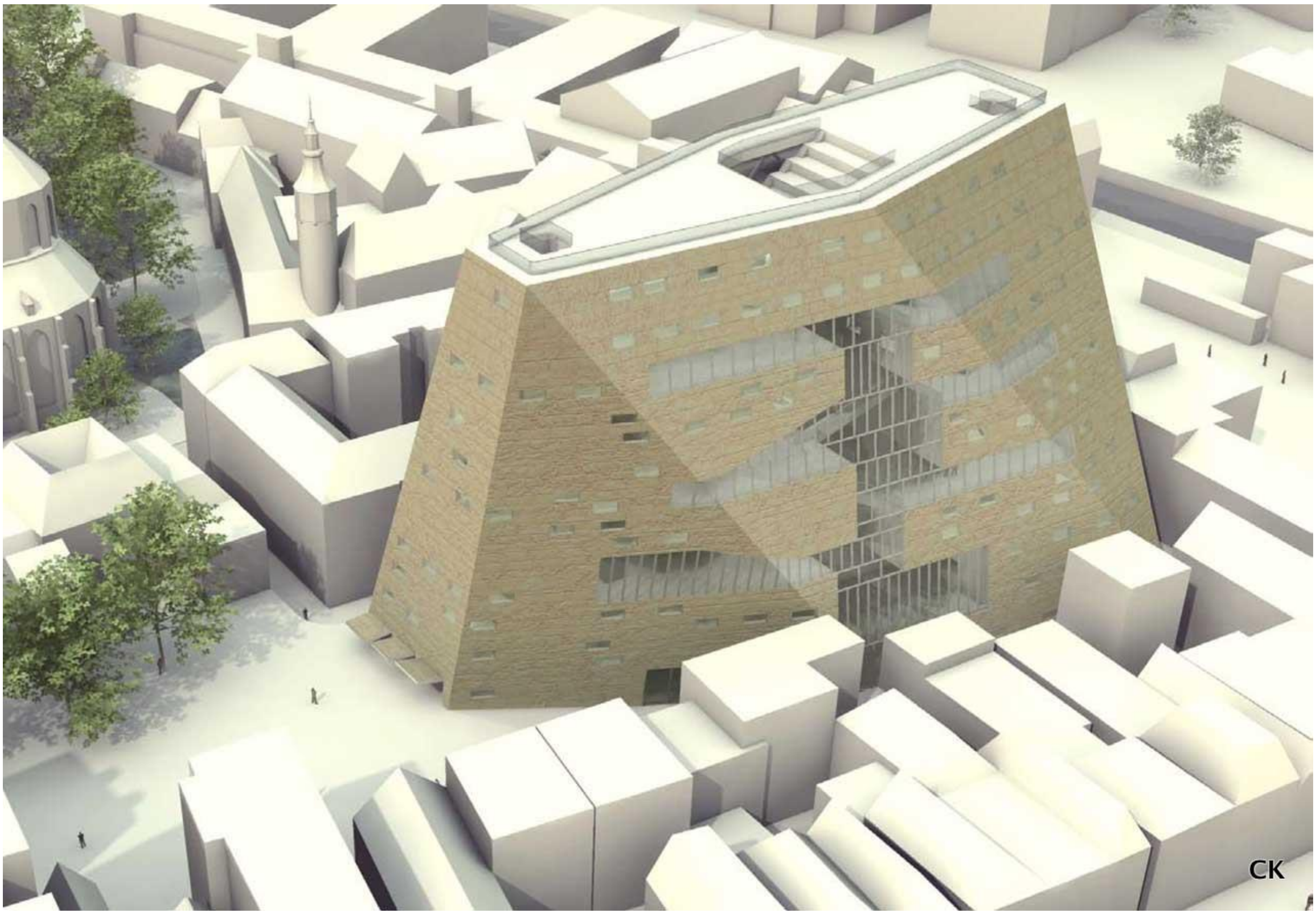
Improving the planning process and the plan

BIM and Prefabrication at the Groninger Forum



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Preface

This report is the result of the research performed at the Groninger Forum, a project of BAM, to finish my master study Industrial Engineering and Management. First of all I want to thank BAM for giving me the opportunity to write my master thesis and for giving the opportunity to get acquainted with the construction industry. More specifically I want to thank Marco Klein Paste, my first supervisor at BAM, for the interesting discussions and feedback on my thesis and for showing something more about his way of working. I want to thank Rens Polinder as well for taking over the last part of the supervision when Marco left. His influence was of less importance than Marco's influence but I appreciate the feedback he gave to complete my thesis.

Next to my supervisors at BAM I want to thank my supervisors at the University of Twente, Peter Schuur and Hans Voordijk. Their feedback was very useful to get focus in my research and to get a clear structure in my thesis. Besides that, I enjoyed the monthly meetings with them. The feedback I received during those meetings was very useful and I also got the chance to share some of my experiences about the construction industry and discuss those as well.

Besides my supervisors, I want to thank my girlfriend Benthe Bemelman and Wim Jansen for the feedback they gave on my thesis.

Finally, I want to thank the employees of BAM at the Groninger Forum. They were always helpful when I had questions and during the breaks it was always nice to walk through the city centre of Groningen.

Jasper Janssen
Groningen, March 2014

Management summary

This report is written to complete my master study Industrial Engineering and Management at the University of Twente. The research is performed at the Groninger Forum, a project of BAM. This research is about how BIM (building information modelling) can assist in the planning process at the Groninger Forum and how BAM can improve the plan by making use of prefabrication.

The causes for this research are the logistic challenges that arise because of the construction site of the Groninger Forum with little space in the middle of the city centre of Groningen. For the Groninger Forum, BAM wants to deliver to the construction site JIT (Just In Time). To assist in arranging the logistics, BAM created a hub just outside the city centre. To have a good foundation to control the logistics, the focus of this research is on the planning process. For this research, the planning process is defined as: all activities and decisions made regarding the planning from the start of the project till the actual work is done.

The research question answered in this research is: *How can (i) the planning process of a construction project efficiently be supported by the BIM model and (ii) how can the plan be improved by prefabrication?*

To answer this research question, literature about BIM and prefabrication is projected on a case study about the early involvement of duct suppliers and the collaboration between the duct supplier and the steel supplier. In the case study the steel plan and an LP (Linear Programming) model to crash the steel plan when there are no prefabrication options or it is too late for prefabrication are discussed. With this LP model it is possible to calculate what jobs to crash to reach a desired lead time against minimum costs.

Assistance of the BIM model in the planning process

Based on the case study and the literature it can be concluded that the assistance of the BIM model in the planning process can be improved. BAM already works with a 4D planning; this makes it possible to visualize the plan. Due to the visualization it is possible to see errors in the sequence of jobs. Because of the 4D model it is exactly known when what parts are needed at the construction site. With this information the deliveries are also known. With the 4D BIM model sizes and shapes of all parts in the building are clear, this makes producing materials and prefabrication easier. BAM is also planning to add extra resources as scaffoldings in the BIM model; this will prevent unnecessary delays and the hiring of double or unnecessary extra resources. To improve the assistance of BIM in the planning process the following is advised to BAM. The advice is split in advice for the short term (0-1 year), mid-term (1-2 year), and long term (>2 year). For the short term BAM is advised to:

- Keep working with the 4D model;
- Add weight, the amount of construction workers, and packaging materials to the BIM model;
- Calculate slack when one has decided to adjust the plan based on the amount of construction workers or on the number of deliveries;
- Indicate when it is allowed to work in certain areas and when it is not allowed with respect to safety;
- Visualize the critical path and the progress of actual construction compared to the plan;
- Make short movies about the construction method of difficult parts in the construction;

- Keep on training personnel because BIM keeps on developing and will become more important;
- Use version control software which keeps track of changes in a log to solve the version problem in BIM.

For the mid-term BAM is advised to:

- Use a warehouse management system to keep track of deliveries and inventory.

For the long term BAM is advised to:

- Redesign its financial structure in such a way that it can be integrated with the BIM model in order to be able to create a 5D model.

From the case study it became clear that BIM is not completely integrated in the construction industry. This is concluded because at the Groninger Forum:

- BAM received a BIM model from the client (i.e., the municipality of Groningen) that contained multiple errors;
- The advisors from the client still want 2D drawings for approval because they cannot work with the BIM software BAM is using;
- Version control during the creation of the BIM model resulted in problems;
- Computers were not able to cope with detailed BIM models because of lack of memory;
- Different software packages are used which can lead to loss of information during conversions;
- Not all sub-contractors are ready to use BIM models, this makes it impossible to let sub-contractors draw their parts in the BIM model and impossible to communicate via the BIM model.

Most of these problems are introduction problems because BIM is new for BAM and they are not in the control of BAM. These problems probably will be solved over time. However to solve the version problem, BAM can use version control software which keeps track of changes in a log.

Improving the plan by prefabrication

To improve the plan by prefabrication, BAM should make a more detailed plan after the tender is won with estimations of all activities from sub-contractors to calculate the critical path. When decisions are made about which jobs are in the critical path, these jobs should be examined in order to see if it is possible to prefabricate these jobs. When it is decided what jobs will be prefabricated, the plan should be updated and the critical path should be calculated again to see if there are other jobs that could be prefabricated to save time.

To make the prefabrication a success, the sub-contractors involved in the prefabrication solution should be involved as early as possible and the design should be finished early as well. This is from the moment that it is known that they are involved in finding prefabrication solutions.

The BIM model is important for the collaboration between BAM and sub-contractors. Because of the BIM model there are discussions between sub-contractors and BAM about smart solutions to improve the construction. The visualization of the construction was important to come up with creative ideas. When different sub-contractors are involved in the same prefabrication solution it is important that a team with a common goal is created.

Other recommendations

To be able to cope with JIT deliveries it is important that BAM keeps the planning in control. The LPS (Last Planner System) aims at keeping the planning in control. The current planning process of BAM already has similarities with the LPS. BAM should use parts of the LPS to be able to cope better with JIT deliveries. The three parts of the LPS BAM should use are:

- Calculate the PPC (Percentage Plan Complete) from the weekly plan to use as target and as benchmark;
- Use the five times why method to prevent errors from occurring more than once;
- Discuss during weekly meetings the constraints with all parties involved in the six week schedule.

The last recommendation is that BAM should try to convince clients that it is more profitable if BAM Techniek and BAM Utiliteitsbouw collaborate more often at an early stage, before construction begins instead of putting in separate bids. This will result in a faster and probably cheaper production process as BAM Techniek and BAM Utiliteitsbouw also collaborate on cost level. The collaboration between BAM Techniek and BAM Utiliteitsbouw is also important for prefabrication solutions. The collaboration makes it easier to come up with ideas and help each other improving the construction process.

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1. Introduction

This report is written to complete my master study Industrial Engineering and Management at the University of Twente. The research is performed at the Groninger Forum, a project of BAM. This research is about how BIM (building information modelling) can assist in the planning process at the Groninger Forum and how BAM can improve the plan by making use of prefabrication.

This chapter begins with a short description of BAM in Section 1.1. In Section 1.2 an introduction is given to the research problem. This chapter ends with an outline of the rest of this report in Section 1.3

1.1 Description of BAM

The Royal BAM group, or BAM, was founded in 1869 and unites operating companies in the sectors Construction and M&E services, Civil engineering, Property, and Public Private Partnerships. BAM is listed on the Amsterdam stock exchange. The total revenues in 2012 were €7.4 billion euro. With around 25,000 employees, BAM brings thousands of projects successfully to an end on a yearly basis (BAM, 2012).

BAM has leading positions in home markets the Netherlands, Belgium, United Kingdom, Ireland, and Germany. Characteristic for BAM is the regional network of offices which makes it possible that BAM is always close to its clients. Besides having leading positions in the home markets, BAM-International is active in Australia, the Gulf States, Indonesia, Jordan, Liberia, Libya, Malaysia, Papua New Guinea, Sierra Leone, Sri Lanka, and Tanzania. Currently, BAM international has several projects in progress worldwide in the non-residential, construction and civil engineering sectors (BAM, 2012b).

1.2 Problem introduction

The causes for this research are the logistic challenges that arise because of the construction site of the Groninger Forum with little space in the middle of the city centre of Groningen. To assist in arranging the logistics, BAM created a hub just outside the city centre. To have a good foundation to be able to control the logistics, the focus of this research is on the planning process. The two main questions of this research are: how can BIM assist in the planning process at the Groninger Forum and how can BAM improve the plan by making use of prefabrication. A more detailed description of the problem and the research question can be found in Chapter 2.

1.3 Outline of report

The following topics are discussed in this research. In Chapter 2 the background of the research is given just as the research question and a stakeholder analysis. In Chapter 3 the theoretical framework is described. This includes the role of BIM in the planning process in Section 3.1, how prefabrication can improve the plan in Section 3.2, and how to cope with JIT deliveries in Section 3.3. In Chapter 4, a case study about a small part of the Groninger Forum is presented. In Chapter 5 the theory described in Chapter 3 is projected on the case study. This report ends with conclusions and recommendations in Chapter 6. The goal of this research is to find out how the BIM model can be used to assist in the planning process and how prefabrication can improve the plan.

2. Problem description

In this chapter, the background of and cause for the research are described. First the problem is described in Section 2.1. This is followed by the scope of the research, the research question together with the sub questions, the deliverables of this research, and a stakeholder analysis.

2.1 Problem Description

Currently one of the projects BAM is working on is a prestigious project in Groningen called “Groninger Forum”. In the middle of the city centre at the “Grote Markt”, a new multifunctional cultural hotspot is being built including a new square called “De Nieuwe Markt” and a five layer deep parking garage. The new building will be a supercharger for art, culture, and literature in the city. In the Groninger Forum a public library, a part of the museum of Groningen, Art-house cinema Forum Images with a movie café next to it, a grand café with terrace at ground level, and a restaurant at the top floor with a magnificent view will settle. Besides, there is a lot of not assigned space which can be used for various activities, for example cultural markets. Underneath the Groninger Forum, parking space will be available for 380 cars and 1400 bicycles. The client of the project is the local government of the city of Groningen.

For the execution of this project, a general partnership is founded. The general partnership exists of the partners BAM Civiel, BAM Utiliteitsbouw, and BAM Techniek. The Partnership is named “V.O.F. Groninger Forum” (BAM Techniek, 2012).

The construction site of the Groninger Forum is not an ordinary construction site. It is located in the middle of the city centre of Groningen and therefore there is no place for a traditional construction site where supplies are stored at the construction site. For that reason a change in logistics is needed. In line with the contract with the local government, BAM created a hub a few kilometres away from the construction site to control the amount of transportation movements needed into the city centre, to store materials for the construction if needed, and to transform loads into the desired amount or packaging size. The change in the supply chain caused by the hub is visualized in Figure 1.

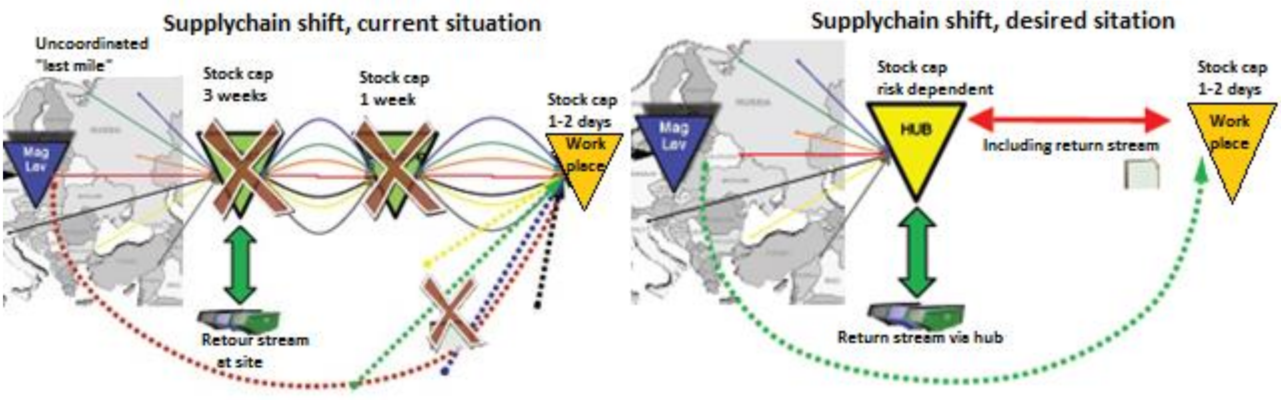

Figure 1 Supply chain shift

In the traditional way (the left image in Figure 1) the materials are brought to the construction site where enough materials are stored for the production in the next three weeks. When the materials are needed somewhere in the building they are brought to the right floor. At the right floor the supplies for another week of production are stored. After that the materials are moved to the actual working place where they are needed. At the working space another one or two days of supplies is stored. These amounts of supplies and periods the materials are at the construction site are different per sub-contractor and per phase in the construction. This example is to illustrate the process and is typical for the fit-out phase. The sub-contractors are responsible for the distribution to the construction site and for the distribution on the construction site of their own supplies. The transportation of materials from the moment they enter the construction site until they reach their destination where they are processed is not coordinated. The stream of used materials, like packaging material, is handled at the construction site.

In the new situation, the supplies are brought to the workplace just in time (JIT) on the day the supplies are needed. The hub will be used when it adds value; this can for example be to transform full truck loads into smaller packaging for JIT delivery. The stream of used materials is also handled at the hub.

The hub is already in place but is not in use yet; the plan is to use the hub from the moment the construction of the parking garage starts. This will be around April 2013. The use of a hub and JIT deliveries bring changes to stock, transportation and planning of the construction process. Besides, it is possible that a change in culture might be necessary because of the changes in the process. BAM does not know how to design these changes.

Before the construction of the Groninger Forum began, a BIM model of the Groninger Forum was created. In this 3D model of the Groninger Forum, all information needed to construct the building is stored. The use of information from BIM in relation to the logistics is not clear yet. It is not known when what information should be input for the BIM model in order to steer the logistics. Another reason for this are new logistics approaches in the construction industry.

2.2 Scope

To have a good foundation to arrange the logistics and to be able to control the logistics, the focus of this research is on the planning process. For this research, the planning process is defined as: all activities and decisions made regarding the planning from the start of the project till the actual work is done. Besides creating different schedules with different levels of detail at different moments in time, the planning process includes creating a BIM model and contracting sub-contractors. Detailed information about the planning process at the Groninger Forum can be found in Chapter 4. The focus of this research is on how the BIM model can assist in the planning process and on how the plan can be improved by making use of prefabrication.

Because of the limited time available for this research is focussed only on the planning process of one specific part of the Groninger Forum. The specific part chosen is the selection of the duct supplier and how the duct supplier is going to collaborate with the steel constructor. This specific part will be used to perform a case study.

For the delivery at the construction site, the focus is on JIT deliveries because at the Groninger Forum, BAM is going to deliver the construction site according to the JIT principle.

The case study will provide for an overview of how the information in the BIM model can be used to assist in making a plan and how prefabrication can improve the plan. In the case study the steel plan will be discussed in more detail and a Linear Programming (LP) model to crash the steel plan is discussed which can be used when it is too late or impossible to prefabricate.

2.3 Research question

The problem explained in Section 2.2 in combination with the scope as determined in Section 2.3 leads to the following research question:

How can (i) the planning process of a construction project efficiently be supported by the BIM model and (ii) how can the plan be improved by prefabrication?

To answer this research question, seven sub questions have been defined:

1) *How can a BIM model assist in creating a plan?*
   The first sub question will give insight in what information is stored in a BIM model and how this information can assist in creating a plan. First the concept of BIM models is explained based on literature followed by the information that should be stored in BIM models in order to assist in making a plan.

2) *What factors influence the decision to use prefabrication or not?*
   By answering the second sub question it will become clear what factors influence the decision to prefabricate certain elements according to the literature. Those factors can be used to identify jobs in the plan that can be prefabricated to improve the plan.

3) *To what extent and how should the client and/or sub-contractors be involved earlier in the planning process?*
   BAM is not the only party which is part of the building logistics. Next to BAM there are the client and a lot of sub-contractors. The goal of answering the third sub question is to make clear what the role of the client and sub-contractors should be in the planning process and how BAM should involve them. This will be done by finding applicable literature and interviewing sub-contractors.

4) *What characteristics must a planning process in the construction industry have to make JIT delivery a success?*
   At the Groninger Forum, deliveries will be made JIT. Answering the fourth sub question gives insight in what the characteristics of JIT delivery are and how these characteristics should be dealt with to make JIT delivery a success at the Groninger Forum.

5) *Which possibilities for the planning process available in the literature can be used in combination with JIT deliveries?*
   The answer on the fifth sub question will make clear how BAM should design the planning process at the Groninger Forum according to the literature taking JIT deliveries into account.

6) *What does the current planning process at the Groninger Forum look like?*
   The answer on the sixth sub question will give insight in the planning process at the Groninger Forum and what the planning process looks like at the Groninger Forum.

7) *What insights in previous sub questions can be extracted from a case study?*
   The case study will be used to give insight in the application of the theory described about BIM and prefabrication and will show if the theory matches with practice. When there are

differences between practice and theory these differences will be explained and recommendations will be given. Besides that, the steel plan is discussed in more detail and an LP model is made to crash the steel plan when it is too late to improve the plan by prefabrication.

2.4 Plan of approach

The research is carried out in the following way. The first five sub questions "*How can a BIM model assist in creating a plan?*", "*What factors influence the decision to use prefabrication or not?*", "*To what extent and how should the client and/or sub-contractors be involved earlier in the planning process?*" , "*What characteristics must a planning process in the construction industry have to make JIT delivery a success?*", and "*Which possibilities for the planning process available in the literature can be used in combination with JIT deliveries?*" are answered based on a literature research. The literature research is performed by making use of scientific search engines Scopus and Google Scholar. Only articles which are free for students of the University of Twente are used.

The sixth sub question "*What does the current planning process at the Groninger Forum look like?*" is answered based on an interview with Sebastiaan Beek a planner of the Groninger Forum and on asking several questions to the executor Henk Broekmans. All questions asked are open ended questions to get as much as possible information about the planning process.

The seventh sub question "*What insights in previous sub questions can be extracted from a case study?*" is answered by making use of a case study. The case study is about the early involvement of duct suppliers and the collaboration of the duct suppliers, the steel constructor, and BAM. The case study is based on interviews with employees from two duct suppliers (Brema-Air and Gebroeders Meijer) and twelve different meetings attended during the selection process between BAM and three duct suppliers (Brema-Air, Vink and Gebroeders Meijer). On three of these meetings, Nagelhout (the steel supplier) was present as well.

The interview with Brema-Air is held with the commercial director Henry Passon and with Fred de Rooy who is also working for Brema-Air. The interview with the Gebroeders Meijer is held with the CEO Johan Vreeken. The questions asked are open ended questions and can be found in Appendix C, the questions are based on information from the literature. Summaries of the interviews can be found in Appendix D and Appendix E. The parts in the case about BIM are based on the interviews and meetings with the duct suppliers and on an interview with another planner of the Groninger Forum, Mark de Vries. The theory described by answering the previous sub questions is compared with the case study to compare the literature with practice. The steel plan as it is at the moment of writing is discussed in more detail in the case study just as an LP model to decide what job in the steel plan to crash when it is too late or impossible to prefabricate.

When all seven sub questions are answered, the research question "*How can the planning process of a construction project (i) efficiently be supported by the BIM model and (ii) be improved by prefabrication?*" is answered.

The relation between the sub questions and the different chapters in this report can be found in Figure 2.

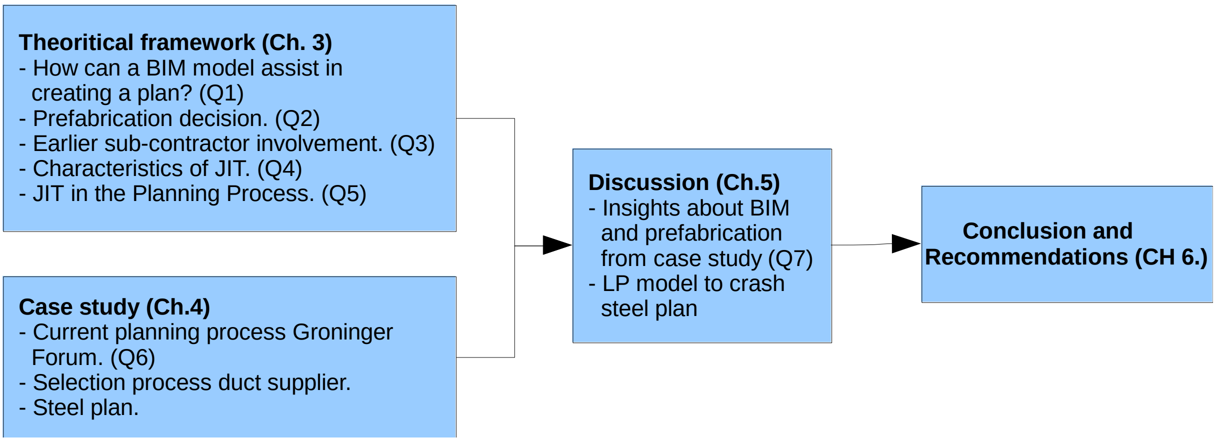

Figure 2: Relation sub questions and chapters

2.5 Deliverables

The deliverables of this research are a report with:

- Advice for BAM how they should cope with JIT deliveries;
- Advice for BAM what information in the BIM model can assist in the planning process at the Groninger Forum;
- Advice for BAM how they can improve the plan by making use of prefabrication;
- An LP model to decide what jobs to crash when it is too late for prefabrication.

