteter. Zonbaserad planering innebär att aktiviteterna sätts i relation till varandra medan aktivitetsbaserad planering enbart innefattar respektive aktivitet.
- Location-based Management System: ett system som tillämpar zonbaserad planering och en kollektiv planeringsprocess där varje zon planeras tillsammans med de som skall utföra aktiviteten för att minska osäkerheten och sätta aktiviteterna i relation till varandra.
- BIM: avser hur BIM kan bidra med visualisering. När, var, hur och till vilken grad undersöks.
- Samordning av produktion: hur sköts planering och vem kommunicerar med vem.

Gällande logistik undersöker vi:

- Tryck- och dragsystem
- Leveranssätt, direktleveranser och konsolideringscenter: avser leveranser till arbetsplatsen.
- Just in Time: system för leveranser av rätt material till rätt plats i rätt tid.
- BIM
- Samordning av logistik: hur sköts logistik och vem kommunicerar med vem.

Gällande synkronisering undersöker vi:

- Tryck- och dragsystem: vad används i vilka fall för effektiv synkronisering?
- Integrering av LBMS och JIT: hur skapas synergier mellan de olika systemen?
- BIM
- Samordning av produktion och logistik: hur sköts planeringen för effektiv synkronisering?

Övrig information

Arbetet omfattar 20 veckor heltidsstudier, utspritt över 22 veckor, och utförs i par om två studenter. Detta motsvarar cirka 1600 timmars arbetstid. Rapporten skall vara färdigställd och lämnas in 16:e juni för erhållen examen denna terminen. Vårt arbete utgår från en litteraturstudie, intervjuer och egna undersökningar vilket tillsammans skall ge ett preskriptivt och explorativt tillvägagångssätt. Resultatet väntas alltså både kunna brygga över aktuell forskning och bidra till nya slutsatser, som skall kunna hjälpa Sernekes planeringsarbeten.

Under arbetet intervjuar vi både akademiker och praktiker både inom och utom Serneke, under fas ett akademiker och fas två praktiker. Detta gör vi för att först studera vad som är aktuellt inom forskningen och sedan studera hur detta står sig mot vad som används i praktiken.

Appendix B

Retired senior director (Northumbria) - Previously the Director of Postgraduate research for the School of the Built and Natural Environment. Joined the University in 1990 after nearly 20 years in Construction and Project Management with one of the country's largest contractors. Mainly working in the North East and Cumbria he was involved in a number of prominent projects including Newcastle Crown Courts and both the Lanes Shopping Centre and the Market Hall Refurbishment in Carlisle. He has been involved in most aspects of academic work from Foundation degree to PhD level and until his retirement in 2016 he taught and researched in the areas of Construction Planning, Lean Construction, Project Management and Project Delivery as well as supervising research and dissertations for undergrad, masters and PhD students.

LPS lecturer (Nottingham) - at the end of his PhD at the Centre for Lean Projects, in the School of Architecture Design and the Built Environment, Nottingham Trent University. His research developed an approach to support construction stakeholders for rapid and successful implementation of the Last Planner System for construction process improvement. Before embarking on his PhD, he was awarded a distinction in his master's degree in project management (Construction) in 2013 at Nottingham Trent University. Prior to this, he obtained a Bachelor degree with 2.1 honours in Building from University of Jos, and a master degree in construction management from University of Lagos both in Nigeria. He has over six years' practical experience in the construction industry, where he occupied various positions such as site engineer, construction manager and project engineer before venturing into academic and research. He is a chartered member (MCIOB) of the chartered Institute of Building, UK.

Programme leader (Northumbria) - Before commencing his academic career as senior lecturer and programme leader he spent a decade in the employment of major construction organisations working in a project management capacity planning construction operations, managing on-site activities, and winning new projects across the UK and for a brief early period in Washington DC. The contract values of his live projects ranged from £6M - £45M and were a mix of new build, demolition and refurbishment schemes in the following sectors: residential, hotel and office accommodation, retail space, and medical and laboratory facilities.

Research engineer – Teaches BIM, CAD, and construction management at Chalmers University of Technology since 2009. He is a doctoral student since 2014, and focuses on planning in construction scheduling and more specifically how BIM could enhance understanding and communication in this process. Has previous experience from project management in several laser scan to BIM modelling projects.