2.6 Stakeholders

The stakeholders involved in the planning process at the Groninger Forum are:

- BAM
- Sub-contractors
- A logistics service provider
- The local government of the city of Groningen (the client)
- Advisors of the client
- Local residents who live near the construction site

<u>BAM and sub-contractors</u>

BAM is responsible for creating the plan and making sure the Groninger Forum will be finished on time. For the specialized work BAM cannot do itself, BAM hires sub-contractors. For the Groninger Forum there will be between 40 and 50 sub-contractors. All these sub-contractors have their own interests and are not used to collaborating. Due to the contract situation, BAM is the only party in position to manage all different sub-contractors and make sure the sub-contractors can do their job when it is planned.

The process hiring of sub-contractors is conflicting. BAM wants to hire the sub-contractor who offers the best price given a certain minimum quality level, but because of the current economic situation there are sub-contractors who are in bad financial health. So BAM wants to hire sub-contractors for a price as low as possible but when they hire a sub-contractor who goes bankrupt during the construction process, BAM might have a lot of more costs to find a replacement sub-contractor.

Logistics service provider

To deliver the supplies needed at the construction site JIT, BAM will hire a logistics service provider who is responsible for delivering the supplies JIT. The logistics service provider will also be responsible for the hub.

BAM hires a logistics service provider because BAM and the sub-contractors do not have enough logistic expertise.

The local government of the city of Groningen

The local government of the city of Groningen is the client; they hired BAM through two management organisations, Twijnstra and ABT, to build the Groninger Forum. The demands of the community of Groningen for the Groninger Forum are declared in the specifications, these demands should be met by BAM. BAM and the community of Groningen have a couple of discussions going on about changes in the specifications and about interpretations of the specifications and who should pay for the extra work created by these changes. This happens often in the construction .

When BAM and a sub-contractor want to change the construction method or the materials described in the specifications, the local government of the city of Groningen (the client) has to approve this. When after approval BAM or the sub-contractor decides again that there should be a change in either the materials used or in the method of building, this needs to be approved again.

Advisors of the client

BAM communicates with the client via the advisors of the client. The advisors approve the work plans of BAM and the BIM model. There are weekly meetings with BAM and the advisors.

Local residents

The local residents who live near the construction site may have complaints about the noise, BAM made clear agreements about the noise levels and working times with the local government of the city of Groningen. Another important part of the nuisance for the local residents who live near the construction site is the construction traffic. About the amount of traffic and safety measure clear appointments are made as well with the local government of the city of Groningen.

3. Theoretical framework

In this chapter, the theory used in this report is described. The theory is used in Chapter 5 to discuss the case study. For this research the planning process is the central theme. The main research question can be split in two parts. One part is about the assistance of BIM in the planning process and the other part is about the effect of prefabrication on the planning process. The planning process at the Groninger Forum is discussed during the case study in Chapter 4.

In Section 3.1 the role BIM can play in the planning process is discussed. In Section 3.1 the sub question "*How can the BIM model of the Groninger Forum assist in creating a plan?"* is answered. After that in Section 3.2 the effect of prefabrication on the planning process is discussed by answering the sub questions "*What factors influence the decision to use prefabrication or not?"* and "*To what extent and how should the client and/or sub-contractors be involved earlier in the planning process?"*.

For the Groninger Forum is decided that deliveries will be done JIT, to see the effect of JIT deliveries at the planning process the sub questions "*What characteristics must a planning process in the construction industry have to make JIT delivery a success?*" and "*Which possibilities for the planning process available in the literature can be used in combination with JIT deliveries?"* are answered in Section 3.3. These sub questions give insight in how the planning process should be designed to cope with JIT deliveries. Each section ends with a conclusion in which the sub question is answered.

3.1 BIM and the planning process

In this section the first sub question, "*How can a BIM model assist in creating a plan?",* is answered. This gives insight in the first part of the research question. In Section 3.1.1 BIM models are explained. In Section 3.1.2 is described how information in the BIM model influences making a plan and what information in BIM models can be useful for assisting in creating the plan. This section ends with a conclusion.

3.1.1 BIM models

Construction projects are becoming more complex and difficult to manage. One complexity is the mutual dependencies between different stakeholders, such as authorities, architects, engineers, lawyers, sub-contractors and suppliers. Information and communication technology has been developed very fast to deal with this increasing complexity. BIM is currently the common name for a new way of approaching the design, construction and maintenance of buildings. BIM is defined by Succar (2009) as "a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle". Succar's definition of BIM highlights its holistic nature; BIM not only includes software that allows 3D modelling and the input of information but also project management related tools and processes. "BIM takes the traditional paper based tools of construction projects, puts them in a virtual 3D environment and allows a level of efficiency, communication, and collaboration that exceeds those of the traditional construction processes" (Bryde, Broquetas & Volm, 2013).

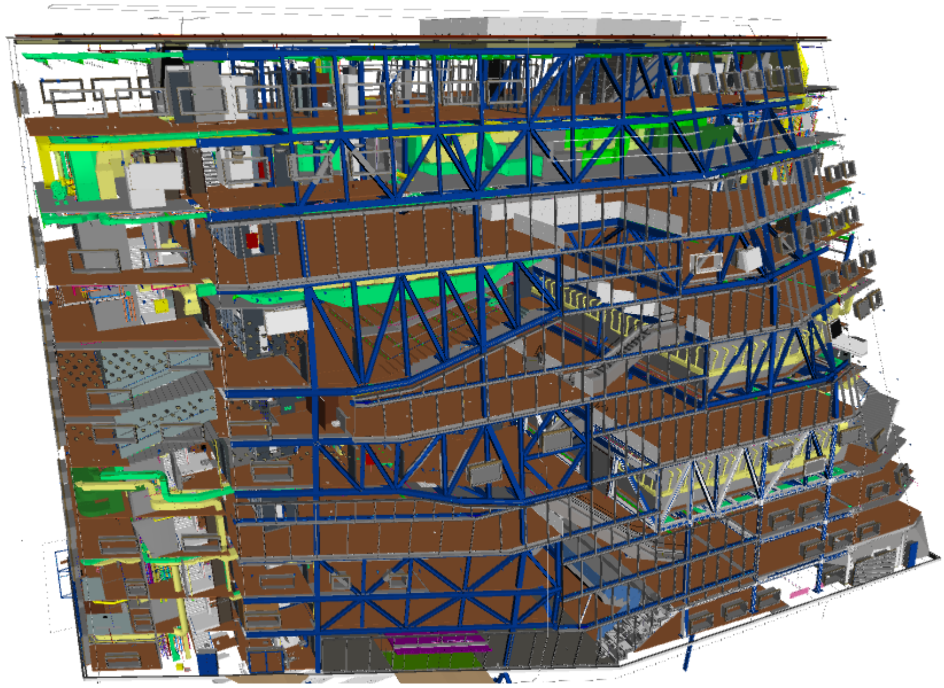

Figure 3: BIM image Groninger Forum

Figure 3 is a typical BIM image, a 3D view of the project. Everything that will be constructed in the physical building is put in the 3D model. In this way all kinds of problems can be seen and solved before the construction starts. For example it can be seen if sprinklers and ducts cross, this is called clash detection. The final version of the 3D model will be how the building will be constructed. The 3D model is the most important way of communication between the stakeholders. Of course meetings still take place, but the BIM model generates most input for these meetings. A BIM model is called 4D when the scheduling information is put in the 3D model and the plan is made visual. The model is called 5D when next to the scheduling, the budget information is also put in the model (Bryde et al., 2013). Next to time or budget information, it is possible to put more information in the BIM model. This is called nD, an example is the amount of people in certain areas at the construction site to prevent congestions. Moreover, simulations for temperature, sunlight, and sound analysis can be done. These simulations are important for, amongst others, implementation decisions and materials choice (Oliveira, 2010).

According to Bryde et al. (2013) possibilities of BIM models are to organize the project schedule and budget, enable good collaboration with the design team, hire and control sub-contractors, and to optimize the owner’s experience and satisfaction. According to Yan & Damian (2008) possibilities are improved creativity, sustainability and quality, and a reduction in cost and time. Dawood and Sikka (2006) name reduction in interference problems, reduction in rework, enhancement in engineering accuracy, improved jobsite communications, better design and quality, and an early generation of reliable budget for the project as possibilities of BIM models. Reducing the risks of working with old version data, communicate openly with team members, although virtually, and monitor and manage the construction process are possibilities named by Oliveira (2010).

Challenges when using BIM are: personnel needs to be trained, BIM keeps on developing, and a change in the process is needed since more work is done in advance to save work and cost during construction (Bryde et al., 2013; Yan & Damian, 2008).

A BIM model is created at the beginning of the planning process of a construction project. The information inserted in the BIM model influences how useful the model can be for the rest of the planning process.

3.1.2 BIM and Planning

In a BIM model all kinds of different information can be stored. In this section , different possibilities for information in the BIM model that can assist in creating a plan are discussed.

Planning software can calculate the critical path and the slack of activities. Because this software is linked to the BIM model, it is possible as well to visualize the critical path and see what happens with the critical path when the plan changes. The visualization of the critical path should help the planner to decrease the length of the critical path and see if there are errors in this path. The visualization is also important for the understanding of the critical path by other parties involved (Out-law, n.d.).

The BIM model and the plan combined result in a detailed plan; for every material used in the building is exactly known when it is needed at the construction site. The BIM model combined with the plan is called the 4D model. With the 4D model it is possible to discover impossible schedule sequences and the 4D model makes it possible to deliver materials JIT at the construction site (Bryde et al., 2013). With data from the BIM model about sizes and weight of the materials and the amount of materials, deliveries can be planned. The type and amount of trucks needed can be calculated with this information. A change in the design or in the plan can lead to a better fit in trucks or the amount of trucks needed for the total delivery could be less. For JIT deliveries from the hub can be calculated if certain loads combined fit in one truck. With the 4D model it can be seen when too much deliveries are planned at the construction site, subsequently with a small change in the plan a peek in deliveries can be lowered. The parameters weight and size can also be used to test prefabrication solutions on feasibility. In this way, errors in the plan can be prevented in an early stage. The prefabrication solution cannot be too heavy to lift or too big to transport. Weight is a parameter that is not standard given in BIM; it is possible to add weight as parameter.

With the 4D model it is also possible to keep track of the progress of the construction. With the BIM model the actual progress can be visualized together with the plan. It can be seen whether the project is on schedule or behind schedule and where the plan is not met, as well as where extra attention is needed. (Klein Paste, personal communication, 10-10-2013).

A 5D BIM model can assist in making the plan by for example creating different scenarios for materials or construction methods and see what the result on the budget is of the different scenarios. When necessary the plan can be adjusted when it turns out during construction that the budget will not be met. Another advantage of using a 5D BIM model is that future cash flows can be forecasted accurately (Bryde et al., 2013).

In a BIM model, it can be seen exactly how parts have to be cut or prefabricated in order to fit in the construction. This can be done in advance at the sub-contractor or at the hub. This saves time for the construction at the construction site and makes the control of waste easier. The shorter time needed at the construction site affects the plan.

Extra resources needed at the construction site as cranes and elevators to lift materials or scaffoldings and cherry pickers can be drawn in the BIM model. It can be asked to sub-contractors what they need to perform their job. This information can be communicated with the rest of the sub-contractors so they do not all hire a cherry picker or build their own scaffolding. With this information, the utilization and location of the extra resources can be seen in the BIM model. Besides that, it can be indicated where the extra resources are located. They can be positioned in such way that they do not interrupt the construction process. The positioning of the shuttering struts is also important to make sure the construction process is not intervened. This makes the plan easier to control because there are less unexpected problems (Klein Paste, personal communication, 5-11-2013).

Another type of information that can be used to assist in making a plan is the amount of construction workers in a specific area. According to the plan, a sub-contractor knows how much time is available to complete his job. With this information the sub-contractor also knows how many construction workers are needed to finish on time. When every sub-contractor knows how many construction workers are needed on a specific day, the utilization of a specific area can be seen. When the utilization is too high or when there are too many construction workers at the construction site, there should be a change in the plan. With respect to safety it can also be indicated when it is allowed to work in certain areas and when it is not allowed (Klein Paste, personal communication, 16-01-2014).

With the BIM model it is possible to make a short movie of a construction method or part of the building, in this way it is clear for all parties involved how it is done and when it is done. This improves the reliability of the plan because fewer errors will be made. This short movie can for example make clear where and when certain materials can be placed at a floor. In this way, the tower crane driver knows in advance what has to be done and how it has to be done, which makes the lifting process faster (Klein Paste, personal communication, 20-11-2013).

Sizes and types of packaging materials should also be known to control waste and to plan storage and transportation. When the type of packaging material is known it can be calculated how much waste should be collected at the construction site. This makes it easier to plan the reverse logistics.

With deliveries at the hub and materials placed in the building by the tower crane it is important to know where materials are stored. To keep track of what materials are stored and where they are stored, there should be a kind of warehousing system. In order to make it easy to find materials there should be a clear hierarchical structure which results in unique locations. Every floor can for example be divided into smaller sections. With the BIM model it is not possible to control inventory. It would be ideal that when a part in the BIM model is clicked on information about delivery and storage becomes visible. If the materials are not delivered yet, the location and date of delivery becomes visible and when the materials are delivered the location of the materials become visible. This makes the plan easier to control because fewer errors will be made in searching for materials.

It might not be possible to store all desired information in the BIM model. It can be the case that BIM has to communicate with for example a warehouse management system or another database. In the ideal situation all information is stored in one program but when that is not possible as long as the information can be reached and used it is a good way of getting to the ideal situation.

3.1.3 Conclusion

In this section the sub question "*How can a BIM model assist in creating a plan?*" is answered. When the right information is added to the BIM model, the BIM model can assist in creating a plan. What information can be added to the BIM model is discussed below.

With a 4D model, the amount of deliveries at certain days and wrong scheduling sequences can be seen. When there is a peek in deliveries, a small change in the plan can lower the peek if necessary. For these adjustments the slack of activities should be known.

Because everything about sizes and shapes is known, materials can be shaped right in advance and the information can be used for prefabrication solutions. It is also possible to draw extra resources as scaffoldings in the BIM model; this prevents unnecessary delays.

When budget information is added to the model, cash flows can be forecasted and different scenarios in the plan can be compared based on the budget. Next to the sizes and shapes, the parameter weight should be added to the BIM model. For projects with a fixed crane capacity this is important, especially for prefabricated parts, because the maximum weight lifted by the tower crane is fixed and cannot be adjusted anymore.

For a planner it is important to know what jobs are in the critical path. With the BIM model it is possible to visualize the critical path. This makes it clear for all involved parties what is in the critical path and what happens when the critical path changes. With the 5D model the result of a delay on the budget can immediately be seen as well. For a planner or an executor it is also important to see where the construction is behind schedule, when this is visualized by adding the finishing time of a job to the BIM model the planner or executor can immediately see and react on it, if necessary.

The amount of construction workers is another parameter that should be added to the BIM model as well. Especially in the fit-out phase, there are a lot of construction workers at the construction site. When information about the amount of construction workers is added, congestions or too crowded areas can be indicated and small adjustments in the plan can be made to prevent this. To make these adjustments it is important to know the slack of activities. With respect to safety it can also be indicated when it is allowed to work in certain areas and when it is not allowed.

For the difficult parts of the construction, short movies can be made. When the movies are seen by the construction workers before they have to perform their job it is exactly known what they should do and this will result in less errors, thus a plan that is more in control.

Sizes and type of packaging materials should be added as well. With this information the waste can be controlled and storage and transportation can be planned. With the information from the 4D model the reverse logistics stream per day is known and can be planned.

The last piece of information in the BIM model that can assist in the planning process is that there should be a link with a warehouse management system. It is important to know where what materials are stored or when and where they will be delivered.

It can be the case that not all described information is stored in the BIM model. As long as it is clear where what information is stored and that the information can be used easily, it is a good way to reach the ideal situation of one computer system in which BIM is integrated as well.

To overcome the challenges that arise when using BIM, personnel needs to be continuously trained because in the future, BIM will be used more and more and because BIM keeps on developing. Besides that, people need to get used to a change in the process since more work is done in advance to save work and cost during the construction.

3.2 Prefabrication to improve the plan

In this section the fifth and sixth sub question are answered. This gives insight in the second part of the research questions. In sub section 3.2.1 the sub question “*What factors influence the decision to use prefabrication or not?”* is answered and in sub Section 3.2.2 the sub question “*To what extent and how should the client and/or sub-contractors be involved earlier in the planning process?”* is answered.

3.2.1 Factors influencing the prefabrication decision in the planning process

In this sub section the second sub question “*What factors influence the decision to use prefabrication or not?”* is answered. In sub Section 3.2.1.1 factors found in relevant literature are described. In sub Section 3.2.1.2 is described how these factors can be used in the planning process to improve the plan. Improving the plan here means reducing the planned time needed to complete the construction, reducing the planned lead time to complete the construction. This sub section ends with a conclusion in sub Section 3.2.1.3 in which the second sub question is answered.

3.2.1.1 Factors from the literature

“Off-site production is the manufacture and preassembly of building components, elements, or modules before installation into their final locations” (Pan, Gibb & Dainty, 2012). In the literature there are many terms for off-site production which are used interchangeably. These terms can be categorised in four categories: off-site (off-site construction, off-site fabrication, and off-site manufacturing), pre- (preassembly, prefabrication, and prework), modern (modern methods of construction), and building (system building, non-traditional building, and industrialized building). There are small differences between the terms and the context in which they are used (Pan et al., 2012). For this research, the term prefabrication is used.

There are four different levels of prefabrication (Pan et al., 2012):

- Component and subassembly: those elements are always made in a factory and never considered for on-site production, for example windows;
- Non-volumetric preassembly: this are preassembled elements that do not enclose usable space, for example prefabricated concrete walls or steelwork;
- Volumetric preassembly: this are preassembled elements that enclose usable space and are typically fully factory finished internally but do not form the building structure, for example bathrooms;
- Modular building: this consists of preassembled modules that together form the whole building, for example hotel modules.

Benefits of using prefabrication in the construction industry are reductions in time, health and safety risks, environmental impact, and defects and an increase in predictability, productivity, quality, and profitability (Pan et al., 2012).

There are several factors that influence the decision to prefabricate elements or not. These factors can be divided into the following categories: design related factors, module related factors, site attributes, labour considerations, manufacturing unit, transportation and equipment, organization's readiness, codes and permits, technology related factors, owner's perspectives, sustainability requirements, and finance related factors. To give an example of decision factors that influence the decision to prefabricate or not, the eleven most critical decision factors are identified (Azhar, Lukkad & Ahmed, 2013):

1. Suitability of design;
2. Use of repetitive components in the design;
3. Site accessibility;
4. Structural stability of individual and assembled elements;
5. Organization's familiarity with prefabrication;
6. Client's receptivity and willingness to accept modular construction;
7. Need for expediting the schedule;
8. Early up front involvement of top management in the project;
9. Well defined project scope and budget;
10. Integration of a well-versed team and strong collaboration among players;
11. Getting complete product submittals, show drawings, and co-ordination drawings ahead of decision making.

Next to the decision factors there are several constraints for using prefabrication. These constraints are divided in several categories as well: site related, process related, procurement related, planning-design related, resource related, and management related. To give an example of constraints for using prefabrication, six major constraints are identified from these categories (Azhar et al., 2013):

1. Key decisions about construction methods made by the designers without involvement of contractors;
2. Client's wrong conception about modularity;
3. Non-availability of prefabrication unit near the construction site;
4. Restricted site layout;
5. Decreased flexibility for design changes later in the project;
6. Carrying out on-site modifications is difficult.

A key factor for success of prefabrication is the effective collaboration of the parties involved in the prefabrication in the early stages of the project. If all parties involved are involved early in the project planning phases, it will be easier to plan and implement prefabrication (Azhar et al., 2013).

Since the introduction of BIM, prefabrication has evolved greatly. Within the BIM model the designer is able to determine the exact dimensions of the prefabrication solution. With this information, the structure can be prefabricated with precision and no waste (Gohmert, 2013).

3.2.1.2 Improving the plan with prefabrication

Prefabrication can improve the plan because it is possible to start earlier with certain jobs and do multiple jobs at the same time at different locations. It might be possible that certain jobs will take longer but the total lead time will improve. This is illustrated in Figure 4. The upper Gantt chart is the traditional situation of for example the steel construction and different sub-contractors that have to wait for each other to mount their part to the steel construction. The bottom Gantt chart is the prefabrication situation in which different sub-contractors can work at the same time. It can be seen that in the prefabrication situation job 1 takes longer because the steel constructor has to wait and adjust its work to the other sub-contractors, but since multiple jobs can be executed simultaneously the total lead time is shorter.

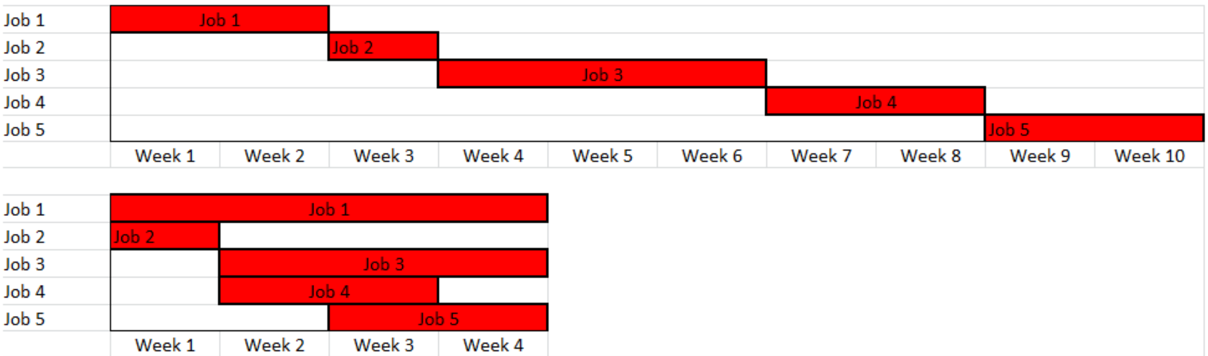

Figure 4: Planning improvement

The decision to prefabricate or not to improve the plan is a decision that has to be taken in the early stages of the project. To improve the plan by prefabrication, jobs in the critical path should be analysed for prefabrication options. This can be done by using the twelve categories of factors mentioned in 3.2.1.1. Instead of planning the critical path as good as possible parts of the critical path are taken out of the plan, which means that - when the plan is updated - new jobs are in the critical path. How much the plan improves depends on the slack of the other jobs in the plan. The jobs in the new critical path will also be looked at if it is possible to prefabricate them. When that is known, the plan can be updated again and the new critical path can be calculated as well. This process has to be repeated until the plan does not improve anymore. The sub-contractors involved in the prefabrication solutions should be involved from the moment it is decided to use prefabrication. They can help in creating prefabrication solutions for the part of the construction they have specific knowledge about.

To be able to analyse the critical path for prefabrication options the plan should be finished in an early stage as well. This plan does not have to be a fully detailed plan but it should contain the main activities at the construction site to be able to identify the jobs in the critical path. For example for the steel plan it is enough to know how long it takes per floor. In this way can be seen if the steel floor is in the critical path or not. The improvement process is illustrated in Figure 5.

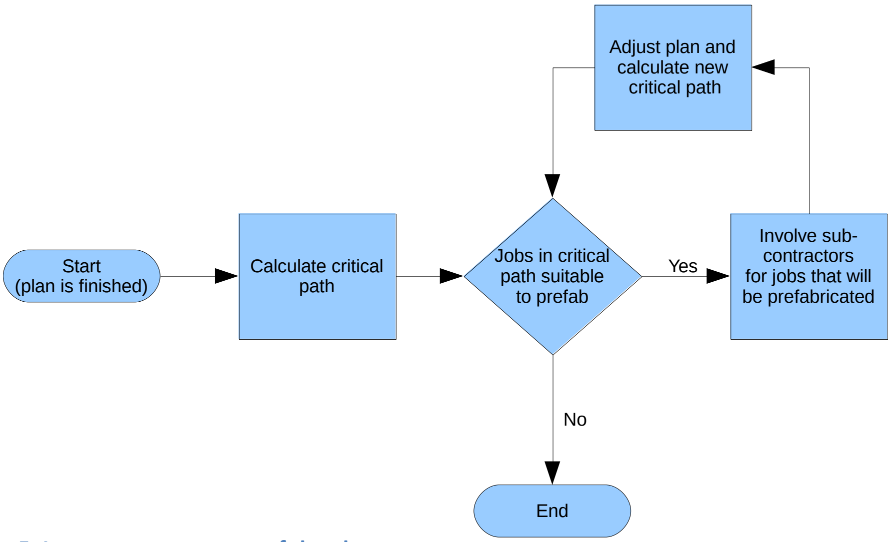

Figure 5: Improvement process of the plan

The decision to prefabricate a job or not should be based on the twelve categories of factors mentioned in sub Section 3.2.1.1. The most important factors are that the design and the plan are finished and that it is possible to come up with a solution for prefabrication. When the design is finished on time it is also possible to adjust the design if possible in such way that prefabrication is easier. There are several factors mentioned in sub Section 3.2.1.1 that result in constraints for prefabrication. Examples of constraints are – at first – that the accessibility of the site might constrain the size or weight of the prefabricated unit. Secondly, when the costs of prefabrication are higher than constructing in the traditional way, it should be calculated if the extra costs are worth the time saving.

Prefabrication can also be used to reduce complexity at the construction site instead of reducing the lead time of the plan. When there are a lot of different activities at the same time at the construction site, it is possible with prefabrication to move certain activities away from the construction site. Reducing complexity at the construction site leads to less variability (fewer mistakes) at the construction site which makes it easier to control the plan. At the prefabrication site will also be less variability because of the controlled circumstances (Lennartsson, Bjornfot & Stehn, 2009).

3.2.1.3 Conclusion

The sub question answered in this sub section is: *"What factors influence the decision to use prefabrication or not?"* The most important aspect for improving the plan by prefabrication is the early finishing of the design and the detailed but not fully detailed plan. In this plan estimations of the activities of future sub-contractors should be planned. With this plan the critical path can be identified and with the twelve categories of factors, it can be decided to prefabricate a job in the critical path or not. The improvement in the plan depends on the slack of the other jobs in the plan. When it is decided to prefabricate, the sub-contractor should be involved from that moment on. When the design and plan are finished, the plan can be improved according to the steps illustrated in Figure 5.

The twelve categories of factors that influence the decision about if a job can be prefabricated or not are: design related factors, module related factors, site attributes, labour considerations, manufacturing unit, transportation and equipment, organization's readiness, codes and permits, technology related factors, owner's perspectives, sustainability requirements, and finance related factors.

When there are no prefabrication solutions or it is too late to implement prefabrication solutions and the plan needs to be improved, crashing the plan is the last option. Crashing the steel plan is discussed in Section 5.3.

3.2.2 Earlier sub-contractor involvement

In Section 3.2.1 it became clear that for prefabrication decisions, it is necessary to involve the sub-contractor early in the process. That is why in this section the third sub question "*To what extent and how should the client and/or sub-contractors be involved earlier in the planning process?*" is answered. The concept of earlier involvement of sub-contractors by partnering according to the literature is described in sub Section 3.2.2.1. This chapter ends with a description about how to involve sub-contractors earlier in the planning process based on the literature in sub Section 3.2.2.2 and a conclusion in sub Section 3.2.2.3.

3.2.2.1 Earlier sub-contractor involvement according to literature

In Figure 6 the traditional interaction patterns in the construction industry are illustrated. Firms A and B are involved in construction project P1 together with teams from other firms. Firm A is simultaneously involved in P2 and P3 and firm B is simultaneously involved in P4, P5 and P6. These interactions within projects do not provide long-term orientation and learning (Gadde & Debois, 2010).

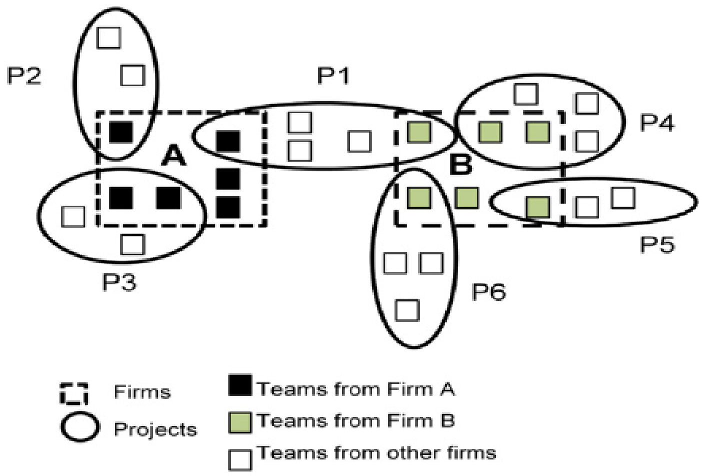

Figure 6: Traditional interaction patterns (Gadde & Debois, 2010)

The most used definition of partnering is the definition from the Construction Industry Institute (Bygballe, Jahre & Sward, 2010):

''A long-term commitment by two or more organizations for the purpose of achieving specific business objectives by maximising the effectiveness of each participant's resources. This requires changing traditional relationships to a shared culture without regard to organization boundaries. The relationship is based upon trust, dedication to common goals, and an understanding of each other's individual expectations and values. Expected benefits include improved efficiency and cost effectiveness, increased opportunity for innovation, and the continuous improvement of quality products and services.''

Based on this definition, three key dimensions of partnering are identified: relationship duration, relationship partners, and relationship development (Bygballe et al., 2010).

The relationship duration can be short term or long term. Short term relationships in the construction industry are project based and aimed at short term benefits. Long term relationships are for more than one project and are called strategic partnerships. Project based partnerships are seen as the first step towards strategic partnering. Project partnering is described as “a method of transforming contractual relationships into a cohesive, project team with a single set of goals and established procedures for resolving disputes in a timely and affective manner” (Bygballe et al., 2010). At the end of a project the relationship is terminated and another relationship may start at the next project. Strategic partnerships are not common in the construction industry. This is because the environment is characterised by price chasing, one-off contracts, and short term gains while the strategic partnerships are based on mutual trust and long-term collaborations. The tendering procedures and public procurement regulations are perceived as the main factors contributing to the maintenance of the traditional short-term and often adversarial relationship in construction (Bygballe et al., 2010). Due to fewer projects based management, it is easier to make the first steps in creating strategic partnerships with sub-contractors for more projects at the same time. Standardized materials which are needed at multiple projects at the same time can be bought at a lower price at the same sub-contractor. This is easier when demand is known far in advance (Gadde & Dubois, 2010).

The client or sub-contractors are possible relationship partners for BAM. The relationship can exist between BAM and the client or BAM and a sub-contractor, but the relationship can also consist of a team with multiple sub-contractors with or without the client. Essential factors for a successful team are equal status within the team, cooperative interaction, dedication for common goals and authority support. Authority support is authority from top management to make decisions (Anvuur & Kumaraswamy, 2007).

Relationships can develop by formal tools and by informal aspects. Examples of formal tools are: selection procedures, workshops, TQM, measurements, and critical success factors needed to develop partnerships. Next to the formal tools, informal aspects are important as well. With informal aspects, social dynamics and cultural-structural aspects are meant (Bygballe et al., 2010). Another formal tool that can be used to develop a relationship or drive behaviour is contractual financial incentives. There are three different types of financial incentives: share of savings incentive (rewarded for savings), time incentive (rewarded for timely delivery), and performance incentive (reward for quality) (Rose & Manley, 2011). The use of incentives is a trigger to align the objectives of different parties in the team and devoting special efforts to performance improvement. When incentives are used combined with disincentives, they have a more positive effect on project performance (Meng & Gallagher, 2012). Underlying distrust between project participants can result in negative perceptions of the incentive intention, limiting its impact on motivation. Financial incentives should be promoted as a supporting tool in the development of trust, cooperation, and motivation and not as performance control mechanism within highly detailed contractual specifications (Rose & Manley, 2011). Contractual incentives can work counterproductively, they can work against the objectives of the team; they encourage focus on the specified tasks that influence the performance incentives. Team members will evade action unless their action contributes directly to their own economic self-interest. Measurement problems further complicate the use of performance incentives. Contractual incentives create more contractual disputes between contractual partners than the same situation without contractual incentives (Anvuur & Kumaraswamy, 2007).

Potential benefits of partnering are lower costs, improved team approach, less confrontations, improvement in performance, more innovation initiatives, better quality, improved understanding of the project, lower tendering costs, an increase in productivity, reduced project times, improved client satisfaction, and better responsiveness to changes (Humpreys, Matthews & Kumaraswamy, 2003; Gadde & Dubois, 2010).

According to Gadde & Dubois (2010) there are seven challenges for partnering in the construction industry. Firstly partnering does not provide sub-contractors with many tangible benefits. Secondly deep-rooted cost driven agendas still persist in most transactions. The third reason is the unwillingness to fully commit to the partnering agreement. Fourthly is a failure of stakeholders to develop the attitudes required for making partnering effective. The fifth reason is that collaborative approaches do not necessarily remove conflicts. The Sixth challenge is the historically developed adversarial culture between stakeholders in the construction industry. The last challenge concerns difficulties in converting strategic decisions concerning partnering arrangements into real behaviour at operational levels.

It is not possible to become partners with all sub-contractors, therefore it is advised to only become partners with the key sub-contractors. The key sub-contractors are the sub-contractors who are the most important for the completion of the project (Bygballe et al., 2010). The key sub-contractors can be identified by the following characteristics (Humphreys et al., 2003):

- Design content
- Complexity of construction
- High contract value
- Long period(s) of construction
- Long procurement times
- Could add value with early input

3.2.2.2 Earlier involving sub-contractors

The process of involving sub-contractors should start with identifying the key sub-contractors of a project. The key sub-contractors should become partners for the duration of a project. The most important factor for selecting a key sub-contractor is not mentioned by Humphreys et al. (2003). The most important factor is whether or not the activity of the sub-contractor is in the critical path. When that is the case, the six factors mentioned by Humphreys et al. (2003) can be used.

There should be no focus on creating long term strategic relationships when there is no experience with strategic relationships because there is no full understanding of the practicalities and legal implications of creating partnerships. For that reason, one should always start with finding project partners although strategic partnering might offer more cost savings on the long term. Successful project partnering can lead to strategic partnering in time if this is desired by all involved parties (Humphreys et al., 2003).

Project partners should be involved earlier in the process than traditional. The sub-contractors should be involved before the approval of materials and methods with the client. In this way the specific knowledge from the sub-contractor can be used and the approval process only has to be done once. The earlier involvement has consequences for the procurement process. The procurement has to be done earlier as well. The parts for which project partners are needed, multiple possible sub-contractors can be approached to still get a market price. When other criteria than price are important to select a potential project partner, those criteria should be communicated clearly to the potential project partners. Other criteria might be: understanding of partnership concept, alternative proposals for design, innovation, past experience, and quality awareness (Humphreys et al., 2003). The process of identifying key sub-contractors and involving partners earlier should start when there is insight in the critical path.

Project partners who influence each other's job should be put together in one team and should make each other's job as easy as possible. The main goal of the team should be to complete the construction as fast and cost efficient as possible. It could be that there are different teams. Because of the early involvement of those teams, the sub-contractors can perform their job in the way they want to perform it instead of the way how the contractor thought they want to perform it. The client should be included in the team as well. In this way the client understands how sub-contractors or contractors think and why they propose changes. This makes discussing the changes easier and the client can immediately indicate why he rejects or accepts the changes.

An even further improvement of the planning process is to include partners in the designing of the BIM model. Sub-contractors might have a library in which they can immediately place their materials with the right data in the model. Another advantage is that the sub-contractor can draw his part in the BIM model how he wants it to be. Besides that, it saves work in creating the BIM model. Different sub-contractors can communicate in this way via the BIM model and can solve problems in an early stage. When sub-contractors are going to draw their own parts in the BIM model good coordination is needed.

After a project is finished, the partnerships should be evaluated together with the partners. In this way the partnerships can improve in the future.

Because of the earlier involvement of the key sub-contractors, the procurement process has to start earlier as well. Improvement in the procurement process is possible by sharing knowledge about demand between projects. There probably are more projects that need standard materials around the same time. When this demand is combined, the materials can be bought cheaper.

When financial incentives will be used to stimulate performance of the key sub-contractors, the disadvantages of financial incentives should be kept in mind. Team members can act only in self-interest and disputes about the incentives because of the contract can occur. So the incentives should be aimed at team goals, not at individual goals and it should be clear when a financial bonus can be earned.

3.2.2.3 Conclusion

The sub question answered in this sub section is: "*To what extent and how should the client and/or sub-contractors be involved earlier in the planning process?*" Key sub-contractors should be involved earlier in the process by creating teams. The teams should consist of BAM and sub-contractors who work on the same part of the construction. The teams should involve the client or advisors from the client as well. The most important factor of a key sub-contractor is if the sub-contractor is in the critical path. Other factors to select key sub-contractors are the design content, the complexity of construction, the contract value, long periods of construction, long procurement times, and that the sub-contractor could add value with early input. Because of these teams, more activities take place in the early stages (before the actual construction begins) of the planning process with as goal to reduce the construction time.

The key sub-contractors should be involved in creating the BIM model. Therefore the key sub-contractors should be involved as early as possible. In this way the sub-contractor can design its own part and the sub-contractor does not have to change the BIM model that is already created. The sub-contractor probably has a library in which his objects are already drawn with the right properties.

Because the selection procedure and the moment of the selection procedure are important for the success of prefabrication, the selection procedure of the duct supplier at the Groninger Forum is discussed in the case study in Section 4.2.

3.3 JIT delivery

JIT deliveries are important for prefabricated parts because it is costly to store large prefabricated parts and handle them twice or more. Besides that, for the Groninger Forum all other deliveries will be made JIT at the construction site as well. Therefore the sub questions *" What characteristics must a planning process in the construction industry have to make JIT delivery a success?"* and "*Which possibilities for the planning process available in the literature can be used in combination with JIT deliveries?"* are answered in sub Section 3.3.1 and 3.3.2.

3.3.1 Characteristics of JIT delivery in construction industry

In this sub section the sub question *" What characteristics must a planning process in the construction industry have to make JIT delivery a success?"* is answered. First the characteristics of JIT are described in sub Section 3.3.1.1; this is followed by a description of the characteristics of JIT in the construction industry in sub Section 3.3.2.2. This section ends with a conclusion in sub Section 4.4.3.

3.3.1.1 Characteristics of JIT

JIT is a management philosophy developed by Taiichi Ohno in the 1970s at Toyota. JIT is also known as the Toyota production system and is aimed at reducing waste. According to JIT there are seven types of waste (Bayazit, 2011):

- Inventory
- Transport of products
- Motion of people or equipment
- Waiting
- Overproduction
- Defects in products
- Inefficient processing

JIT is a pull system, it is driven by demand. Upstream work centres are creating demand for downstream work centres. Products are delivered at the work centre at the moment they are needed, so there is no stock. Another important aspect of JIT is for organizations to create continuous improvement and reach zero defects in production (Bayazit, 2011).

In order to make JIT a success, there needs to be (Bayazit, 2011):

- Uniform demand
- Low product variability
- Low process variability
- Small lot sizes
- A flexible work force
- A few core suppliers
- Preventive maintenance

3.3.1.2 Characteristics of JIT in the construction industry

Delivering JIT means deliver building materials on the day they are needed at the place they are needed. When a construction worker reaches its workplace he can immediately start working because the building materials needed are already at the workplace. At the end of the day all materials are used, the waste can be collected and the materials for the next day can be placed at the workplace again. Research showed that better planning and control could raise the productivity of construction workers with thirty minutes a day and that well-coordinated deliveries could save sixty per cent on transportation costs (Dijkhuizen, 2014). In order to make JIT deliveries in the construction industry a success, the following aspects are important (Ballard & Howell, n.d.):

- Predictability of demand
- No variability in process
- Delivery in small lot sizes

The predictability of demand is very high since the entire project is put in a BIM model. All the work that has to be done can easily be planned, only the parts for which there was no reason to draw are missing in the BIM model. With the BIM model and XD manager combined, the theoretical demand off all materials can be predicted 100% accurately. With XD manager, information about components from the BIM model is collected and the amounts of components plus their information is sorted. In practice, construction errors can be made or materials can be damaged so it is never 100% accurate.

Variability is uncertainty in the duration of building activities. Variability leads to higher costs because it makes buffering necessary, which leads to an increase in lead times and work in progress, lower resource utilization, and lost throughput (Ballard, 2000). Besides, variability in the process leads to a deviation of the plan. The construction industry is schedule driven; this means that if everything goes according to plan, the work flows smoothly and maximum performance is achieved. In order to maximize the use of JIT, the variability in the process must be minimized, in other words the plan must be kept in control. If there is no control, deliveries are made for activities which are not performed on that specific day. A good planand control leads to good logistics; good logistics results in fewer accidents and less spoiled time (Ballard & Howell, n.d.).

Delivery in small lot sizes might be necessary since the amount of materials delivered must be aligned with the daily productivity of the sub-contractor. For the Groninger Forum, delivery in small lot sizes is made easier by a hub. At the hub there is place for storage of supplies which can then be delivered in the right amounts to the construction site or materials can be repacked at the hub and then delivered to the construction site. Especially for sub-contractors who are not from the area of Groningen it might be less costly to bring full truck loads to the hub instead of daily smaller JIT deliveries.

3.3.1.3 Conclusion

The sub question answered in this sub section is: *"What characteristics must a planning process in the construction industry have to make JIT delivery a success?"* To make JIT deliveries a success, three important characteristics of the planning process have to be taken into account:

- The demand must be predictable
- Minimal deviations from the plan (minimal variability)should be made
- Delivery sizes must be aligned with productivity of sub-contractor

The predictability of demand and the delivery sizes which are aligned with the productivity of the sub-contractor are not a problem at the Groninger Forum. To keep the variability of the process as low as possible, the plan must be kept under control.

3.3.2 Planning process and control

From Section 3.3.1 it became clear that for JIT delivery to be successful it is necessary that the plan is in control. In sub Section 3.3.2.1 till sub Section 3.3.2.3, three methods found in the literature are discussed which are aimed at keeping a planning process in control. Two fundamental and competing conceptualizations of management are management by means and management by result. Lean planning and the Last Planner System (LPS) are examples of management by means. The earned value method (EVM) is an example of management by result and is described after the Last Planner system (Kim & Ballard, 2010). The three methods are shortly discussed, more detailed information about LPS and the EVM can be found in Appendix A and B. In sub Section 3.3.2.4 the best method to keep the plan in control is chosen. Sub Section 3.3.2 is ended with a conclusion in which the sub question "*Which possibilities for the planning process available in the literature can be used in combination with JIT deliveries?"* is answered.

3.3.2.1 Lean planning

Lean planning is a concept that is inter alia used to plan projects in the construction industry. During the lean planning all parties involved are involved from the start of the planning. These parties are the main contractor, the sub-contractors, the architect, and the suppliers. During one or more planning days, every party plans its work in collaboration with the other parties. Conflicts in the plan are solved immediately and clear appointments between the sub-contractors are made. During the execution of the plan, evaluations are made on a regular basis. The advantages of lean planning are: a shorter planning process, less conflicts and ambiguities during execution, sub-contractors recognize problems of other sub-contractors, less stock and buffers, and a shorter lead time of the project (Arpa, n.d.). A disadvantage of lean planning is that some sub-contractors do not agree with lean planning because it is not always executed in the right way. These sub-contractors are obliged to participate in the lean planning sessions so at these sessions there are some unmotivated sub-contractors (J. Vreeken from Gebroeders Meijer, personal communication, November 13, 2013).

From the lean planning concept, a more detailed planning concept is developed; the Last Planner system (LPS). The Last Planner system is described next.

3.3.2.2 Last Planner

The goal of the LPS is to keep the plan in control. According to Ballard (2000) "control causes events to approximate the desired sequence, initiates replanning when the established sequence is either no longer feasible or no longer desirable, and initiates learning when events fail to conform plan." The Last Planner production control system is a philosophy, and consists of rules, procedures, and a set of tools that facilitate the implementation of these procedures. Regarding the procedures, the system has two components: production unit control and work flow control. According to Ballard (2000) "production unit control is to make progressively better assignments to direct workers through continuous learning and corrective action. Work flow control is to proactively cause work to flow across production units in the best achievable rate and sequence."

The most important aspects of the LPS for the planning process are:

- The quality of the plans is measured by the Percent Plan Complete (PPC). PPC is the number of planned activities completed divided by the total number of planned activities. A higher PPC corresponds with doing more of the right work with the given resources, i.e. to higher productivity and progress. By analysing the root causes of the not finished assignments, problems can be found and improvements can be made in future performance. The root causes can lead to changes at any organizational level. The root cause can be found by making use of the five times why method (Ballard, 2000);

- The lookahead schedule: this is a schedule with potential activities for the next three to twelve weeks with a rolling horizon. Activities which enter the lookahead schedule can only move forward when via constraint analysis is clear that all constraints can be removed when the activity will be executed. When the planner is convinced a constraint cannot be removed in time, the assignment is not allowed to move forward in the lookahead schedule. In absence of constraint analysis a throw-it-over-the-wall mentality will be created (Ballard, 2000);

- Next to the lookahead schedule and the master schedule, it is beneficial to let the team involved in the next phase of a project, collectively produce a phase schedule which coordinates actions that extend beyond the lookahead window. It is important that all sub-contractors are willing to participate in the Last Planner process; otherwise it affects the PPC in a negative way (Ballard, 2000);

- During a weekly planning meeting the status of the constraints in the lookahead schedule are discussed and the weekly plan is made. The status of the constraints should be known to all participants before the weekly planning meeting starts. In this way the focus can be on planning and problem solving instead of data collection. From the weekly plan the PPC is calculated. The PPC is only meant to improve the process and not to point out the weakest link. When the causes for delays are not clear, the foreman and the sub-contractor must ask five times why the delay happened. This helps to find the root of the problem (Becktechnology, 2013; Ballard, 2000).

3.3.2.3 Earned value method

The earned value method (EVM) is a method which integrates schedules, resources, and scope for measuring project performance. It compares the amount of work that was planned with what was actually earned and spent to determine if cost and schedule performances are as planned (Naderpour & Mofid, 2011). EVM is an early warning method that enables managers to identify and control problems before they become too big. It allows projects to be managed better on time and on budget (Nagrecha, 2002).

To analyse if the plan is in control, three terms are important; Actual Cost of Work Performed (ACWP), Budgeted Cost of Work Performed (BCWP), and Budgeted Cost of Work Scheduled (BCWS) (Kim & Ballard, 2000).

- Actual Cost of Work Performed (ACWP) is the actual incurred cost of work performed in a specified period of time expressed in terms of euros or man-hours (Actual);
- Budgeted Cost of Work Performed (BCWP), or Earned Value, is the budgeted value, usually in terms of euros or man-hours, of work actually performed in a specified period of time;
- Budgeted Cost of Work Scheduled (BCWS) is the budgeted value, usually in terms of euros or man-hours, of work scheduled to be performed in a specified period of time (Plan).

Since the objective of EVM is to achieve an integrated cost and schedule progress monitoring and control system, it requires the monitoring of two kinds of variances: Cost Variance and Schedule Variance. There is a third variance which can be monitored: Accounting Variance (AV). Early cost control systems focused on AV to monitor cost variance, but EVM does not use it anymore since it does not take performance into account (Kim & Ballard, 2000).

- Cost Variance (CV) is the difference between the budgeted and actual costs of the work performed;
- Schedule Variance (SV) is the difference between the budgeted cost of work actually performed and the budgeted cost of the work schedules to be performed;
- Accounting Variance (AV) is the difference between what is actually spent and how much is supposed to be spent.

Figure 7 shows the relationships between BCWS, BCWP, ACWP, CV, SV and AV.