VDC coordinator (Ramirent) – Graduated from Borås school of technology in 2005 and have since then focused on fall protection solutions on construction sites. Previously spent several years at a company called Combisafe but in 2014 he started a company called Safety Solutions which later merged with Ramirent. Since 2015 he has been the VDC coordinator at Ramirent where he is responsible for developing VDC within the company where they use BIM models to visualise when and where demand for certain tools and equipment arise.

Installations coordinator (Time-IT) – Initially educated as an electrician but since 1996 he has worked as an installations coordinator at two different companies. Presently has his own company that specialises in installations coordination, which involves planning, governing and monitoring during the construction phase. Places great focus on developing a production schedule tailored to the entrepreneur's needs in order to avoid production disturbances. Responsible for developing the production time schedule in the project of Karlatornet.

Calculations manager (Serneke) – Graduated from Chalmers University of Technology in 2008 and has since then been employed at Serneke. Started as a calculator and has since then moved on to calculations manager. He has together with the BIM Coordinator shaped how BIM should be used throughout the entire project. Responsible for the calculations department at Karlatornet.

Project manager A (Serneke) - Project manager of internal works at Karlatornet since 2016. Graduated from Chalmers University of Technology in 2008 and have nine years' experience of working in the construction industry. After his graduation he spent three years in China, working as a project manager. Previously worked at a company called Pharmadule which produced modular building of pharmaceutical plants with a high BIM involvement. He is very interested in industrial construction and the usage of both BIM and lean within the construction industry.

Project manager B (Serneke) - Project manager of structural works at Karlatornet since 2016. Graduated from his bachelor from Borås school of technology in 1999 and have 18 years of experience from the industry from a number of companies. Has previous connections to BIM that dates back to when he was studying where he wrote his own dissertation on the early usage of BIM. In regards to lean he participated in an education arranged by CMB, which stretched over a two-year period.

Purchasing manager (Serneke) – Initially educated as a concrete placer but during the recession in the 1990s he started his education at Silf where he graduated in 1997 as a purchasing manager. Since then he has worked with purchases in several industries and companies and has thereby wide expertise regarding purchasing. Returned to the construction industry in 2007 as purchasing manager. With regards to experience of BIM he has participated in previous projects that has utilised BIM but never past 3D. Was until march 2017 responsible for purchases at Karlatornet.

Logistics manager A (Serneke) – Graduated from Chalmers University of Technology in 2010 and has seven years of experience from the construction industry. Started as a foreman in 2010 and since 2012 she is a logistics manager at Serneke where she has previous experience of handling large and complex projects. She now is responsible for managing logistics at Karlatornet.

BIM coordinator (Zynka BIM) – Initially educated as a civil engineer and have 23 years of experience from the construction industry. He has previous experience from working as an Architectural CAD Engineer and Team leader. In 2014 he founded the company Zynka BIM where he is their present CEO. He is currently communication and information manager at Karlastaden but also responsible in supports Serneke with development of Serneke VDC.

Structural engineer (VBK) – Graduated from Chalmers University of Technology as a civil engineer in 2007 with a master in Structural Engineer. Has worked with BIM in past projects, however only to the extent of 3D where various quantities could be extrapolated from the model. He is responsible for calculations at VBK on Karlatornet.

Structural BIM manager (VBK) – Graduated from Linnaeus University in 2005 and has 12 years of experience from the construction industry. Has worked with BIM in past projects, however only to the extent of 3D where various quantities could be extrapolated from the model. He is responsible for modelling and coordination at VBK on Karlatornet.

Logistics manager B (Peab) - Started working with logistics management in the construction industry in 2006. Has previously worked with management within the car manufacturing industry, resulting in extensive experience with lean. She has worked with logistically complex projects such as Gothia Towers and refurbishment of Nordstaden in Gothenburg.

Appendix C

Bakgrundsinformation	• Ålder • Utbildning • Arbetslivserfarenhet • Position	- Presentation av den intervjuade.
Koppling till BIM och Lean	• Vad är din koppling till BIM? • Vad är din koppling till Lean?	- Hur använder du respektive i ditt dagliga arbete?
BIM i projektering	• Hur anser du att BIM bör användas i projekteringen? • När lämpar sig BIM i projektering? • På vilka sätt ser du att osäkerheten kan minskas med hjälp av BIM?	- Kollaborativt eller separat med samordning av ansvarig part? - 3D, 4D eller 5D? Ritning, tidplanering och kostnad. - På vilken detaljnivå är modellen användbar? När överstiger kostnaden nyttan?
BIM i planering	• Hur anser du att BIM kan användas i planering av produktion? • Vilken information från BIM anser du är lämplig att använda i planeringen? • Hur anser du att BIM kan hjälpa till att visualisera produktionen i planeringen?	- Kollaborativt eller separat samordning av en ansvarig part? - Uppdelad i aktiviteter eller i ytor? - 3D, 4D eller 5D? Ritning, tidplanering och kostnad. - Kan modellen överföras till produktion? Är detta värdeskapande?