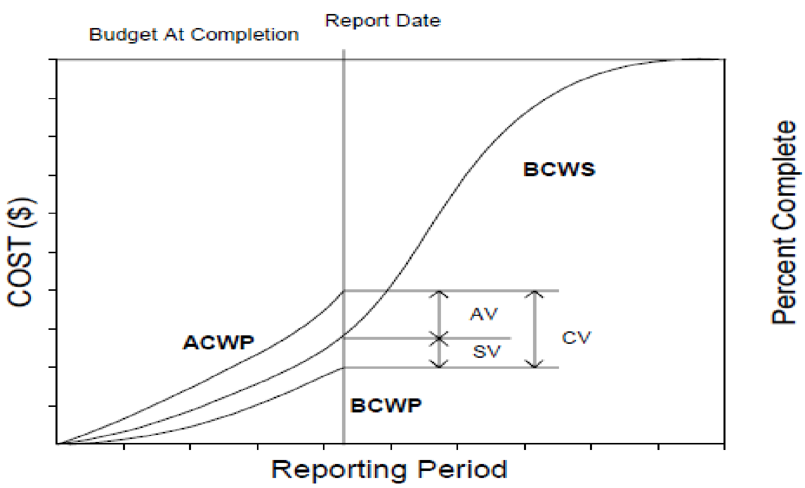

Figure 7: relations evm (Kim & Ballard, 2000).

The performance interpretations that may be drawn from cost and schedule variance values are summarized in Table 1 (Kim & Ballard, 2000). Next to the variances there are two indices which can be calculated; the cost performance index (CPI) and the schedule performed index (SPI). The CPI is the ratio between budgeted cost and actual cost. The SPI is the ratio between budgeted work and performed work (Nagrecha, 2002).

Table 1: performance interpretations (Kim & Ballard, 2000).

Variance	-	0	+
Cost Variance (CV)	Cost overrun	On budget	Cost underrun
Schedule Variance (SV)	Behind schedule	On schedule	Ahead of schedule

With the actual values of the costs and schedules during a project, a prediction about the final costs and delivery date can be made. In case the prediction does not satisfy the manager, he must decide how to overcome the budget or schedule problems. Weekly calculation of the SPI and CPI can be used as a benchmark.

3.3.2.4 Best method to keep the plan in control
From the described methods in sub Sections 3.3.2.1 till 3.3.2.3, the LPS is the method most suitable to keep the plan in control which is needed for JIT deliveries.

The LPS is more suitable than lean planning because lean planning is not aimed at keeping the plan in control. The idea behind lean planning is that all parties involved collaborate and understand each other's problems and that it results in a more efficient plan. In reality, lean planning is almost never executed in the right way. Sub-contractors are often put under too much pressure to perform their work faster and it is often seen that when the plan is not reached, the foreman makes his own plan and does not look anymore to the lean planning. This results in another plan than made during the lean planning session which makes JIT deliveries harder.

The LPS tries to keep the plan under control by trying to perform as much work as possible when it is planned. The EVM tries to keep the plan under control by focussing on the end date of the project. For JIT delivery it is important that as much as planned is executed on the day it is planned. Another aspect important for JIT delivery is that everything that is planned can be executed, meaning that there are no constraints anymore. The LPS makes sure that is the case; the EVM does not take constraints into account. Besides JIT is a concept coming from lean management; the LPS has the same background and is based on the same principles.

3.3.2.5 Conclusion
The sub question answered in this sub section is "*Which possibilities for the planning process available in the literature can be used in combination with JIT deliveries?*" According to the literature, the LPS is most suitable to keep the plan in control because it is aimed at performing as much as activities on the moment that they are planned. What the effect is from the LPS on the planning process will become clear during the discussion of the case study in Chapter 5.

4. Case study

In this chapter the case used for this research is described. The case is originating from the construction of the Groninger Forum. The first part of the case is a description of the current planning process at the Groninger Forum and a description of the traditional relation between BAM and sub-contractors in Section 4.1. In Section 4.1 the sub question *"What does the current planning process at the Groninger Forum look like?"* is answered. The second part of the case focuses on the early involvement and collaboration of the steel supplier and the duct supplier and is described in Section 4.2. The selection procedure and the moment of the selection procedure have influence on the success of prefabrication. In Section 4.2 the two parts of the research question (the role of the BIM model in the planning process and prefabrication to improve the plan) at the Groninger Forum will be discussed.

4.1 Current planning process

In this section the current planning process at the Groninger Forum is described. The description of the planning process is based on an interview with a planner at the Groninger Forum. In this section the sixth sub question *"What does the current planning process at the Groninger Forum look like?"* is answered. Because the planning process at the Groninger Forum differs from the traditional way BAM plans, those two different ways are described in separate sub sections. At the Groninger Forum, BAM tries to improve the planning process compared to the traditional way. In sub Section 4.1.1 the planning process at the Groninger Forum is described and in sub Section 4.1.2 the traditional planning process is compared to the planning process at the Groninger Forum. In sub Section 4.1.3 the relation between BAM, the sub-contractors and the client is discussed in more detail. This section ends with a conclusion in sub Section 4.1.4.

4.1.1 Planning process at Groninger Forum

A first rough plan is made by a calculator at the head office. This plan is not very detailed, it consists of large parts of work, as for example, fitting out which is not specified into smaller actual jobs. This rough plan is made based on experience of the calculator and rules of thumb. The calculator plans all activities within the timeframe the client has set. The delivery date of the building is determined in advance by the client. The rough plan is used for the tendering process.

If the project is assigned to BAM, a more detailed plan is made by the planner of the project. The large parts of work used in the rough plan are worked out in more detail. The plan is mainly based on precedence relations and is made entirely by the planner of the project. The planner does not use any algorithms or heuristics to create the first draft of the plan. With this plan the critical path of the project is calculated.

When the critical path is clear, the planner tries to make the length of this path as short as possible by planning activities in the critical path as efficient as possible. This is done for example by developing prefabrication solutions, looking critically to the activities in the critical path and come up with smart solutions to shorten the duration of activities, or by removing activities from the critical path. This is not done by the planner itself but by the planner together with the responsible persons for the work preparation. The resulting plan is called the master schedule.

When it is too cold or the wind is too hard, it is not allowed to work outside, this is called unworkable weather. The master schedule takes the possibility of unworkable weather into account by allotting a certain amount of unworkable days in the plan. The number of these days is based on experience just as the time of the year these days are placed in. This means that the plan is not completely correct on a daily basis because the unworkable days are most of the time not on the days they are planned.

The master schedule is made visual with the use of a BIM model. The visualization of the plan makes it easier to notice errors or to see where improvements can be made. This visualization is made by the planning software in combination with the BIM model. Every component in the 3D BIM model has a unique code which is found in the plan as well. The BIM model and the plan combined make it possible to see in 3D what is built when, it is like a short movie in which one can see the progress of the building in time. Specific information about every component can be found in the BIM model as well.

The BIM model is constructed by modellers from BAM Utiliteitsbouw and BAM Techniek and is based on the specifications. At the Groninger Forum BAM Utiliteitsbouw, BAM Techniek and BAM Civiel collaborate and work together in one office space.

From the master schedule a more detailed plan per construction phase is made. This is done by lean planning. Lean planning is a concept that is inter alia used to plan projects in the construction industry. During the lean planning all parties involved in the project are involved from the start of the creation of the plan. These parties are the main contractor, the sub-contractors, and the important suppliers. During one or more planning days, every party plans its work in collaboration with the other parties. Conflicts in the plan are solved immediately and clear appointments about construction times are made. During the execution of the plan, evaluations are made on a regular basis (Arpa, n.d.). The executor of the Groninger Forum arranges those planning days.


Figure 8: Lean Planning (Arpa, n.d.)

When the materials used and the construction method are known the client must approve this. When changes are made in the construction method or used materials after the approval, it should be approved again.

Based on the lean plan, the foreman makes a six week schedule with a rolling horizon in which he communicates with all sub-contractors and makes sure they start their activities on time and they can do their jobs. From the six week schedule a more detailed week schedule is made every week. The different levels of the different plans are visualized in Figure 9.The current planning process is visualized in Figure 10.

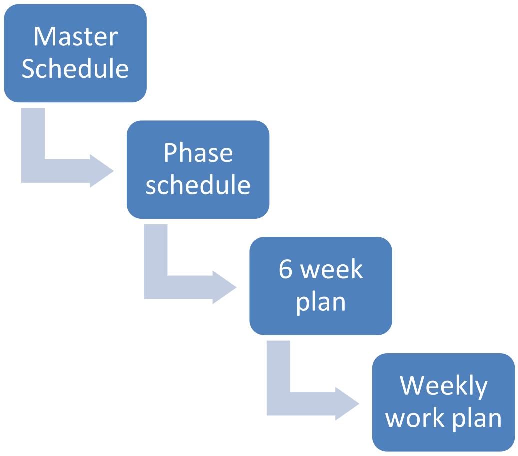

Figure 9: Different levels of plans

4.1.2 Traditional planning process

The planning process describe in Section 4.1.1 is not common practice for BAM. At the Groninger Forum it is the first time the plan is made this way. The plan at the Groninger Forum is determined in detail half a year before the construction starts. Traditionally the plan is finished a few weeks before construction starts. This means that there is less time to think of smart building solutions.

The collaboration of BAM Techniek, BAM Utiliteitsbouw, and BAM Civiel is not common as well; especially the collaboration in one office space is unique. Normally BAM Techniek and BAM Utiliteitsbouw do not collaborate in such an early stage of the project because most of the time they have to put in a separate bid. It is often the case that BAM Techniek is responsible for the technique in a building built by another party. When BAM Techniek and BAM Utiliteitsbouw both win the tender they both have separate contracts and will be judged on their own result; this means they are only looking at their own profit and that an opportunity where one party extra costs, but which results in higher savings for the other party are not considered.

Besides the stage in which the plan is ready and the collaboration between BAM Techniek and BAM Utiliteitsbouw, the construction and the intensive use of a BIM model are also new for BAM.

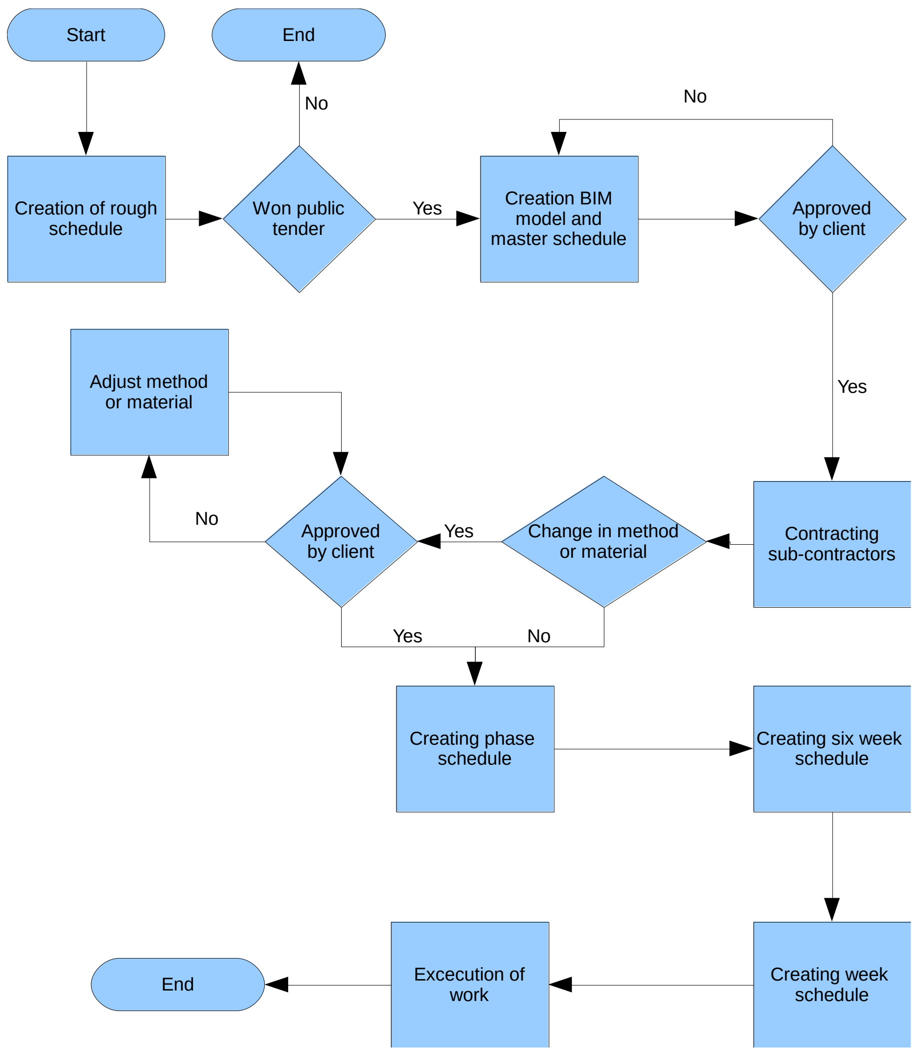

Figure 10: Current planning process Groninger Forum

4.1.3 Traditional relation BAM, sub-contractors, and the client

As can be seen in Figure 10 the sub-contractors are involved in the planning process after the approval of the construction method and materials. When a sub-contractor thinks there is a better way to do his job with other materials or by using another construction method, this needs to be approved by the client again. The sub-contractors do not have much influence in the planning process because the master schedule is already made. With lean planning, the phase schedule is made. Lean planning was explained in more detail in Section 3.3.1.

BAM chooses its sub-contractors based on the price they offer given a certain quality level. Different offers are asked from different sub-contractors who can deliver the required quality. From these offers the lowest offer is chosen. There are framework contracts between BAM and certain suppliers or sub-contractors but when another party is offering a lower price for the same product this is accepted by BAM. The reason for the acceptance of the lower price is that the project leader is judged on the financial result of the project. This way of judging results in the current way of working with sub-contractors. There are no good long term relationships with sub-contractors because of optimism; it is thought that it will always be cheaper elsewhere (Klein Paste, personal communication, 10-11-2013).

In the traditional way, the client contracts BAM and BAM contracts the sub-contractors. In this process the collaboration is minimal. This is visualized in Figure 11. Every party does what is described in the contract and when it is finished, it is passed on to the next party.

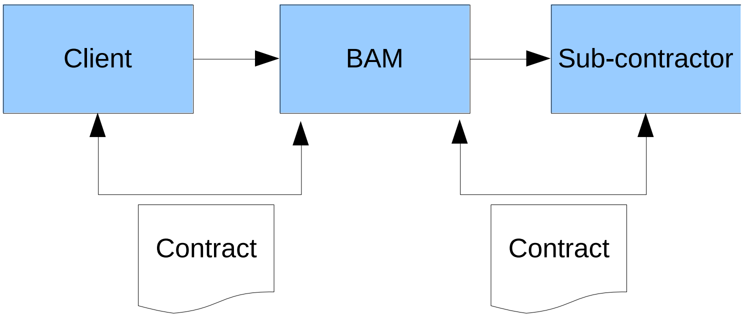

Figure 11: Relations between client, BAM, and sub-contractors (Klein Paste, personal communication, 5-11-2013)

4.1.4 Conclusion

In this section the sixth sub question *"What does the current planning process at the Groninger Forum look like?"* is answered. The current planning process is visualized in Figure 9.

Bam should try to convince clients that it is more profitable if BAM Techniek and BAM Utiliteitsbouw collaborate more often at an early stage, before construction begins instead of putting in separate bids. This will result in a faster and probably cheaper production process when BAM Techniek and BAM Utiliteitsbouw also collaborate on cost level.

4.2 Selection procedure of the duct suppliers

The second part of the case study is about the selection procedure of a duct supplier early in the process to ensure collaboration between the steel supplier and the duct supplier and to make prefabrication a success. The collaboration between the steel supplier and the duct supplier is a part of the construction process of the Groninger Forum. The steel supplier and the duct supplier are two of the 40 till 50 sub-contractors involved in the construction of the Groninger Forum. The decision was made to use the selection procedure of the duct supplier and the collaboration of the steel supplier and the duct supplier for this case study because the selection procedure took place during the period of research. The process of early involving sub-contractors is new for BAM so BAM does not know what the result will be or how they should go through the process of selecting a duct supplier earlier than usual. The role of the BIM model and the information needed in the BIM model of the Groninger Forum for the planning process are also not completely known because the use of BIM in the process is new for BAM. During the case study the rough steel plan is discussed in more detail.

Section 4.2 is split up in two parts according to the two parts of the research question. In Section 4.2.1 the role of the BIM model is discussed and in Section 4.2.2 prefabrication is discussed. Section 4.2.1 and Section 4.2.2 are based on observations made during attendance at different meetings between BAM and the duct suppliers, a meeting between BAM and the steel supplier, and on interviews with duct suppliers. The next part of the case study is described in narrative form.

4.2.1 BIM model

In the Groninger Forum, the ducts and the steel construction often cross. BAM wants to involve the steel and duct supplier earlier than usual in the planning process so the duct supplier and the steel supplier can collaborate in the design of the steel and ducts, resulting in a faster construction process.

In the Groninger Forum there are difficult areas for the construction of ducts. On the ninth floor for example is a technical room located in which little space is available for the ducts. To get the ducts at the ninth floor is a short time window available because the construction of the ninth floor is in the critical path. Next to that, there are some areas in which the ducts have to go through the steel construction. This is illustrated in Figure 12. For the selection process of the duct supplier, BAM finished the drawing of the ducts in the BIM model for about 80 per cent and gave the unfinished model to three duct suppliers. Some parts of the ducts where not drawn because BAM did not know exactly how to draw these parts. Since the sub-contractors have specific knowledge and experience with ducts, BAM hoped the sub-contractors could finish the remaining 20 per cent and come up with smart solutions to save work during the construction.

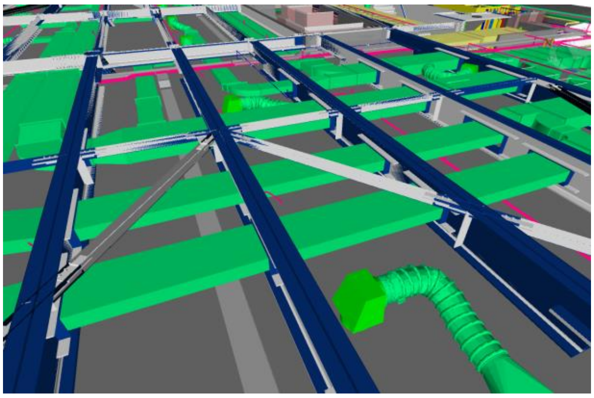

Figure 12: Ducts (green) cross the steel (blue) in the BIM model

During the negotiations with the three duct suppliers, the role of BIM was that visualisation of the ninth floor made it possible to discuss prefabrication solutions and what they would look like. It was easy to for example indicate where extra steel was needed to make the job of the duct supplier easier and to see what that would look like. This could be drawn immediately in the model and was input for discussion. Visualisation of the plan in BIM clarified for the duct suppliers why fast construction of the ducts on the ninth floor is so important.

Another important role of the BIM model was that it was used as model and not as drawing. The information about sizes in the BIM model could immediately be used to discuss prefabrication options. Weight was another factor discussed for prefabrication options. This information did not come from the BIM model but from the steel supplier who said what the weight of certain steel beams was. The amount of ducts where the duct suppliers have to base their offer on, is coming from the BIM model. All different types of ducts, their amount, and their sizes could be retrieved from the model.

The last role of the BIM model during this case study was a short movie made with the idea of prefabricating the shafts in the Groninger Forum. This movie made the sub-contractors realize that BAM wanted to do things completely different at the Groninger Forum.

BAM received a BIM model from the advisors of the local government of Groningen which was insufficient, that is why BAM designed their own BIM model. The received BIM model should have been exactly what BAM should have built, but because of errors in the BIM model this was not possible. In the BIM model from the advisors of the local government of Groningen, parts were missing (floating ducts and some toilets were missing), drawn in the wrong place (parts of the ventilation system where drawn outside the building), or drawn in a way impossible to construct (ducts, sprinklers and steel where drawn in the same place in multiple parts of the building). With the received model it was impossible to calculate how much materials were needed because parts were missing and it was impossible to construct because parts were drawn at the wrong place or were crossing each other. Besides that, the advisors who have to approve the BIM model and the calculations made in the BIM model want 2D drawings instead of a 3D BIM model because they cannot work with the BIM software BAM is using. Because of their required approval, BAM needs to generate 2D drawings from the 3D BIM model.

The creation of the new BIM model by BAM did not go without problems. The biggest problem that occurred during the creation of the BIM model is the control of different versions of the model. Because everyone is working in the same model, it is not clear which parts are updated and when they are updated. It is also not clear which parts are approved. When there are parts approved, it is still possible to change them which should not be possible. Another problem is the size of the model; because of the level of detail it is not possible anymore for the computers at BAM to process the model. That is why the model is split in different parts; the facade for example is made in a separate model.

Between BAM and the duct suppliers some problems existed as well related to BIM. The duct suppliers received the BIM model of the Groninger Forum. One of the duct suppliers kept asking for 2D drawings to calculate the amount of square meters of ducts in the Groninger Forum, one of the duct suppliers was able to use the model but could not draw in the BIM model yet, and one of the duct supplier was able to use the BIM model and draw in the BIM model as well. Besides that, it can happen that the duct supplier who can work with BIM uses different software or a different version of the same software. When the versions are converted it can happen that characteristics of objects change. For example centimetres change to inches.

At the Groninger Forum the BIM model is linked with the plan in ASTA (the planning software used) and the XD manager, this means that the BIM model is 4D. To steer the construction, all information from the BIM model, the plan and the XD manager is stored in a new created Access database. This is illustrated in Figure 13.

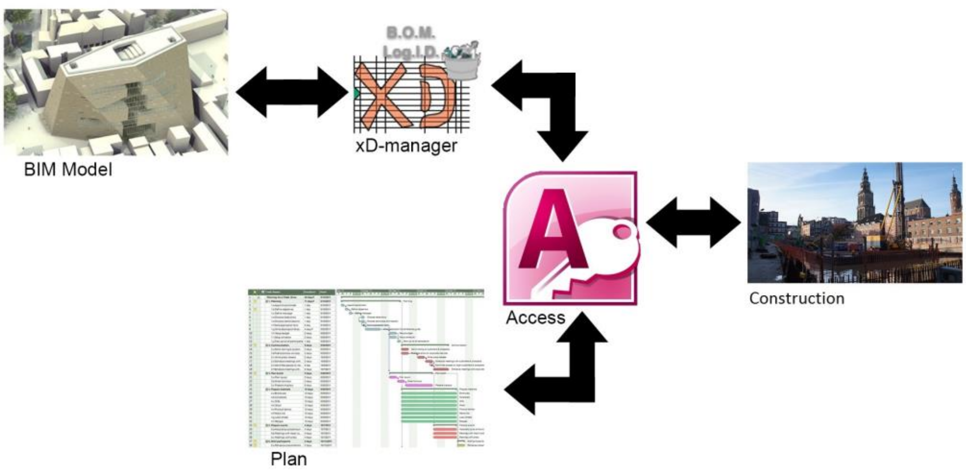

Figure 13: Connection BIM model with other databases

How the connection with other databases works is illustrated by an example. When information about plasterboards is requested, the total amount of plasterboards can be found in the Access database. In the database the amount or type of plasterboards per floor or room can be found as well, just as the dates when the plasterboards are needed. Besides that, supplier information as name and material number can be found in the database. The sizes and shapes of the plasterboards can be found in the database as well. It is also possible to generate a view from the BIM model in which a specific type of plasterboard in a specific room is displayed in 3D or 2D.

The ducts and the steel will be delivered to the construction site JIT. The JIT delivery of the steel, ducts and prefabricated parts will be coordinated by making use of building tickets. A building ticket has to be approved at the hub and gives admission to the tower crane for a certain time window. The building tickets make sure that there are no trucks waiting at or around the construction site because there is no space available for waiting trucks in the city centre. If a truck arrives too early it has to wait at the hub. When the trucks arrive at the construction site according to the time on their building ticket, they are delivering JIT. The arrival time on the building tickets is known in advance and is deviated from the 4D BIM model.

4.2.2 Prefabrication

BAM decided to involve the duct suppliers earlier than usual to be able to discuss prefabrication solutions for parts of the ducts. The reason for the earlier involvement of the duct supplier is that the ducts are difficult to mount in the Groninger Forum and that part of the construction of the ducts on the ninth floor is in the critical path. For the selection of a duct supplier, BAM asked three different duct suppliers to make an offer for the Groninger Forum.

The main goals of the earlier involvement for the Groninger Forum are that BAM, the steel supplier and the duct supplier are going to collaborate before the construction starts. In this way they can share their knowledge to come up with (prefabrication) solutions to make each other’s job easier and, above all, complete the job faster than it would have been with the traditional construction process.

The reduction in time of the activities in the critical path results in a reduction of the total construction time as well. The prefabrication solutions were constrained by transportation and crane capacity and the costs of the prefabrication solution were important as well. The location where the ducts are mounted in the steel is not yet known. There are several options but there is not selection made yet. Apart from time, the two other factors where the decision to prefabricate or not is based on, are quality and money.

The steel constructor had to be selected earlier than the duct supplier because the steel supplier had to start already according to the plan. BAM selected Nagelhout as sub-contractor for the steel construction in the traditional way; Nagelhout was selected because they offered the lowest price in the tender.

Figure 14: Welding steel at Nagelhout (Nagelhout, n.d.)

Before coming to an offer, the duct suppliers had the opportunity to ask questions about the BIM model and about what BAM expected during three different meetings. BAM in return asked what BAM could do to let the sub-contractor perform its job perfectly and if the sub-contractors could come up with smart solutions to make the construction easier or less costly. For example, a solution might be to prefabricate the ducts in the steel construction where possible at Nagelhout before the construction is transported to the Groninger Forum.

Short movies of the prefabrication ideas of the shaft, which were created in the BIM model, were used to provide the duct suppliers an overview of what BAM expected from them. They showed that the duct suppliers needed to think totally different than they were used to and that they really should come up with out of the box ideas. Those movies helped with the understanding of the process and what was expected from the duct suppliers.

During the first meeting, BAM explained to all three duct suppliers individually why BAM wants to do the selection in this way and that BAM expects from the next meeting that the duct suppliers can ask questions about the model and can explain some of their solutions for critical parts of the ducts. During the second individual meeting which was together with Nagelhout and BAM, none of the duct suppliers came with solutions. They thought that, just as in the traditional way, BAM and Nagelhout were going to explain them what BAM expected. Although after the first meeting, in which BAM and the duct supplier together went through the BIM model, they agreed that during the second meeting the duct suppliers would present their ideas.

At the third meeting with the duct suppliers one of the three suppliers already came with an offer. The supplier came to this offer without asking questions to BAM. The other two suppliers took the opportunity to ask questions about solutions they thought of. For example the weight that can be lifted by the crane for prefabrication solutions.

After the sessions with BAM and Nagelhout the three duct suppliers had to hand in their final offer. BAM gave an indication for the suppliers about what price range they expected. BAM chose Gebroeders Meijer as duct supplier. The other two suppliers received a small compensation for the time they took to come up with an offer and for the information BAM received during the meetings.

BAM chose Gebroeders Meijer based on a comparison of the offers on price, the use of the BIM model, the plan made, the collaboration with Nagelhout and the plan of approach. Nagelhout also had some influence in the decision of the duct supplier because Nagelhout and the duct supplier will work together in the future. The selection procedure of the duct supplier took around six weeks since the first meeting.

After the selection procedure the prefabrication solutions will be discussed in more detail and the feasibility of the solutions will be researched. Nagelhout and Gebroeders Meijer will work together by letting the Gebroeders Meijer indicate where they need some extra support steel or drilling holes in the steel. For Nagelhout this is hardly any extra work and it makes the work of Gebroeders Meijer a lot easier. The deadline for the Gebroeders Meijer to give information about support steel and extra holes is twelve weeks before construction starts; that is the time Nagelhout needs to produce the steel. The Gebroeders Meijer will put the ducts in the steel construction where possible before it goes to the construction site.

BAM indicated during the negotiations with the three duct suppliers that the goal of the tendering phase was to find a suitable and reliable partner for the Groninger Forum. The goal was to find a project partner and not to find a strategic partner. However, BAM indicated as well that, when the Groninger Forum is finished and it was a successful collaboration, the relationship might develop further by choosing the supplier again for upcoming projects.

After the selection of the duct supplier, a new plan will be made, this plan includes the specific jobs for the ducts instead of a global plan with unspecified big tasks. (At the moment of writing this plan is not finished yet.)The time needed in the new plan for the steel will be slightly longer and the jobs in the new plan of the duct supplier will be at different places in time because of prefabrication. The jobs of the duct supplier will be shorter because the mounting becomes easier. Instead of mounting in areas which are hard to reach, the mounting can be done off-site in a hall with a crane and without bad weather conditions. This means that the quality will be better as well. Besides that, the mounting can start earlier. Gebroeders Meijer does not have to wait until the steel construction is finished; this means that Gebroeders Meijer is finished earlier as well. It is not possible to discuss the differences between the new steel plan and the rough steel plan based on estimates steel used before the collaboration because the new steel plan is not finished yet. The rough steel plan based on estimates is finished and is discussed in more detail below.

Another improvement of the plan made by prefabrication involving the Gebroeders Meijer is with the shafts. They will be prefabricated instead of built on site. Traditionally the construction of the shafts takes a week per floor and with the prefabrication solution it will take one to two weeks for the entire building of ten floors.

<u>The rough steel plan</u>

The rough steel plan is based on rules of thumb which are used for every construction project. For the steel, these are based on the kilos and meters steel. The ducts were not planned yet during the negotiations with the duct suppliers; the ducts are incorporated in the plan in the amount of m^2 of fitting out in the total construction.

Currently, the plan is carried out by using a Gantt chart. The Gantt chart of the steel plan can be seen in Figure 15. In Table 2 the activities, the predecessors of the activities, and the duration of the activities in the steel plan are displayed to give a clear overview per activity. The information in Table 2 is deviated from the Gantt chart.

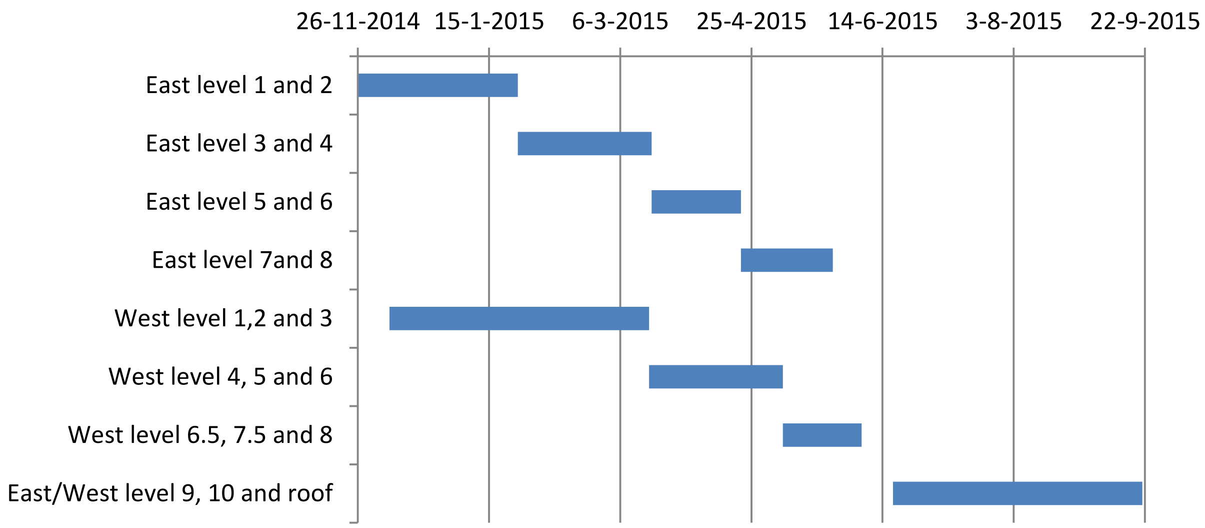

Figure 15: Gantt chart steel plan

Tabel 2: Activities in the steel plan

Activity	Description	Predecessors	Completion time (days)
A	East level 1 and 2	--	17
B	East level 3 and 4	A	24
C	East level 5 and 6	B	19
D	East level 7 and 8	C	20
E	West level 1,2 and 3	--	36
F	West level 4, 5 and 6	E	30
G	West level 6.5, 7.5 and 8	F	30
H	East/West level 9, 10 and roof	D and G	64

4.3 Adding transparency to the steel plan

In this section a different way of visualizing the steel plan is described to add more transparency to the steel plan.

To clarify the underlying activity structure, the activities in the steel plan are visualized in an activity on node diagram in Figure 16. In Figure 17, the same activity structure is given without the use of dummy activities to give a clearer overview. In Figure 18 can be seen where the activities take place in the Groninger Forum. The lengths of the activities in the Gantt chart are longer than the durations of the activities because in the Gantt chart, weekends and unworkable days which are determined statistically are included.

To illustrate the structure in an activity on a node diagram three dummy nodes are needed. This can be seen in in Figure 16. To illustrate the way of process, the values for the dummy variables are shortly explained. One dummy is needed for activity E of duration 7 because activity E cannot start before day 7. Because activity H can start 5 days before activity G is finished, one dummy variable is needed for activity G and one for activity H. Both dummy variables have length 5. The numbers in the nodes are the durations of the activities, the numbers above the nodes are the earliest start en finish times, and the numbers below the node are the latest start and finish times. These are based on the durations in Table 2. The red nodes illustrate the critical path.

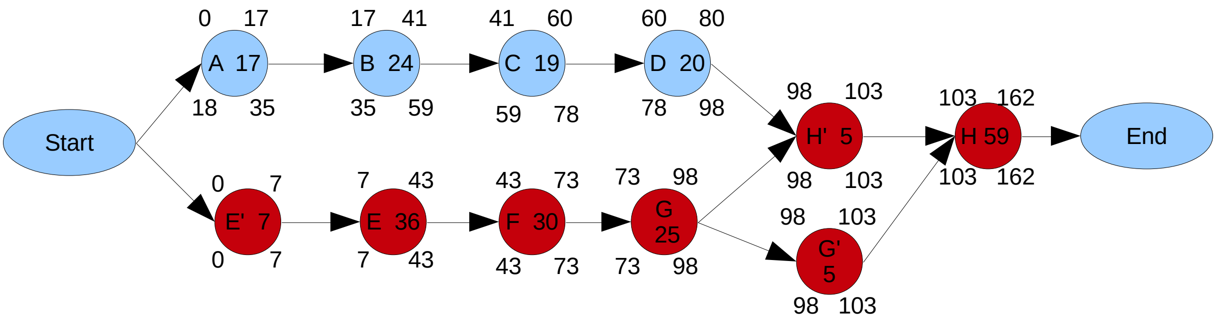

Figure 16: Activity on a node diagram of the steel plan

In Figure 17 the activity on a node diagram without dummies is illustrated to give a clearer overview of the activity structure. To illustrate the way of process, the two values on the arcs are shortly explained. In the project network two values are added to two arrows, one before activity E and one after activity G. Activity E can start on day seven because of a predecessor outside of this plan, this is can be seen by the value seven at the arrow from start to activity E. Because activity H can start five days before activity G is ended the value minus five is added to the arrow from G to H.

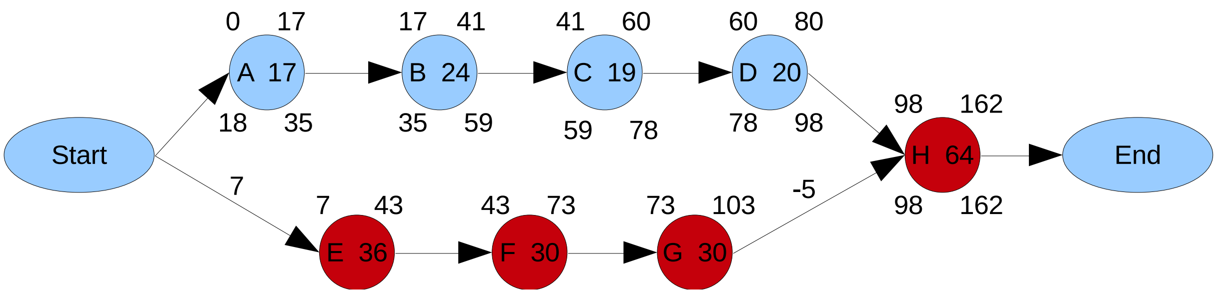

Figure 17: Activity on a node diagram of the steel plan without dummies

The critical path consists of the activities E, F, G, and H. The total length of the critical path is 162 days. These are working days and do not include unworkable days, weekends, or holidays. Activities A, B, C and D have a slack of 18 working days. This means that those activities can have a delay of 18 working days without delaying the end date.

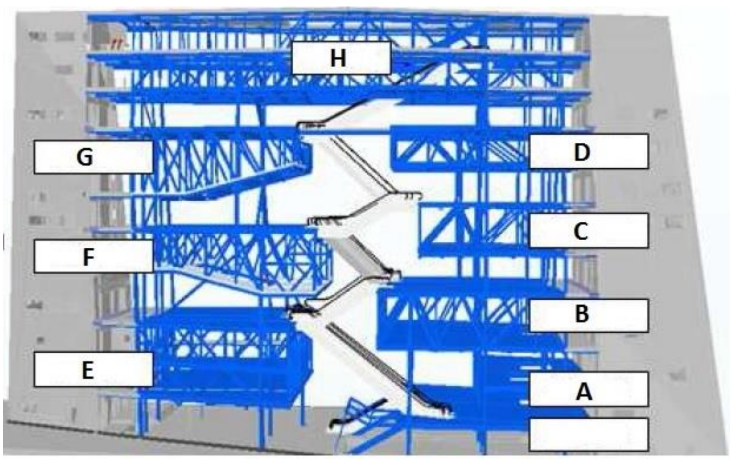

Figure 18: Location of the activities in the steel plan

4.4 conclusion

In Section 4.1 the current planning process at the Groninger Forum is described to answer the sixth sub question “*What does the current planning process at the Groninger Forum look like?”.* The planning process can be seen in Figure 10.

In Section 4.2 the selection procedure of the duct supplier is described. For the selection procedure the role of BIM and prefabrication in the selection procedure are discussed. In this section the rough steel plan of the Groninger Forum is described as well. In the next chapter the case study is compared to the literature described in Chapter 3.

In Section 4.3 an addition to the current steel plan is given by an activity on a node diagram to clarify the underlying structure of the plan. Crashing of the steel plan might be necessary when improvement of the plan is needed but prefabrication is not possible or it is too late for prefabrication. Crashing the steel plan is described in Section 5.3.

5. Discussion: literature versus practice

In this section the theory described in Chapter 3 is compared to the situation described in the case study in Chapter 4 to see how well BAM is performing according to the described theory. The discussion is split in two parts (BIM and prefabrication) according to the research question. In Section 5.1 the theory about the BIM model is compared with the case study and is described how the steel plan should be kept in control for JIT deliveries. In Section 5.2 the theory described about prefabrication in Section 3.2 is compared with the case study. In Section 5.3 the options for crashing the steel plan are described including an LP model to support the crash decision. This chapter ends with a conclusion in which the last sub question "*What insights in the previous sub questions can be extracted from a case study?"* is answered.

5.1 BIM model

According to the literature, BIM allows a level of efficiency, communication and collaboration that exceeds those of the traditional construction processes. However, the use of BIM does not go flawless. The BIM model BAM received from the client was insufficient; it was not possible for BAM to work with the received model. Besides that, the advisors of the local government of Groningen want to have 2D drawings to approve the calculations in the BIM model because they cannot work with the BIM software BAM is using. The creation of the new BIM model by BAM did not go without problems. The control of different versions of the model because of adjustments and approval was not clear. It was not clear when adjustments were made and what adjustments were made. And it was not clear from the BIM model when an object was approved. When an object was approved, it was still possible to adjust the approved object. The second problem was that the model became too big to handle by computers of BAM because of a lack of memory.
Besides that, the sub-contractors are not completely ready for BIM either. Some sub-contractors are not able to draw in BIM models and there are sub-contractors who do not know how to work with the model. When a sub-contractors is not able to use the BIM model, communication via the BIM model cannot happen. When a sub-contractor uses the BIM model, remarks can be made in the model and the sub-contractors can respond to those remarks by adjusting parts in the model. Besides that, when a sub-contractor uses different software or different versions of the same software, characteristics of objects can be lost or changed when the software is converted.

There are positive effects of the BIM model as well. Because of the BIM model, there is discussion between BAM and the duct suppliers. For example about the complex ninth floor a lot of questions were asked by the duct suppliers. The ninth floor has to be finished as fast as possible because the construction of the Groninger Forum can only continue when all the ducts of the ninth floor are stored or installed at the ninth floor. Before BIM models were used, BAM thought how the ducts should be done and the duct suppliers made what BAM said they should make. From the BIM model, the amount of ducts can easily be calculated. Another positive effect is that because of the BIM model there are less failure costs because errors can be prevented during the design by clash detection. Besides that, BIM makes the maintenance of the Groninger Forum when it is finished a lot easier.

The three duct suppliers did not finish the BIM model. It was not clear for them that they were supposed to do that. Besides that, two of the three duct suppliers are not able yet to draw in a BIM model. They are able to read them but not to draw in them yet. It is the question whether they will be able to do draw in BIM models on short term because BIM modellers are expensive for them. A trigger might be if the production can be controlled by the BIM model but that is not possible at the moment. This will be possible in a few years. When the duct suppliers were involved before the ducts where drawn in the BIM model, they could have drawn it instead of BAM (when a sub-contractor was selected who could already draw).

The model used at the Groninger Forum is a 4D BIM model; the plan is linked with the BIM model. The 4D model is used to see wrong schedule sequence. A peak in deliveries can be seen with the 4D model but there is nothing done with this information. A peak in construction workers can also be seen with the 4D model when the amount of construction workers is entered in the BIM model but only information about the employees of BAM is inserted in the BIM model and no information about the sub-contractors. BAM is adding the extra resources as scaffoldings to the BIM model; this will prevent unnecessary delays from happening. The BIM model at the Groninger Forum is not made 5D.

The visualization of the critical path is not done yet but would add value. This makes the understanding of the critical path clearer for all parties involved. The progression of the construction compared to the plan is not visualized as well. The progress compared to the plan is valuable information for the executor. When this is visualized, it is known if and where extra attention is needed. It would also add value to know where deliveries are made and where materials are stored, this is not done in detail at the moment.

Information about the packaging materials is not inserted in the BIM model, when this is inserted the reverse logistics can be planned in detail. The parameter weight is also not used in the BIM model; this information is valuable for prefabrication solutions due to the tower crane capacity. There are also no plans to make short movies about the difficult parts of the Groninger Forum.

When it is decided to adjust the plan, it is necessary to calculate the slack of activities not in the critical path to see what the result of the adjustments will be. It is possible to calculate slack with the planning software but when the work preparer knows the amount of slack, he will use it. Therefore it is not calculated.

Keep the steel plan in control for JIT deliveries

As mentioned in the case study the building tickets will be deviated from the 4D BIM model. With this model, the time window for deliveries can exactly be given. To make sure the arrival time on the building tickets is reliable, the plan must be in control. According to the literature described in Section 3.3, BAM should use the LPS to keep the plan in control. The current planning process at BAM as described in Section 4.1 has a lot of similarities with the LPS. The lookahead schedule of the LPS is already used by BAM in the form of the six week schedule. With the parties involved in the six week schedule, a weekly meeting is already taking place in which the constraints to begin with the activities are discussed and solved. From those meetings a week schedule is made just as in the LPS a week schedule was made from the lookahead schedule. BAM does not yet calculate the PPC or use the five time why method to find root causes for not executing an activity in the week schedule. To have a larger control of the plan, BAM should use the five times why method and calculate the PPC of the week schedule. The five times why method will prevent errors from happening twice and the PPC can be used as target and as benchmark. The LPS also recommends to make a phase schedule with lean planning which is also already done at BAM.

For the Groninger Forum the steel plan will be kept in control as follows. In the master schedule the individual jobs are listed. It is important that the jobs are defined well, the right sequence of work is selected, the right amount of work is selected, and that the work can be done. Examples of jobs in the steel plan are mounting safety nets, setting the steel columns or brining on support. From the master schedule, the phase schedule will be made. The phase schedule will be made by lean planning and involves all sub-contractors involved in the structural phase. It is important that the lean planning is executed the right way and that no changes are made by the project manager without negotiation at the end of the lean planning session. Six weeks before jobs have to be executed according to the phase schedule, they will enter the six week schedule. The jobs in the six week schedule are moved every week by a week when the executor is confident that all constraints will be solved before the job has to be executed. From the six week schedule, jobs are moved to the week schedule.

During weekly meetings the status of the constraints in the six week schedule are discussed and the weekly plan is made. All sub-contractors involved in the six week schedule will attend those meetings. The frequency of those meetings can also be higher if that proves to be necessary. From the weekly plan the PPC is calculated, this can be used as a benchmark with previous weeks and as a goal. The cause for not executing an assignment from the week schedule will be analysed by using the five times why method.

During different interviews, it became clear that coordination and communication are very important at the construction site and that this often goes wrong. It happened often that one of the duct suppliers reached the construction site or prefabrication location and that they could not start with their work because another sub-contractor did not finish yet (J. Vreeken (Gebroeders Meijer), personal communication, November 13, 2013; F. de Rooy & H. Passon (Brema Air), personal communication, December 6, 2013). When making proper use of the planning process as described above, it will not happen that sub-contractors arrive at the wrong time because if the constraints to perform a job are not met, the job is not scheduled. The sub-contractors will know this since they attend the weekly meetings in which the six week schedule is made and discussed.

The differences and similarities between the literature in Chapter 3 and the case study are summarized below in Table 3.

Table 3: Comparison literature about BIM and case study

According to literature	In case study
According to the literature BIM allows a level of efficiency, communication and collaboration that exceeds those of the traditional construction processes.	The received BIM model from the client was insufficient, the advisors of the client want 2D drawings to approve calculations, there were problems with version control, the model was too big for the computers of BAM, conversion of different models lead to loss of characteristics of objects, and some sub-contractors do not know how to work with BIM models and are not able to draw in BIM models. Because sub-contractors are not able to work with the BIM model communication is not possible via the model.
Information in the BIM model to assist in the planning process:	**Information in the BIM model used by BAM:**
A 4D BIM model	Yes, the plan is linked to the BIM model.
Peak in deliveries	No, can be seen but is not used.
Peak in construction workers	No, can be seen for construction workers of BAM only not for the sub-contractors but is not used.
Extra resources as scaffoldings	Yes, they will be drawn in the BIM model.
A 5D BIM model	No, financial data will not be used in the BIM model.
Visualization of critical path	No, this is not used.
Progression of construction	No, this is not used.
Where deliveries are made and where materials will be stored	No, this is not used.
Packaging materials	No, this is not used.
The parameter weight	No, this is not used.
Short movies about difficult parts	No, this is not used.
Calculation of slack	No, this is possible but is not used.
JIT deliveries according to literature:	**JIT deliveries at BAM:**
BAM should use the LPS to keep the plan under control.	Because of similarities current planning process of BAM and LPS BAM should use only parts of LPS: calculate the PPC to set as target or use as benchmark, use the five times why method to prevent errors from happening twice, and discuss all constraints during weekly meetings.

5.2 Prefabrication

From the twelve categories of factors important for the prefabrication decision mentioned in Section 3.2.1.1, design factors (suitability of design and design flexibility), module related factors (stability of prefabricated parts, size and weight, and ease of fabrication), site attribute factors (accessibility, space constraints, and weather conditions), labour condition factors (impact of solution on amount of construction workers needed, labour productivity), manufacturing unit factors (prefabrication location and the possibilities at that location), transportation and equipment factors (sizes and weight of prefabrication solution and delivery distance), organization's readiness (experience with prefabrication), technology related factors (use of BIM), Owner's perspective factors(need for an early completed schedule), and finance related factors (costs for prefabrication and transportation) were taken into account. Sustainability requirement factors (reduction in waste, reduced disturbance at construction site) are known but did not play a role in the decision to prefabricate or not. Codes and permits factors did not apply for this situation so they were not taken into account. All these twelve categories of factors will be translated to three major decision factors: money, time and quality.

According to Section 3.2.1.1, a key factor for success of prefabrication is the effective collaboration of the parties involved in the prefabrication in the early stages of the project and the early finishing of the design. BAM involved the Gebroeders Meijer early and the success of the early involvement can be seen for example by the drilling of the extra holes in the steel. The Gebroeders Meijer had eight weeks after their selection to communicate their needs, before Nagelhout started its production (this included two weeks of Christmas holiday). When the Gebroeders Meijer would have been involved later than eight weeks before, Nagelhout started its production and would the prefabrication solutions be less successful. Than the Gebroeders Meijer would not be able to profit from a shorter assembly time because Nagelhout could not drill extra holes and mount extra support steel. The eight weeks for the Gebroeders Meijer was enough but it should not have been much less. The Gebroeders Meijer already had a chance to think about their solutions during the selection phase so they did not start unprepared when they were contracted.

During the negotiations with the different duct suppliers, the capacity of the tower crane turned out to limit the possible prefabrication solutions. The maximum weight the tower crane can lift is 20 ton and that cannot be changed anymore. For prefabrication solutions this is the limit that can be lifted. It would not have had influence if the prefabrication options were discussed before the construction for the tower crane was designed. The foundations could have been made stronger for a bigger crane but a bigger crane would not have fitted at the construction site.