BIM i produktion	● Hur bör BIM användas i produktion? ● Kan det bidra till förbättrad visualisering? ● När lämpar det sig att använda BIM i produktion? ● Hur kan BIM användas för att förenkla logistiken?	- Lämpar det sig att överföra modellen till produktionen? - Vilka barriärer finns för implementering av BIM i produktion? - På vilka sätt kan BIM bidra till förenklad samordning mellan logistik och produktion?
Lean i projektering	● Hur anser du att projekteringen bör drivas för att undvika icke värdeskapande arbete? ● På vilka sätt anser du att osäkerheten kan minskas?	- Kollaborativt eller separat med samordning av ansvarig part? - Ger en integrerad modell förutsättningar för minskat dubbelarbete?
Lean i planering	● Hur anser du att olika moment bör planeras inför produktion? ● Hur bör planeringen utformas för att överföra rätt information från projekteringen? ● Vilka för- respektive nackdelar ser du med Location-based Management System?	- Kollaborativt eller separat med samordning av en ansvarig part? - Kan gemensamt arbete mellan parter i projektering och produktion förbättra överföringen av information eller bör det samordnas av en ansvarig part? - Är dessa tankesätt applicerbara i svensk byggindustri?
Lean i produktion	● Hur anser du att produktion bör drivas? ● På vilka sätt kan ett Lean tankesätt effektivisera produktion? ● Hur kan tidplan för	- Lämpar sig ett push eller pull-system bäst i byggindustrin? - Kan Location-based Management System användas på ett effektivt sätt i Sverige?

	arbete och logistik samordnas? ● Hur kan krockkontroll göras mellan arbete och logistik?	- Vem bör vara ansvarig för samordningen? - Hur säkerställs att rätt material är på rätt plats i rätt tid?
Synergier mellan BIM och Lean	● Hur kan implementering bidra till en mer integrerad arbetsprocess? ● På vilka sätt kan överföring av information förenklas med hjälp av Lean och BIM? ● Hur kan transparens skapas mellan projektering och produktion?	- Vilka fördelar respektive nackdelar ger en integrerad process där konsulter och ex. UE arbetar närmare varandra? - Vad kan en förbättrad visualisering bidra till? - Kan kollektiv intelligens genom hela byggprocessen förbättra effektiviteten? - 3D, 4D eller 5D? Ritning, tidplanering och kostnad.
BIM i höga konstruktioner	● Vilka för- och nackdelar ger användning av BIM i höga konstruktioner? ● Hur kan BIM bidra till att skapa effektiva produktionscykler? ● Anser du att BIM bör användas genom hela processen vid Karlatornet?	- Anser du att BIM lämpar sig för denna typ av projekt, med hög grad av upprepning? - Vilka risker och möjligheter ser du med BIM i höga konstruktioner?
Lean i höga konstruktioner	● Vilka för- och nackdelar ger användning av Lean i höga konstruktioner? ● Hur kan en kollektiv planeringsprocess skapa effektiva produktionscykler? ● Hur kan zonbaserad planering, istället för aktivitetsbaserad, bidra till att skapa	- Anser du att Lean lämpar sig för denna typ av projekt, med hög grad av upprepning? - Vilka risker och möjligheter ser du i Location-based Management System i höga konstruktioner? - Anser du att logistik

	effektiva produktionscykler? ● Anser du att Lean bör användas genom hela processen vid Karlatornet?	bör hanteras baserat på zoner?
Integrering av BIM och Lean i höga konstruktioner	● Vilka för- och nackdelar ger integrerad användning av BIM och Lean i höga konstruktioner? ● Anser du att en integrerad process bör användas vid Karlatornet?	- Lämpar sig en integrerad eller separat implementering bäst? - Finns det några övervägande negativa synergier? - Finns det några övervägande barriärer?