BAM decided to select a steel constructor and a duct supplier early in the process as key sub-contractors because they are in the critical path. The critical path was not calculated but based on experience, the decision was made that the construction of the ninth floor would be crucial. Other reasons for selecting Nagelhout and the Gebroeders Meijer as key sub-contractor are that BAM thought that earlier involvement of those two sub-contractors could add value, the complexity of the construction was big, and because of the criticality and long procurement period of the steel construction. These reasons are in line with the described literature in Section 3.2. BAM is looking for a partnership for the Groninger Forum and not for a strategic partner. This is in line with the literature described in sub Section 3.2.2.1 as well, because BAM has no experience with partnerships it is good to first gain experience with partners on project basis.

The critical path was not calculated because the plan that was used is not detailed enough to calculate a useful critical path. The finishing of the construction is still in one piece in the plan. In this way it cannot be seen which activities are in the critical path and what sub-contractors should be involved earlier in the process to come up with prefabrication solutions to improve the plan. An estimation of all activities from future sub-contractors should be in the plan to calculate a useful critical path. It is not necessary that the duration of all activities in the plan are known; the level of detail of the rough steel plan in Section 6.1.2 is enough. In this way is at least known what sub-contractors are involved in the critical path.

The improvements in the plan because of the prefabrication solutions are not calculated yet in a new plan as recommended in sub Section 3.2.1.2. The new critical path is not calculated because the plan is not detailed enough. This new plan will probably have another critical path. With the new critical path, it has not yet been tried to come up with prefabrication solutions and the sub-contractors of these jobs are not contracted yet. The effects of calculating the critical path and involving sub-contractors involved in the prefabrication earlier on the planning process can be seen in Figure 19.

A disadvantage of involving three different duct suppliers that became clear during the sessions with the duct suppliers is that some of the duct suppliers clearly did not want to show all the smart solutions during the negotiations, probably because they feel that someone else will get the job and will use the ideas they came up with. This is because the environment of the duct suppliers used to be characterised by price chasing, one-off contracts, and short term gains while the partnerships are based on mutual trust and long-term collaborations. On the other hand, the involvement of three different duct suppliers meant that the price of the different offers will be based on market prices.

The duct suppliers did not fulfil the demands BAM had before the selection process. The duct suppliers hardly came up with new ideas. This is due to the fact that they are not used to help thinking in this phase of the construction process. When this process will happen more often the duct suppliers will get used to it and BAM will benefit from the early use of knowledge from duct suppliers.

All involved parties recognized that the way of working with BIM and earlier involvement will be the future for the construction industry. For both BAM and the sub-contractors this is a learning experience. The decision for the Gebroeders Meijer over the other two sub-contractors meant that they will be prepared better for the future and have an advantage over competitors for future similar projects. Because the sub-contractors and BAM think this way of working is the future, BAM should watch out to not fall back to the traditional way; this can happen because with all the information available in the BIM model it is easy to tell sub-contractors what to do. When this happens, it makes no sense to involve the sub-contractors earlier and ask them for input because they will do what BAM will tell them to do. The sub-contractors have specific knowledge and experience with parts of the construction that BAM does not have itself. During the selection process it became clear that the sub-contractors are not used to tell how they can perform best; this change will take time. When the knowledge of the sub-contractors is used, BAM reduces the risk of performing a job in an inefficient or expensive way. The ideal situation for the sub-contractors would be that sub-contractors become partners and that they can work together with the same other sub-contractors for five or six projects next to each other. When the sub-contractors are used to each other and work together as a team, the performance of the construction process will improve a lot (F. de Rooy & H. Passon from Brema Air, personal communication, December 6, 2013).

The essential factors for a successful team mentioned in sub Section 3.2.2.1 are present in the team of Nagelhout, the Gebroeders Meijer, and BAM. There is equal status within the team and cooperative interaction, at least during the tendering phase. There is dedication for a common goal, faster construction of the Groninger Forum by making each other’s job as easy as possible. And there is authority support; top management was involved in the negotiations. The client did not attend any of the meetings with the sub-contractors. This did not have any influence on the prefabrication decisions or early involvement decisions. So it is not necessary to involve the client.

The BIM model played an important role in the prefabrication solutions, especially for the prefabricated shaft. With the BIM model it is possible to determine the exact dimensions of the shaft and the pipes in the shaft and it is possible to select the best materials for each element, including size and type. With this information, the structure is able to be prefabricated with precision and little to no waste with the materials accurately cut and assembled. When the duct supplier is involved early in the process the ducts in the BIM model can be adjusted to the preferences of the duct supplier. The lengths of the duct parts can be adjusted for optimal use of the machinery of the duct supplier and can be made in such a way that mounting is easy; this is the same for the shapes of the ducts.

The differences and similarities between the literature in Section 3.3 and the case study are summarized below in Table 4.

Table 4 Comparison literature about prefabrication and case study

According to literature	In case study
12 categories of factors to make prefabrication decision: design related, module related, site related, labour condition related, manufacturing unit related, transportation and equipment related, organization related, technology related, owner's perspective related, finance related, sustainability related, and codes and permit related.	10 out of the 12 categories of factors were used in the decision to prefabricate or not. Sustainability requirements as reduction in waste or reduced disturbance at construction site are known but were not important for the final decision and codes and permits were not needed so they were not taken into account as well. All factors are translated to three major decision variables: money, quality, and time.
Earlier involvement and the early finishing of the design are essential for the success of prefabrication.	Before the involvement of the Gebroeders Meijer the largest part of the design was finished. For the implementation of ideas to improve the process the earlier involvement of the Gebroeders Meijer was a success, the adjustments in the steel were known before construction of the steel started. However the Gebroeders Meijer did not come up with ideas themselves, the ideas came from BAM.
Reasons for earlier involvement of sub-contractors: design content, complexity of construction, high contract value, long period of construction, long procurement times, and the sub-contractor could add value with early input.	Reasons for earlier involving the Gebroeders Meijer: activities are in the critical path, construction is complex, early input could add value by shortening the project duration, and a long procurement period of the steel construction.
BAM should not look at strategic partners because of lack of experience with strategic partnerships.	BAM is looking for project partners and not for strategic partners.
Use a detailed enough plan to calculate critical path and see if it is possible to use prefabrication for jobs in the critical path. Calculate new critical path with prefabrication options taken into account. These steps need to be repeated until the plan does not improve anymore.	The plan is not detailed enough to calculate critical path, fitting out for example is still in one piece in the plan. There is not searched for prefabrication options in the new critical path.

Essential factors for a successful team are: equal status within the team, cooperative interaction, dedication for common goals, and authority support	The four factors mentioned in the literature for a successful team are present in the team of BAM, Nagelhout and the Gebroeders Meijer.
Since the introduction of BIM models prefabrication has involved greatly.	The BIM model played an important role in the prefabrication solution. Exact dimensions could be determined and waste could be minimized because shapes and sizes were exactly known.

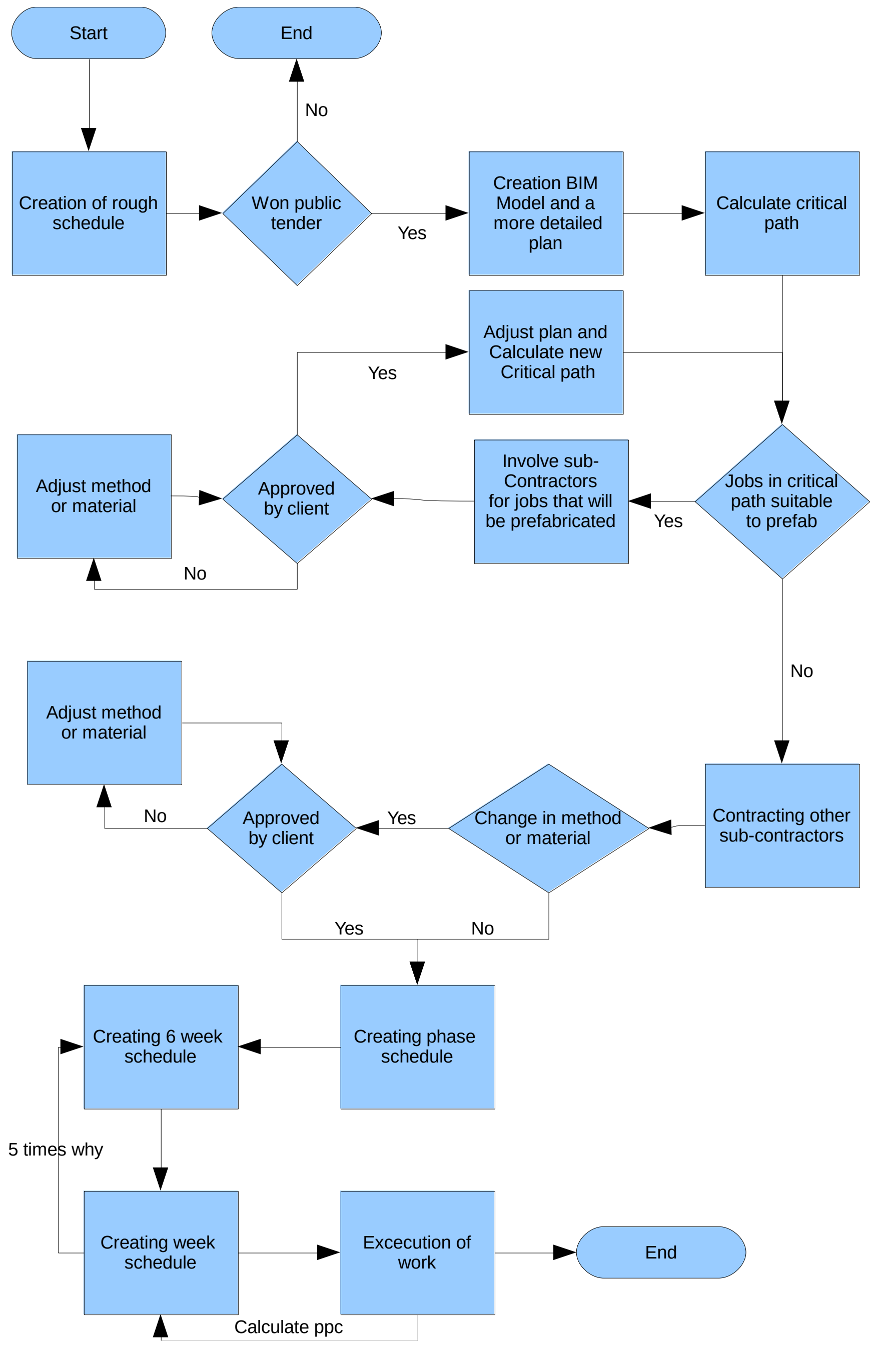

Figure 19: Planning process for prefabrication

5.3 Options for crashing

In this section the options for crashing the steel plan are explored. When the plan has to be improved to meet a desired deadline and it is too late to try and improve the plan by prefabrication or it is impossible to come up with prefabrication solutions, crashing is the last option to improve the plan. Sub section 6.3.1 describes what the implications for the rough steel plan are for the fabrication of the steel for the Groninger Forum at Nagelhout. In sub Section 6.3.2 a crashed version of the rough plan is calculated by making use of an LP (linear programming) model. With this LP model it is possible to calculate what jobs need to be crashed to reach a desired lead time and what the minimum costs are to reach the deadline. The goal is to demonstrate how an LP model can be used to help in deciding which job to crash; the goal is not to create an executable crashed plan.

5.3.1 Implications of rough steel plan for Nagelhout

The production of steel for the Groninger Forum is too much for Nagelhout, they collaborate with a partner to be able to produce all the steel for the Groninger Forum within the given timeframe. The implication for the production of steel for Nagelhout with the rough plan is that their production is for half a year fully dedicated to the Groninger Forum.

Nagelhout delivers the steel JIT at the construction site of the Groninger Forum. When Nagelhout knows when the steel is needed at the construction site they calculate backwards when the production needs to start. It takes Nagelhout about twelve weeks from work preparation until delivery. The activities that take place at Nagelhout are production, composing the steel beams and weld them together, and coating. The composing and welding of the steel beams is the activity that has the longest duration. The production of the steel is controlled by the BIM model. The machines that cut the steel and the machines that drill the holes in the steel are controlled by the BIM model.

5.3.2 Crashing the rough steel plan

"Crashing is a process of expediting the project schedule by compressing the total project duration" (Foya, 2013). To reduce the total project duration activities, in the critical path need to be reduced. This can be done by adding extra resources: by adding extra construction workers or an extra tower crane for example. The downside of crashing is that it costs extra money and that it is not good for safety reasons because more people work in the same area. The maximum amount an activity should be reduced by crashing, depends on the amount of slack of other activities (Foya, 2013).

When the steel plan is crashed, Nagelhout will have to produce its steel faster. An acceleration in the steel plan means that Nagelhout needs to involve a third party to produce the steel. For Nagelhout and their partner, it is not possible to accelerate since they are producing at their maximum capacity. It is possible for Nagelhout to involve a third party; they have another partner who is willing to join production for the Groninger Forum if necessary, however involving a third party results in extra costs.

When the plan is crashed this needs to be known at least twelve weeks in advance since the production of the steel takes about twelve weeks.

For the calculation of crashing options, it is assumed that the crash options can be executed at the construction site and that the decision to crash is made on time to be produced at Nagelhout.

To cope with uncertainty of activity durations, the duration of the activities is calculated by making use of the PERT method. The duration of the activities is calculated by the following formula: $\frac{optimistic\ duration + 4 * average\ duration + pessimistic\ duration}{6}$ (Harris & McCaffer, 2013). The variance of an activity's duration is $\sigma^2 = \frac{(pessimistic\ completion\ time - optimistic\ completion\ time)^2}{36}$ (Harris & McCaffer, 2013). Because data about the pessimistic and optimistic completion times are lacking, several assumptions are made to illustrate the PERT method. The average duration is based on the rough plan, the optimistic duration is assumed to be 10 per cent faster than the average completion time, and the pessimistic plan is assumed to deviate 20 per cent from the average plan. The deviation of the pessimistic completion time is bigger because in the construction industry it happens more often that an activity is delayed than that is it is finished earlier than planned. The deviations are rounded upwards. This is displayed in Table 5 for each activity. In the column next to the pessimistic completion time in Table 5, the duration according to the PERT method is calculated with the formula mentioned above. The PERT durations are rounded to whole days. In the last column of Table 3 the variance of the activities is calculated.

Table 5: Activity durations PERT

Activity	Description	Predecessors	Optimistic completion time (days)	Average completion time (days)	Pessimistic completion time (days)	Pert duration (days)	Variance of activity times (days)
A	East level 1 and 2	--	15	17	21	17	1
B	East level 3 and 4	A	21	24	29	24	1,78
C	East level 5 and 6	B	17	19	22	19	1
D	East level 7 and 8	C	18	20	23	20	1
E	West level 1,2 and 3	--	32	36	44	37	4
F	West level 4, 5 and 6	E	27	30	36	31	2,25
G	West level 6.5, 7.5 and 8	F	27	30	36	31	2,25
H	East/West level 9, 10 and roof	D and G	57	64	77	65	11,11

The length of the critical path (E-F-G-H) with uncertainty taken into account is 166 compared to 162 when uncertainty is not taken into account (see sub Section 4.2.2). Next to the critical path and the project duration, the risk of completing the project within the target duration can be calculated. This is done based on the assumption that the durations are standard normal divided and that the activities are statistically independent. For calculating the risk of the project the Z value needs to be calculated. Z $=\frac{\text{(target duration – expected project duration)}}{\text{standard deviation of the project}}$.

With the value of Z, the probability of completing the project within the target duration can be found in the normal probability distribution table. The same can be done for the single activities in the project (Harris & McCaffer, 2013).

The variance of the overall completion time is the sum of all variance of activities in the critical path which is 4+2.25+2.25+11.11=19.61. The standard deviation of the project is $\sqrt{19.61}$ = 4.43. Suppose the target duration is 170 days then Z = (170 – 166)/ 4.43 = 0.90. From the standard normal distribution table P(Z≤0,90)=0.82. So there is 82 per cent chance that the project is finished within 170 days.

Data about the crash costs and crash times of activities are lacking so to illustrate how an LP model can help in deciding which jobs to crash, several assumptions are made. The maximum crash time is assumed to be bigger for activities on higher floors, the costs however are also assumed to be higher. Extra cranes assumed to have more benefits for activities on higher floors however there is assumed that also extra construction workers are needed compared to the crashing on lower floors which results in higher costs. The maximum percentage of crash days is assumed to be 15 per cent for activity A and E, for B, C, and F the maximum percentage of days is assumed to be 20 per cent, for activity D and G the maximum percentage of days is assumed to be 25 per cent, and the maximum percentage of days for activity H is assumed to be 33 per cent. The maximum number of days activities can be crashed and the assumed crash costs per day can be found in Table 6, the days are rounded to whole days.

Table 6: Crash time and costs

Activity	Description	Maximum crash time (days)	Crash costs per day (euro)
A	East level 1 and 2	3	1000
B	East level 3 and 4	5	1250
C	East level 5 and 6	4	1500
D	East level 7 and 8	5	1750
E	West level 1,2 and 3	6	1300
F	West level 4, 5 and 6	6	1600
G	West level 6.5, 7.5 and 8	8	1900
H	East/West level 9, 10 and roof	22	2000

To answer the question what jobs to crash to reach a desired lead time, a linear programming (LP) model is created. The LP model for the above described crashing problem is formulated as follows:

Decision variables:

X(j) = start time of activity j j=a,b,…,h

Y(j) = amount of crash time used for activity j j=a,b,…,h

Parameters:
N(j)= Pert duration of activity j=a,b,…,h

Objective function:
Min 1000Y(a) + 1250Y(b) + 1500 Y(c) + 1750Y(d) + 1300Y(e) + 1600Y(f) + 1900Y(g) + 2000Y(h)

Constraints:
X(a)= 0
X(b)≥X(a) + N(a) – Y(a)
X(c) ≥X(b) + N(b) – Y(b)
X(d) ≥X(c) + N(c) – Y(c)
X(e)=7
X(f) ≥ X(e)+N(e)-Y(e)
X(g) ≥ X(f) + N(f) – Y(f)
X(h) ≥X(d)+N(d) –Y(d)
X(h) ≥X(g) + N(g) – Y(g) – 5
X(finish) ≥ X(h)+N(h) – Y(h)
X(finish) ≤ desired length

Y(j) ≤ Max crash time activity j j=a,b,…,h

With the LP model, it can exactly be calculated what the minimum costs are to reach a desired lead time and what activities have to be crashed by how many days to reach the desired lead time. The values of X(j) display the start time of activity j. The duration of the activities without crashing is 166 days. The LP model is solved by making use of the solver in Excel. For example for a lead time of 142 days activities E, F, G and H have to be crashed by 6,6,8 and 4 days. From the LP model, it can be concluded that the minimal amount of days needed is 124. This is 42 days faster than the durations calculated with PERT in Table 1. The costs for this solution are €76,600 and activities E, F, G and H are crashed to their maximum crash time. Activities A, B, C and D are not crashed in the solution of 124 days. Activities A, B, C and D are never crashed because when one of those activities is crashed activity E, F or G has to be crashed as well. Crashing two activities is more expensive than crashing activity H by 1 day which has the same result. The project network of the solution of 124 days is displayed in Figure 20.

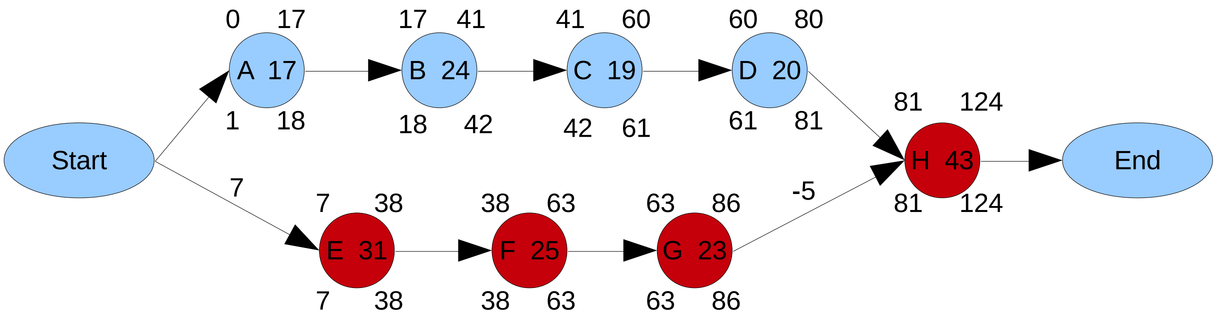

Figure 20: Project network of the maximum crashed steel plan

5.4 Conclusion

In this chapter the last sub question "*What insights in previous sub questions can be extracted from a case study?*" is answered. This question is answered for the assistance of the BIM model in the planning process in Section 5.4.1 and for how the plan can be improved by prefabrication in Section 5.4.2.

5.4.1 Insights about BIM

The first insight from the case study is that BIM is not completely integrated in the construction industry. BAM received a BIM model from the client that contained multiple errors, the advisors from the client still want 2D drawings for approval because they cannot work with the BIM software BAM is using, version control during the creation of the BIM model resulted in problems, computers are not able to cope with detailed models because of a lack of memory, different software is used which can lead to loss of information during conversion, and not all sub-contractors are ready to use BIM models which makes it impossible to let sub-contractors draw their parts in the BIM model and impossible to communicate via the BIM model.

Most of these problems are introduction problems because BIM is new for BAM and the construction industry. These problems are not in the control of BAM. The problems probably will be solved over time. The software will be developed further just as computers which results in no more loss of characteristics because of conversions and computers that can process the models. The version control is a widely known problem, since BIM software is developing fast at the moment this will be solved in a couple of years or even faster. However to solve the version problem, BAM can use version control software which keeps track of changes in a log. Because BIM is becoming the standard in the construction industry, more experience with BIM at clients and advisors will result in better BIM models from clients and approval of components in the BIM model. In a few years, sub-contractors can control their production with the BIM model. When that is possible, most sub-contractors will and can work with BIM.

The second insight from the case study is that improvements are possible for assistance of BIM in the planning process. Because of the BIM model there is discussion between BAM and the duct suppliers. Before BIM models were used, BAM designed the ducts and the duct suppliers made what BAM said they should make. Because of the visualization in the BIM model, it was easier to discuss prefab solutions, the visualization of the plan showed the importance of fast construction of the ninth floor, errors in the planning sequence were made visible, the sizes in the BIM model could be used for fabrication, the amount and types of ducts could easily be taken out of the model, and a short movie created in the BIM model of the prefabrication of the shafts made the sub-contractors realize that BAM wants to do things differently. Weight of the steel parts was also discussed and important for the feasibility of prefab solutions, but this did not come from the BIM model because this was not inserted as a parameter. When the parameter weight is added to the bigger parts in the BIM model, it is clear what can be hoisted by the tower crane. The progression in the plan should be visualized; the executor can react to that if necessary.

Slack of activities should be calculated, but does not have to be communicated. This information can be used by the planner when peaks in deliveries or peaks in construction workers are lowered. For the peaks of construction workers, information from sub-contractors about their workforce is needed. With respect to safety it can also be indicated when it is allowed to work in certain areas and when it is not allowed. Besides that, the critical path should be visualized.

The BIM model should be made 5D; this makes it easier to predict future cash flows and gain insight in the financial situation. To be able to do this, BAM should redesign its financial structure in such a way that it can be integrated with the BIM model. Besides that, the deliveries and location of deliveries and the amount of stock and location of stock should be known especially when the hub is used. This can be done by making use of a warehousing management system. Information about packaging materials should be added as well to control the reverse logistics and plan deliveries from the hub.

The sub-contractors were involved too late to draw the BIM model. For new projects of BAM, key sub-contractors should be involved in an earlier stage so they can create their parts in the BIM model if they are able to draw. This should become a selection criterion.

The JIT deliveries for the Groninger Forum will be coordinated with building tickets and is steered with the 4D BIM model. For JIT deliveries it is important that the plan is in control. To keep the plan in control, BAM should leave the planning process how it is at the moment. Elements from the LPS that should be used within the existing planning process are the calculation of the PPC, the five times why method, and the systematic constraint analysis.

5.4.2 Insights about prefabrication

The first insight from the case study about prefabrication is insight in the reasons and results of earlier involvement of sub-contractors. BAM wanted to involve the duct and the steel suppliers early in the process because the activities of these two sub-contractors are in the critical path. This is not based on critical path calculations but on experience. Other reasons for the earlier involvement were the complexity of the construction and the long procurement period. According to involved sub-contractors, the earlier involvement of sub-contractors will happen more and more in the future. The sub-contractors are not used to help thinking about the construction process, this will happen more often when they are getting used to this change. The team created with BAM, Nagelhout, and Gebroeders Meijer has a common goal and all the team members have an equal status. This is essential for a successful collaboration. A disadvantage of the selection procedure of the duct suppliers with three different suppliers is that before they are contracted, the sub-contractors do not want to tell all their solutions. It is not necessary to include the client in the teams for a successful collaboration.

The early involvement of the Gebroeders Meijer made the drilling of extra holes for prefabrication solutions a success. If they were involved a month later, they had only the opportunity to give their demands to Nagelhout for parts of the building instead of the whole building. Gebroeders Meijer was involved eight weeks before Nagelhout started production of the steel. For the success of the early involvement, this should not have been less. When the earlier involvement had not taken place, the discussions about prefabrication solutions would have not taken place either.

The second insight is about factors that influence the decision to prefabricate or not. Without knowing the twelve categories of factors important for prefabrication, BAM used ten of them in making a decision about prefabrication. However in the end those factors are translated to three major decision variables: money, quality, and time. After the selection procedure, the prefabrication solutions for parts of the ducts are examined to the factors time, money, and quality. Although these categories of factors can be reduced to quality, money, and time it is good to take the twelve categories of factors into account to make sure no factors are missing. After that, definite decisions will be made about which parts to prefabricate and which parts to construct in the traditional way. Because of the prefabrication, the plan will probably be improved (this cannot be confirmed because the new plan is not finished yet).

The third insight is about the calculation of the critical path. The critical path should have been calculated, this should have happened with a more detailed plan than was available when the decision about the ducts and steel was made. Estimations of all activities from future sub-contractors should be in this plan. The improvements of the plan by prefabrication should have resulted in new critical path calculations and the possibilities of further improvement of the plan.

The last insight is about the importance of the BIM model for prefabrication. The BIM model was important for the prefabrication solutions; the sizes and shapes of the prefabricated parts could be copied from the model and the model lead to discussion resulting in new prefabrication solutions. Without the model these discussions would have not taken place.

5.4.3 Crashing the steel plan

When the construction needs to be finished earlier and when it is too late for prefabrication or not possible to prefabricate, crashing is the last option. Although the steel construction is in the critical path, the steel plan is not suitable for crashing because of the long fabrication times of the steel. Crashing is used when it turns out that the plan will not be met, this is often not known twelve weeks in advance. The price offered by Nagelhout is based on the collaboration of Nagelhout and its partner. Crashing the steel will be extra expensive because, next to extra resources, a third party needs to get involved. Without crashing, the length of the steel plan cannot be shortened. Nagelhout and its partner are producing at their maximum capacity to reach the plan and are not able to accelerate their processes.

When is decided to crash the steel plan and the maximum days of crash time per activity and the crash costs per day are known, an LP model can calculate what the minimal costs are to reach a certain deadline.

When the optimistic completion time, the average completion time, and the pessimistic completion time of all activities in the steel plan are known, the probability that the project is finished on time can be calculated by making use of PERT. With this probability, the risk can be estimated that the project is finished on time and adjustments can be made if the risk is too high.

6. Conclusions and recommendations

In this chapter the research question "*How can (i) the planning process of a construction project efficiently be supported by the BIM model and (ii) how can the plan be improved by prefabrication?"* is answered. This is done in Section 6.1; in Section 6.2 recommendations for BAM are presented. This chapter ends with limitations of this research and recommendations for future research in Section 6.3.

6.1 Conclusion

Section 6.1 is split in two parts according to the research question; assistance of the BIM model in the planning process and improvement of the plan by prefabrication. In the sub Section 6.1.1 the first part of the research question *"How can the planning process of a construction project efficiently be supported by the BIM model"* is answered and in sub Section 6.1.2 the second part of the research question *"how can the plan be improved by prefabrication?"* is answered.

6.1.1 Assistance of BIM model in the planning process

There are different ways how the BIM model can assist in the planning process. These are:

- Materials can be shaped in advance because everything about sizes and shapes is known;
- When the plan is linked to the BIM model the BIM model is called 4D. With a 4D model it is possible to see wrong scheduling sequences and to see the amount of deliveries per day. When there is a peek in deliveries this can be adjusted if necessary;
- The parameter weight can be added so the BIM model can assist in prefabrication decisions and the tower crane plan;
- When budget information is added to the BIM model cash flows can be forecasted and different scenarios in the plan can be compared based on budget;
- With the BIM model it is possible to visualize the critical path and the progress of construction compared to the plan;
- The amount of construction workers can be added to the BIM model. With this information peeks in the amount of construction workers can be lowered if necessary and too crowded areas can be indicated;
- With the BIM model it is possible to create short movies of difficult parts of construction. This will prevent errors from happening because it is exactly known what should be done;
- Sizes and type of packaging materials can be added. With this information the reverse logistics can be controlled and planned;
- When the BIM model is linked with a warehouse management system. It is important to know where what materials are stored and when and where they will be delivered.

With these measures, fewer errors will be made and less unexpected delays will occur during construction. This means that the plan will be better in control which makes the JIT deliveries more reliable.

For JIT deliveries it is important that demand can be predicted, that delivery sizes must be aligned with productivity of the sub-contractor, and that there are as less as possible deviations from the plan. The demand can be predicted with the 4D model and the delivery sizes can be adjusted. If necessary, the hub can be used to adjust delivery sizes. To get as less as possible deviations in the plan, the plan must be kept in control. To keep the plan in control BAM should use some parts of the

LPS. Since the planning process at the Groninger Forum has a lot of similarities with the LPS, it is not necessary to implement the LPS. There are small parts of the LPS that BAM can use to improve its planning process. The percentage of plan completed (PPC) should be calculated, this can be used as target and as benchmarks with previous weeks. The five times why method should be used when a job is not completed according to plan to prevent errors from happening twice and a systematic constraint analysis should be performed in such way that jobs can only enter the week schedule when all constraints are gone. Communication is very important to keep the plan in control; during weekly meetings the constraints should be discussed with all involved parties. BAM should keep making a phase schedule with lean planning, making a six week schedule out of the phase schedule and from that six week schedule make a week schedule. Lean planning should be executed in the way it should be executed, let the sub-contractors collaborate and acknowledge each other's problems to make a plan.

To improve the planning process with the improvements named, extra data need to be inserted in the BIM model. Besides that, these data need to stay up to date. For example when a change in delivery date occurs this should be changed and when a delivery is made this should be changed real time at the construction site. When this does not happen, the information is of no use.

Based on the case study it can be concluded that BIM is not completely integrated in the construction industry. BAM received a BIM model from the client that contained multiple errors, the advisors from the client still want 2D drawings for approval because they cannot work with the BIM software BAM is using, version control during the creation of the BIM model results in problems, computers are not able to cope with detailed models because of a lack of memory, different software is used which can lead to loss of information during conversion, and not all sub-contractors are ready to use BIM models which makes it impossible to let sub-contractors draw their parts in the BIM model and impossible to communicate via the BIM model.

Most of these problems are introduction problems because BIM is new for BAM and are not in the control of BAM. The problems probably will be solved over time. The software will be developed further just as computers which results in no more loss of characteristics because of conversions and computers that can process the models. The version control is a widely known problem, since BIM software is developing fast at the moment this will be solved in a couple of years or even faster. However, to solve the version problem BAM can use version control software which keeps track of changes in a log. Because BIM is becoming the standard in the construction industry, more experience with BIM at clients and advisors from BAM will result in better BIM models from clients and approval of components in the BIM model. In a few years, sub-contractors can control their production with the BIM model. When that is possible, all sub-contractors can and will work with BIM. Because BIM keeps on developing and because BIM models get more and more complex, BAM needs to keep training its personnel.

6.1.2 Prefabrication to improve the plan

To be able to improve the plan by prefabrication, it is necessary that from the moment the tender is won, a more detailed plan than the rough plan is made to calculate the critical path. In this plan it is necessary that all activities from sub-contractors are planned. Estimations of durations are sufficient to get a good indication of the critical path. Next to the critical path, it is important that the design is finished. For the activities in the critical path it should be checked if there are possibilities for prefabrication. This can be done by criteria divided in twelve categories. The twelve categories of factors that decide if a job can be prefabricated or not are: design related factors, module related factors, site attributes, labour considerations, manufacturing unit, transportation and equipment, organization's readiness, codes and permits, technology related factors, owner's perspectives, sustainability requirements, and finance related factors. Although these categories of factors can be reduced to quality, money, and time it is good to take the twelve categories of factors into account to make sure no factors are missing. When it is decided what will be prefabricated, the new critical path has to be calculated. It can happen that activities that would normally not be in the critical path are suddenly in the critical path. That is why it might be the case that solutions have to be found for jobs that have never been thought of.

To make the prefabrication a success, the sub-contractors involved in the prefabrication solution should be involved as early as possible. This is from the moment that it is known that they are involved in finding prefabrication solutions. In this way their ideas and the possibilities can be taken into account and the sub-contractors can take demands from other sub-contractors into account as can be seen in the case study. Involving sub-contractors earlier and collaborating earlier than in the traditional way will be the future according to the sub-contractors. For the duct suppliers the collaboration was new and it was clear that they were not used to it because they could not come up with smart improvements. When the sub-contractors are involved more often they will probably get used to it and come up with ideas themselves.

From the case study it became clear that the BIM model is important for the collaboration between BAM and sub-contractors. Because of the BIM model there are discussions between sub-contractors and BAM about smart solutions to improve the construction. The visualization of the construction was important to come up creative ideas and the information about sizes and shapes in the BIM model was important as well. It also became clear that it is not necessary to involve the client as well in the prefabrication process. It is important that when different sub-contractors are involved in the same prefabrication solution, that a team is created with a common goal.

When a sub-contractor is involved early in the planning process, the sub-contractor should draw his own parts in the BIM model. In this way it saves BAM work and the sub-contractor has a library in which all his objects have the right information and preferences.

The effect of the conclusions in Section 6.1.1 and Section 6.1.2 on the planning process is visualized in Figure 21.

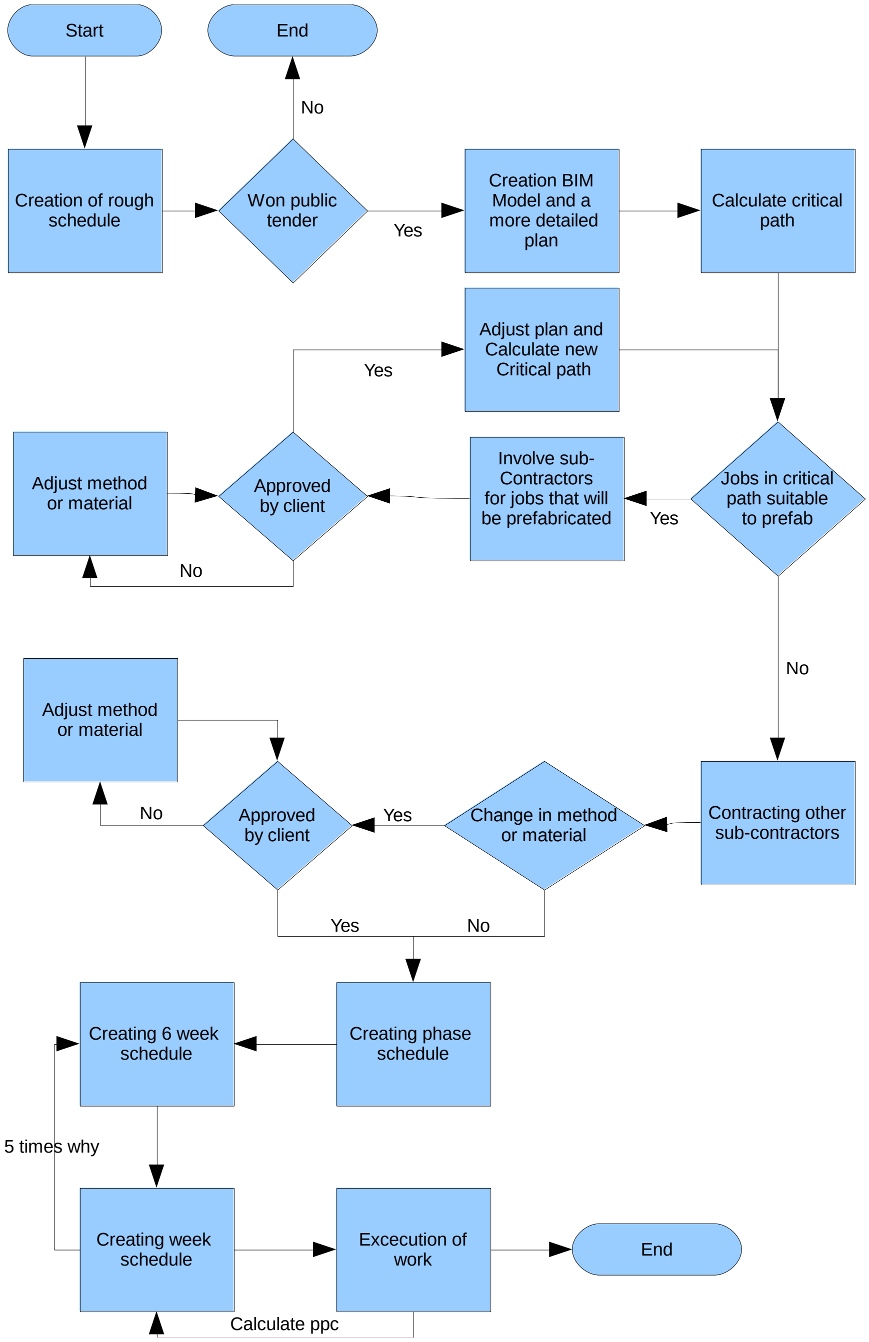

Figure 21: Adjusted planning process

6.2 Recommendations

Section 6.2 is split in three sub sections. The first two sub sections are split according to the two parts in the research question, assistance of the BIM model in the planning process and improvement of the plan by prefabrication. The third sub section consists of recommendations that are not directly linked to the main research question.

6.2.1 Recommendations about assistance of the BIM model in the planning process

Based on the case study and the literature it can be concluded that the assistance of the BIM model in the planning process can be improved. BAM already works with a 4D plan; this makes it possible to visualize the plan. Due to the visualization it is possible to see errors in the sequence of jobs. Because of the 4D model it is exactly known when what parts are needed at the construction site. With this information the deliveries are also known. With the 4D BIM model, sizes and shapes of all parts in the building are clear, this makes producing materials and prefabrication easier. BAM is also planning to add extra resources as scaffoldings in the BIM model; this will prevent unnecessary delays and the hiring of double or unnecessary extra resources.

To communicate the intentions of innovation, BAM created a short movie of the prefabricated shafts in the BIM model. These movies should also be made for the difficult parts in the construction of the Groninger Forum. In this way the construction workers and if applicable the tower crane driver know in advance how they should do their job. This will prevent errors from happening and fasten the construction process.

Weight of the bigger parts is not added to the BIM model, this should be added. Weight is important information for the tower crane and for prefabrication solutions.

BAM should also make the critical path visible and the progress should be made visible as well. With the visualization of the critical path, it becomes clear for all parties involved what the critical path is and with the progress, the executor can immediately see where extra attention is needed to stay on schedule.

The amount of construction workers and the sizes and type of packaging material are two parameters that should be added to the BIM model as well that can assist in the planning process. With the amount of construction workers, peaks in utilization of the construction site can be lowered. With respect to safety it can also be indicated when it is allowed to work in certain areas and when it is not allowed. To be able to lower the peaks, information about the amount of construction workers from BAM and the sub-contractors is necessary. With the sizes and type of packaging material the reverse logistics can be planned.

For small changes in the plan based on for example delivery peeks or construction workers peeks, it is necessary to calculate the slack of jobs in the plan to make sure the critical path is not extended by the changes.

The above named recommendations can all be implemented on the short term; within one year. All these recommendations are possible to execute at the moment. On the mid-term, one to two years, BAM is advised to use a warehouse management system. When the moments of deliveries, the locations of deliveries, the amount of stock, and the location of stock are known, there is no time wasted with searching for materials when a warehouse management system is used. It will take some time to find the right warehouse management system that is compatible with the current systems of BAM.

On the long term, over two years, BAM is advised to redesign its financial structure in such a way that it can be integrated with the BIM model. When this is done, a 5D BIM model can be created. With a 5D BIM model cash flows can be forecasted and different scenarios in the plan can be compared based on the budget.

6.2.2 Recommendations about prefabrication to improve the plan

To first step that BAM should take to be able to make the right prefabrication decisions to improve the plan is to make a more detailed plan after the tender is won. With this plan the critical path can be calculated. All activities from sub-contractors should be in this plan, it is sufficient if estimations from activities are in this plan. The estimation of the durations in the steel plan for example is good enough.

Secondly it is important that the design of the construction is finished in an early phase of the planning process to have a good foundation to make the prefabrication decision. The sub-contractors should be involved from the moment that is decided to prefabricate the part they are involved in and let them draw their own part in the BIM model if possible. BAM should become project partners with the sub-contractors involved in prefabrication.

For finding project partners, BAM should begin with identifying the key sub-contractors of the project. The most important factor is whether or not the activity of the sub-contractor is in the critical path. When that is the case, six other factors can be taken into account. Those factors are: design content, complexity of construction, high contract value, long period of construction, long procurement times, and the sub-contractor could add value with early input. The key sub-contractors should be involved by creating teams just as for example the team discussed during the case study of Nagelhout, the Gebroeders Meijer, and BAM.

In the future the ability of a sub-contractor to draw in a BIM model should become a selection criterion. This saves BAM a lot of work and in this way the sub-contractor does not have to change design or properties in the BIM model.

6.2.3 Other recommendations

To be able to cope with JIT deliveries it is important that BAM keeps the plan in control. This is possible with the current planning process. This process can be improved by the following aspects from the LPS:

- Calculate the PPC from the weekly plan to use as target and as benchmark;
- Use the five times why method to prevent errors from occurring more than once;
- Discuss during weekly meetings the constraints with all parties involved in the six week schedule.

BAM should not focus on creating long term strategic relationships at this moment because BAM does not have experience with strategic relationships. For that reason, BAM should begin with project partners although strategic partnering might offer more cost savings on the long term. Successful project partnering can lead to strategic partnering in time if this is desired by BAM and the sub-contractor.

When BAM decides to use financial incentives to stimulate performance of the key sub-contractors, it should keep the disadvantages of financial incentives in mind; team members can act only in self-interest and disputes about the incentives because of the contract can occur. So the incentives should be aimed at team goals, not at individual goals and it should be clear when the bonus can be earned.

The last recommendation is that BAM should try to convince clients that it is more profitable if BAM Techniek and BAM Utiliteitsbouw collaborate more often at an early stage; before construction begins instead of putting in separate bids. This will result in a faster and probably cheaper production process as BAM Techniek and BAM Utiliteitsbouw also collaborate on cost level. The collaboration between BAM Techniek and BAM Utiliteitsbouw is also important for prefabrication solutions. The collaboration makes it easier to come up with ideas and help each other improving the construction process.

6.3 Limitations and further research

In this section the limitations and recommendations for further research are discussed. In sub Section 6.3.1 the limitations of this research are discussed and in sub Section 6.3.2 recommendations for further research are discussed.

6.3.1 Limitations

The most important limitation of this research is the lack of data. Because of the lack of data it was not possible to zoom in on the plan and see the differences between the plans.

Another limitation of this research is that the recommendations are not tested. It is not tested what the influence is on adding the recommended information to the BIM model and how that will work in practice. It is also not researched what the improvements are when decided to prefabricate jobs in the critical path and if it making the plan earlier in the process improves the planning process.

The last limitation is that the planning process is based on a traditional construction process and not on the contract form design and build. This last contract form is becoming more popular.

6.3.2 Further research

The first advice for further research is that the recommendations have to be tested and the results of these tests have to be analysed.

Because of the earlier involvement of sub-contractors, the procurement process changes compared to the traditional situation. Further research should make clear how the procurement process should be designed and if for example the way BAM involved three duct suppliers proves to be a good way to design the procurement process. It became clear that the duct suppliers did not present all their ideas but involving three duct suppliers might have led to a low price. Besides that, research has to be done about what the contract between BAM and its sub-contractors should look like when a sub-contractor is involved earlier in the process.

Because BIM is relatively new for the construction industry there are no clear guidelines and contracts for who is responsible for what part, this should be made clear as soon as possible.

Further research could be done for procurement for more projects at the same time and the role that SAP can play in that procurement process and the role SAP can play at BAM in general could be researched as well.

From one of the interviews it became clear that the construction process would improve a lot when the same sub-contractors are used for a couple of projects. In this way they can collaborate in early stages of the project and get used to each other. This should be researched as well. This has influences the moment sub-contractors can be involved. When sub-contractors are already known before a project starts, they can be involved immediately because procurement is not necessary anymore.

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Appendix A: The Last Planner

Except for the simplest and smallest jobs, design and construction require planning and control done by different people, at different places within the organization, and at different times during the life of a project. Planning in the top of the organization focuses on global objectives and constraints, and on governing the entire project. These objectives drive lower level planning processes that specify means for achieving those ends. Ultimately, someone (individual or group) decides what physical, specific work will be done tomorrow. That type of plans is called "assignments". The assignments are unique because they drive direct work rather than the production of other plans. The person or group that produces assignments is called the "Last Planner"(Ballard, 2000).

The goal of the LPS is to keep the plan in control. According to Ballard (2000) “control causes events to approximate the desired sequence, initiates replanning when the established sequence is either no longer feasible or no longer desirable, and initiates learning when events fail to conform plan.” The Last Planner production control system is a philosophy, and consists of rules, procedures, and a set of tools that facilitate the implementation of these procedures. Regarding the procedures, the system has two components: production unit control and work flow control. According to Ballard (2000) “production unit control is to make progressively better assignments to direct workers through continuous learning and corrective action. Work flow control is to proactively cause work to flow across production units in the best achievable rate and sequence.”

<u>Production unit control</u>

The key performance dimension at production unit level of a planning system is output quality of the system; i.e. the quality of plans produced by the Last Planner. The four critical quality characteristics of an assignment are:

- The assignment is defined well
- The right sequence of work is selected
- The right amount of work is selected
- The work selected is practical or sound; the work can be done

The quality of the plans is measured by the Percent Plan Complete (PPC). PPC is the number of planned activities divided by the total number of planned activities. A higher PPC corresponds to doing more of the right work with the given resources, i.e. to higher productivity and progress. PPC measures to which extent “Will”, as shown in Figure 23, is realized. By analysing the root causes of the not finished assignments, problems can be found and improvements can be made in future performance. The root causes can lead to changes at any organizational level, not only to changes at the Last Planner level (Ballard, 2000).

<u>Work Flow Control</u>

Work Flow Control coordinates the flow of design, supply and installation through production units. The lookahead process is the process in which the work flow control is determined. The lookahead process has different functions in the LPS:

- Shape work flow sequence and rate
- Match work flow and capacity

- Decompose master schedule activities into work packages and operations
- Develop detailed methods for executing work
- Maintain a backlog of ready work
- Update and revise higher level schedules as needed

The lookahead process is translated into a schedule of potential assignments for the next three to twelve weeks. The length of the lookahead process depends on the project characteristics, the reliability of the planning system, and the lead times for acquiring information, materials, labour, and equipment. Figure 22 is an example of how a five week lookahead process looks like (Ballard, 2000).

Next to the lookahead schedule and the master schedule, it is beneficial to let the team involved in the next phase of a project collectively produce a phase schedule which coordinates actions that extend beyond the lookahead window. It is important that all sub-contractors are willing to participate in the Last Planner process; otherwise it affects the PPC in a negative way (Ballard, 2000).

PROJECT: Pilot 5 WK LOOKAHEAD

ACTIVITY	1/13/97						1/20/97						1/27/97						2/3/97						NEEDS
	M	T	W	T	F	S	M	T	W	T	F	S	M	T	W	T	F	S	M	T	W	T	F	S	
Scott's crew																									
"CUP" AHUs-10 CHW, 2 HW	X	X	X	X	X		X	X	X	X	X		X	X	X	X	X								CHW delivers 1-8-97 thru 1-13. HW delivers 1-20.
Punch, label, & tag AHUs															x	x	x								Materials on site
Ron's crew																									
DI Steam to Humidifier			x	x	x																				Materials on site
DI Steam Blowdown	x	x																							Check material
DI Steam Cond. to coolers (13)							x	x	x	x	x		x	x	x	x	x		x	x	x				Material on site
Charles' crew																									
200 deg HW 1-"H"	x	x	x																						Matl delivery 1-8-97
200 deg HW 1-"B" & 1-"D"							x	x	x	x	x		x	x	x	x	x								Release matl for 1-15-97
1st flr 200 deg HW guides & anchors	x	x	x	x	x								x	x	x	x	x								Material on site. Need West Wing flr covered.
Richard's crew																									
2-"A" HW & CHW	x	x	x	x	x																				Control valves for added VAV coils
CHW in C-E-G tunnels	x	x	x	x	x		x	x	x	x	x		x	x	x	x	x								Need tunnels painted & release materials
Misc FCUs & cond. drains in "I", "J", & "K" 1st flr							x	x	x	x	x		x	x	x	x	x								Take off & order materials
Punch, label & tag							x	x	x	x	x		x	x	x	x	x								Material on site

Figure 22: Construction Lookahead Schedule (Ballard, 2000).

Before entry in the lookahead window, master schedule or phase schedule, activities are transformed into a level of detail suitable for assignment on weekly work plans. This typically results in multiple assignments for each activity. Next, each assignment is subjected to constraint analysis to determine what must be done before the assignment can be executed. Only activities which can be made ready for completion on schedule are allowed in the lookahead schedule or allowed to advance to the next week in the lookahead schedule. If the planner is not confident the constraints can be removed, the potential assignments are moved to a later date. Potential assignments enter the lookahead window six (this can be another number as well) weeks ahead of scheduled execution.

When an assignment is in the lookahead schedule it is moved forward every week by a week until the assignment is allowed to enter into workable backlog, indicating that all constraints have been removed and that the assignments are in the right sequence for execution. If the planner discovers a constraint that could not be removed in time, the assignment would not be allowed to move forward. The objective is to maintain a backlog of ready to performed work with the assurance everything in the workable backlog is indeed workable. Weekly work plans are then formed from workable backlog, thus improving the productivity of those who receive the assignments and increasing the reliability of work flow to the next production unit (Ballard, 2000).

The work plan is formed during a weekly work planning meeting. During a weekly planning meeting the status of the constraints in the lookahead schedule are discussed and the weekly plan is made. The status of the constraints should be known to all participants before the weekly planning meeting starts. In this way the focus can be on planning and problem solving instead of data collection. From the weekly plan the PPC is calculated. The PPC is only meant to improve the process and not to point out the weakest link. When the causes for delays are not clear the foreman and the sub-contractor must ask five times why the delay happened. This helps to find the root of the problem (Becktechnology, 2013; Ballard, 2000).

Once assignments are identified, they are subjected to constraint analysis. Examples of constraints are: prerequisite work should be finished, equipment should be available, labour should be available, and permits should be arranged. Constraint analysis requires suppliers of goods and services to actively manage their production and delivery, and provides the coordinator with early warnings of problems with sufficient lead time to plan around them. In absence of constraint analysis a throw-it-over-the-wall mentality will be created (Ballard, 2000).

The LPS is a type of pull system. Pull systems are systems in which materials or information is allowed in the process only if the process is capable of doing that work. In the LPS conformance of assignments to quality criteria is the capability check. Besides that, making assignments ready in the lookahead process is an application of pull techniques (Ballard, 2000).

In Figure 23 the LPS is displayed. Last Planner can be understood as a mechanism for transforming what ”Should be done” into what “Can be done”. In other words forming an inventory of ready work from which weekly work plans can be formed. The weekly work plan is a commitment by the Last Planners (foreman) to what actual “Will be done” (Ballard, 2000).

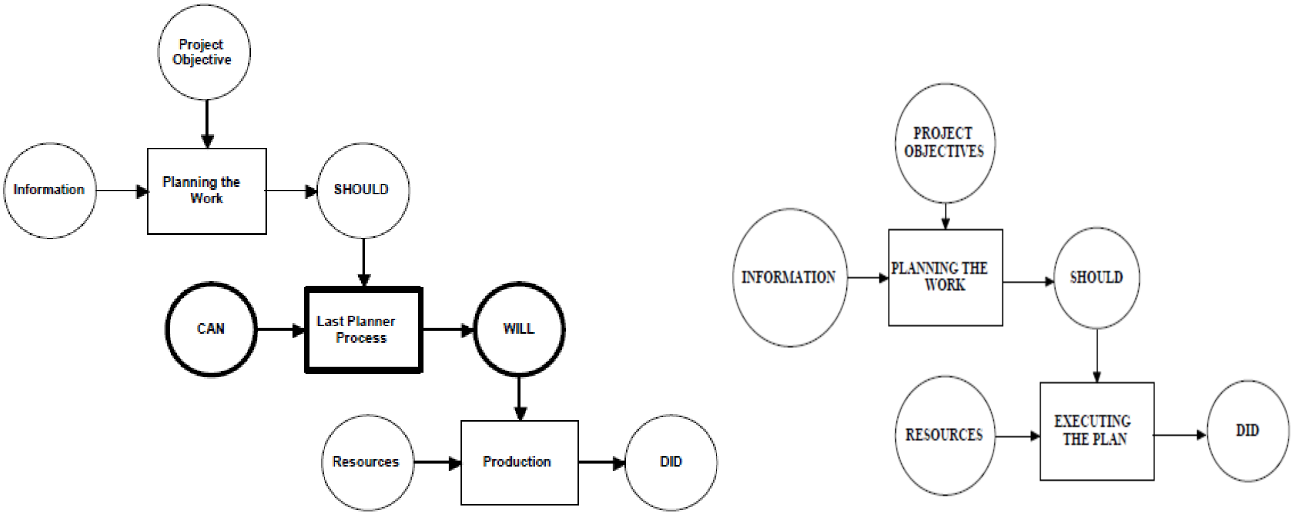

Figure 23: The LPS compared to traditional (push) planning system (Ballard, 2000).

In Figure 24 the relation between the different schedules that are made during the Last Planner process is shown. This visualizes the order in which the different plans are made and where they are based on.

Benefits and challenges of the LPS

Various case studies show the benefits of implementation of the LPS: the PPC of the projects rises(Issa,2013), improved communication and coordination among sub-contractors (Song, Lian & Javkhedkar, n.d.; Fernandez-Solis e.a., 2013), increased workflow reliability, improved supply chain integration, reduction in project delivery, fewer day-to-day problems, improvement in quality of work practice at the construction site, improvement of managerial practices in construction projects, knowledge expansion and learning among project teams, and reduced stress levels on the construction site (Fernandez-Solis, 2013).

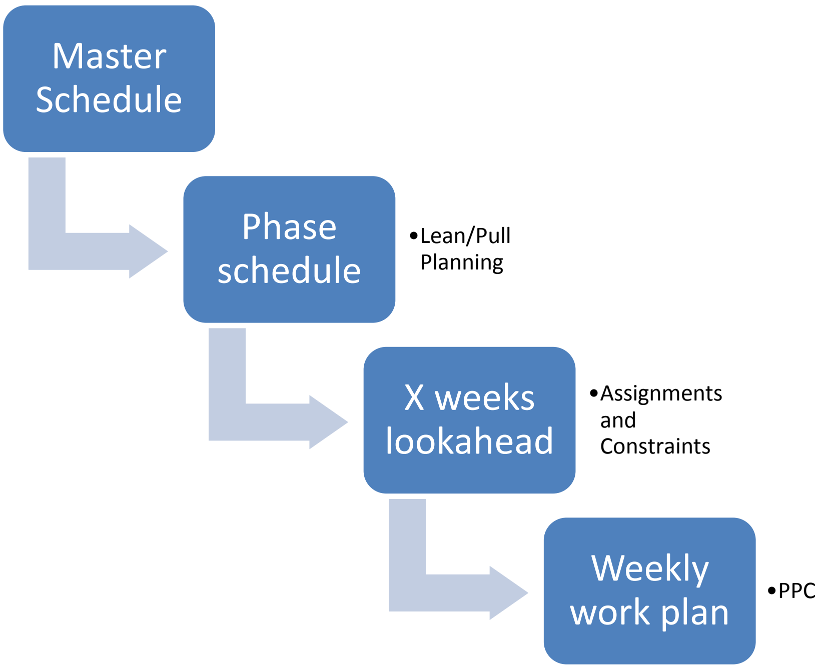

Figure 24: Schedules in LPS

Next to the benefits challenges arise when using the LPS. Those are: resistance to change by employees at construction site and management (Porwal, 2010; Koskenvesa, 2012), lack of training, lack of human capital, lack of leadership, lack of collaboration (Porwal, 2010; Fernandez-Solis, 2013), poor use of information generated during implementation of LPS, lack of collaboration, late implementation of LPS (Fernandez-Solis, 2013), Lack of stakeholder support (Porwal, 2010), lack of understanding of the potential of lean construction management as a production management system, and difficulties in revealing problems (Koskenvesa, 2012). The last two challenges are not particularly for the LPS but hold to the implementation of lean management in general: to successfully implement lean concepts determination and a long term view is needed and it has to be kept in mind that learning to work smarter takes time (Mossman, 2009).

Appendix B: The earned value method

The earned value method (EVM) is a method which integrates schedules, resources, and scope for measuring project performance. It compares the amount of work that was planned with what was actually earned and spend to determine if cost and schedule performances are as planned (Naderpour & Mofid, 2011). EVM is an early warning method that enables managers to identify and control problems before they become too big. It allows projects to be better managed on time and on budget (Nagrecha, 2002).

The first step of using the EVM is to create cost accounts; this is done before the project starts. A cost account is created by using a Work Breakdown Structure (WBS) which divides a project into the elements of work to be accomplished integrated with Organization Breakdown Structure (OBS) that provides the "Responsibility" field. These cost accounts function as management control points. At a management control point actual cost can be accumulated and compared to budgeted cost for work performed. A cost account is a natural control point for cost/schedule planning and control since it represents the work assigned to one responsible organizational element on one contract work breakdown structure element. The creating of cost accounts is illustrated in Figure 25. A cost account consists of schedule and budget information (Kim & Ballard, 2000).

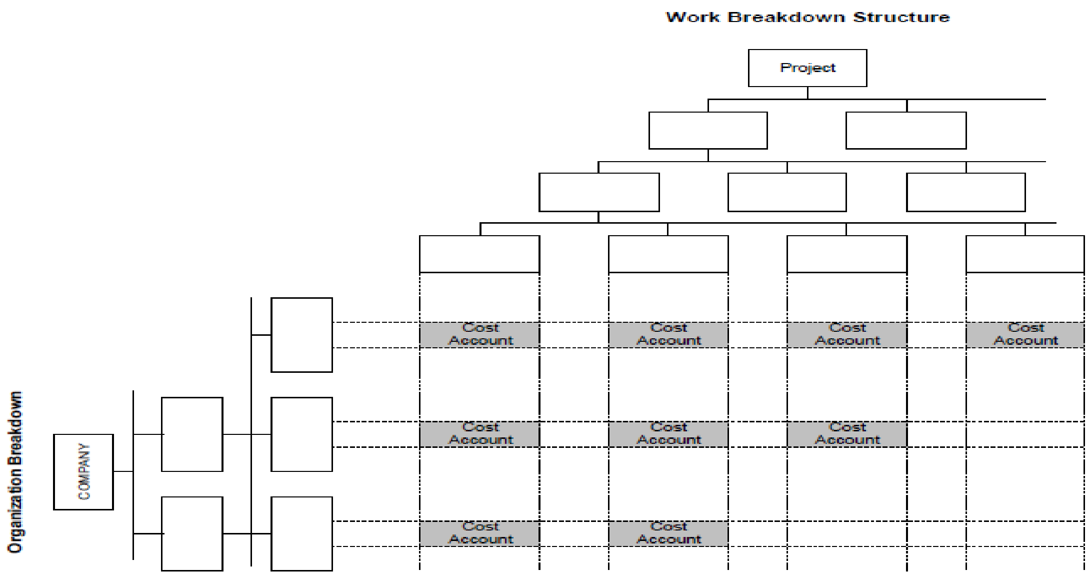

Figure 25: Cost Accounts (Kim & Ballard, 2000).

The next step is to analyse the progress of the project, this step will start when the construction starts. Variance analysis quantifies the deviations from the budget based on the data collected. The variance used in EVM is divided into two terms; Cost Variance (CV) and Schedule Variance (SV). The data collected for analysis is divided into three terms; Actual Cost of Work Performed (ACWP), Budgeted Cost of Work Performed (BCWP), and Budgeted Cost of Work Scheduled (BCWS) (Kim & Ballard, 2000).

- Actual Cost of Work Performed (ACWP) is the actual incurred cost of work performed in a specified period of time expressed in terms of euros or man-hours (Actual).
- Budgeted Cost of Work Performed (BCWP), or Earned Value, is the budgeted value, usually in terms of euros or man-hours, of work actually performed in a specified period of time.

- Budgeted Cost of Work Scheduled (BCWS) is the budgeted value, usually in terms of euros or man-hours, of work scheduled to be performed in a specified period of time (Plan).

Since the objective of EVM is to achieve an integrated cost and schedule progress monitoring and control system, it requires the monitoring of two kinds of variances as mentioned. There is a third variance which can be monitored: Accounting Variance (AV). Early cost control systems focused on AV to monitor cost variance, but EVM does not use it anymore since it does not take performance into account (Kim & Ballard, 2000).

- Cost Variance (CV) is the difference between the budgeted and actual costs of the work performed:
  CV = BCWP – ACWP
  Or CV (%) = (BCWP – ACWP) / BCWP
- Schedule Variance (SV) is the difference between the budgeted cost of work actually performed and the budgeted cost of the work schedules to be performed:
  SV = BCWP – BCWS
  Or SV (%) = (BCWP – BCWS) / BCWS
- Accounting Variance (AV) is the difference between what is actually spent and how much is supposed to be spent.
  AV= ACWP – BCWS

Figure 26 shows the relationships between BCWS, BCWP, ACWP, CV, SV and AV.

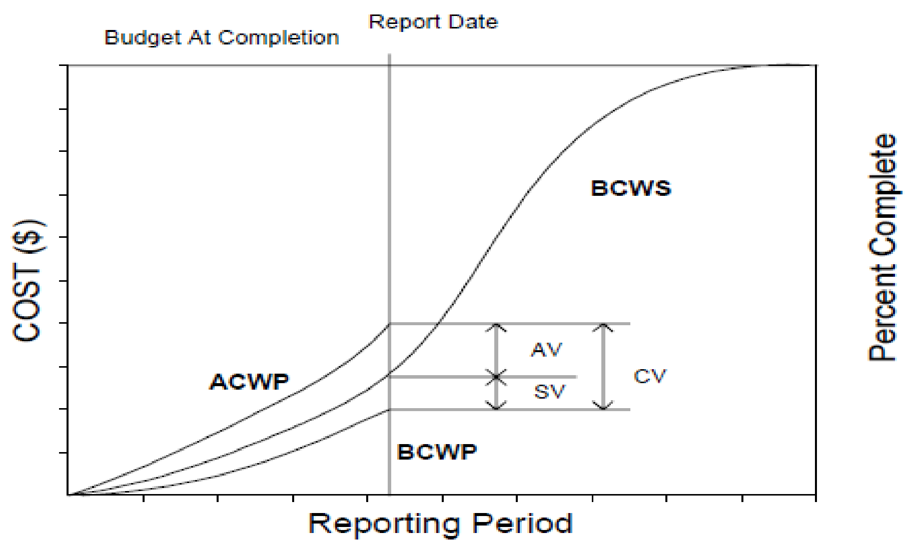

Figure 26: relations evm (Kim & Ballard, 2000).

The performance interpretations that may be drawn from cost and schedule variance values are summarized in Table 5 (Kim & Ballard, 2000). Next to the variances there are two indices which can be calculated, the cost performance index (CPI) and the schedule performed index (SPI). The CPI is the ratio between budgeted cost and actual cost. The formula of the CPI is BCWP/ACWP. If the CPI is bigger than one the program's actual cost is lower than budgeted cost. If the CPI is smaller than one the actual costs are higher than the budgeted cost. If the CPI is equal to one the program's cost is executed according to schedule. The SPI is the ratio between budgeted work and performed work. The formula of the SPI is BCPW/BCWS. If the SPI is bigger than one the program's progress is ahead of schedule. If the SPI is smaller than one the program's progress is behind schedule. If the SPI is equal to one, the program's progress accords with schedule (Nagrecha, 2002).

Table 5: performance interpretations (Kim & Ballard, 2000).

Variance	-	0	+
Cost Variance (CV)	Cost overrun	On budget	Cost underrun
Schedule Variance (SV)	Behind schedule	On schedule	Ahead of schedule

With the actual values of the costs and schedules during a project a prediction about the final costs and delivery date can be made. In case the prediction does not satisfy the manager he must decide how to overcome the budget or schedule problems. Weekly calculation of the SPI and CPI can be used as a benchmark.

Benefits and challenges of the EVM

The benefits of the EVM are that it provides an early warning signal, it makes it possible to benchmark weekly performance, it combines work, cost and schedule, the total costs of the project can be estimated and it is an easy system in which managers can see if the project is still in control (Nagrecha, 2002).

The challenges of the EVM are that it is less effective when cost risk is contractually shifted to others EVM is less effective, EVM assumes that all activities are independent of each other, for cost reasons a decision can be made with no clear insight in constraints, and EVM results in an unreliable workflow(Kim & Ballard, 2000).

Improvement of EVM for construction industry

The target of construction projects is to realize those projects at the lowest costs, in the shortest time, and with the highest quality as possible. The EVM can only integrate time and costs. Ma & Yang (2012) propose an improved version of EVM in which quality cost is introduced. Quality cost is the expense paid to ensure and improve the quality of products and the expense lost to meet the quality standard. These can also be described as control cost and failure cost. To take quality cost into account three new variables are introduced:

- QBCWP (Quality Budgeted Cost of Work Performed) is budget quality cost of accumulated actually performed work at the moment.
- QACWP (Quality Actual Cost of Work Performed), actual quality cost of accumulated actually performed work.
- QBCWS (Quality Budgeted Cost of Work Scheduled), budgeted quality cost of accumulated work performed at the moment.

The budgeted quality cost is equal to the budgeted expense * Q_i. Q_i is the percentage of quality cost determined in the designing phase of construction as percentage of the total cost, or the experience rate of the percentage of quality cost of the enterprise's past construction projects, $0 < Q_i < 1$(Ma & Yang, 2012).

The new performance indices are the Quality Schedule Performance Index (QSPI), the Quality Cost Performance Index (QCPI), and the Quality Performance Index (QPI).

The formula for the QSPI is BCWP/BCWS, with QSPI larger, smaller than or equal to one indicating the progress being ahead of, behind or according to schedule. When the QSPI is smaller than one the cause for schedule delay should be analysed and timely measures should be taken to accelerate progress; when the QSPI is bigger than one the cause should be analysed as well. If the progress runs ahead of schedule because the quality level decreases, then measures should be taken to improve the quality, even if the schedule will be delayed (Ma & Yang, 2012).

The formula for the QCPI is BCWP/ACWP, with QCPI larger, smaller than or equal to one indicating the cost decreasing, increasing or coinciding with budgeted cost. When the QCPI is smaller than, the cause for the gap in the budget should be analysed to see whether it is because of the schedule and measures to lower the cost should be taken according to the actual situation. When the QCPI is bigger than one, the cause for the decrease of cost should be analysed as well. If it concerns the quality, quality should be the priority (Ma & Yang, 2012).

The formula for the QPI is QACW P/ACWP, with QPI larger, smaller than or equal to one indicating the quality economy decreasing, increasing or coinciding with budgeted value. When the QPI is bigger than Q_i the cause for the increase of quality cost should be analysed. If it is because of the increase of construction breakdown, the breakdown cost can be reduced and prevention cost to reduce quality cost can be increased; if it is because the increase of examination cost, these can be reduced to reduce quality cost. When the QPI is smaller than Q_i, the cause should be analysed as well and the factors that did not cause the lowering of quality standard should be kept ($QPI \leq Q_i$) and the management method should be improved (Ma & Yang, 2012).

The improved EVM for construction industry makes it easier to control quality at projects as well. However the challenges are still the same as for the original EVM.

Appendix C: Summary interview with planner about planning process

The interview was held with Sebastiaan Beek who is a planner at the Groninger Forum. The interview was held on the 9th of September 2013. The goal of the interview was to get insight in the planning process of the Groninger Forum.

The first plan is made before BAM is submitting an offer. This plan is solely based on estimations and rules of thumb and the plan is not detailed. Fit-in phase for example is put in the plan as one block and is based on square meters that have to be finished. This is the same for a standard office building or a unique hospital.

The planning has two scales, one continuous scale which is not used and one scale that takes unworkable weather into account. Based on statistics a number of days is left out of the plan in this way the long term planning is more reliable.

When the bid is won a more detailed plan is made per phase of the construction. This schedule is made before the specific phase starts. The phase schedule is made by using the lean planning method and all sub-contractors involved in the specific phase is involved during the creation of the phase schedule. The creation of the phase schedule usually takes a day and is led by the executor. The idea behind lean planning is that all sub-contractors will respect other sub-contractors' ideas and will collaborate to create a feasible planning.

The rough plan made before submitting the offer is to give an indication for the execution, from the rough plan the executor makes the phase planning and from that plan a six week schedule is made. This contains a detailed plan with all activities for the coming six weeks. From this six week plan a an even more detailed week plan is made weekly.

There is no strategy in making the plan, it is based on knowledge and experience. No heuristics are used to create the plan. For the activities in the critical path smart solutions are thought of to shorten the critical path. These come from the planner.

Appendix D: Interview questions duct suppliers

1. Hoe gaat u om met Just-In-Time leveringen?

2. Welke voordelen heeft het gebruik van een hub voor uw bedrijf? En welke nadelen? Kunt u dit kwantificeren?

3. Hoe kijkt u aan tegen het huidige lean plannen? Wat vind u van Last Planner methode (uitleggen lookahead schedule)?

4. Wat moet BAM anders doen zodat u uw werk perfect uit te kunnen voeren? Wat moet er in ieder geval niet gebeuren zodat u uw kostprijs kan halen?

5. Hoe kan het komen dat uw prijs die u aanbied voor hetzelfde werk per aannemer kunnen verschillen? Waar is dat op gebasseerd? Heeft u voorkeur voor bepaalde aannemer?

6. Hoe is het deel van uw kostprijs voor transport opgebouwd? Besteed u delen daarvan uit? Welke criteria hanteert u daarvoor? Welke invloed heeft de bouwplaats/bouwer daarop?

7. Wat voor mogelijke verstoringen komt u tegen in uw werk en hoe gaat u daar mee om? Wat kan BAM hieraan doen? Welke worden door BAM veroorzaakt?

8. Hoe zorgt u dat uw van te voren gemaakte planning overeenkomt met wat er op de bouwplaats uitgevoerd wordt? Wat is uw geschatte % kans op uitloop?

9. Hoe kijkt u aan tegen nauwere samenwerking met BAM op project basis door onderaannemers eerder te betrekken? Wat denkt u dat er verandert kan worden om de samenwerking te verbeteren?

10. Welke andere basis in plaats van onder aannemers eerder betrekken kan leiden tot meer succes?

11. Wat zou er contractueel moeten veranderen volgens u als nauwere samenwerking wil slagen? (Is er in de ideale situatie nog wel een contract nodig?) Wat vind u van een financieel beloningssysteem?

12. Wat ziet u voor voor- en nadelen voor uzelf voor een eventuele samenwerking met BAM?

13. Wat zou BAM moeten veranderen als er nauwere samenwerking plaats gaat vinden?

14. Wat vind u van mogelijkheden om voor langer dan 1 project samen te werken?

15. Wat zou op het gebied van samenwerken voor u de ideale situatie zijn om een project voor BAM uit te voeren? (Met de klant erbij? Of nog iets anders?)

16. Waarom wordt er nu pas nagedacht over partnering en niet een paar jaar geleden al?

17. Hoever bent u in uw ontwikkeling met BIM? Hoe ziet u de rol van BIM in partnering en hoe ziet u de toekomst van BIM? (Zal de onder aannemer zelf gaan tekenen in de toekomst)

18. Wat voor informatie die ingevoerd wordt in BIM kan gebruikt worden om de logistiek aan te sturen? Wat voor informatie zou handig zijn om in BIM in te voeren om de logistiek aan te sturen?

Appendix E: Summary interview Gebroeders Meijer

The interview with the Gebroeders Meijer was held on the 4th of November 2013 with the CEO Johan Vreeken.

To make JIT deliveries successful the plan is very important. For JIT delivery of the ducts the hub the Gebroeders Meijer do not need the hub. However, the hub can be useful for coordination. When the plan is good it is not necessary to wait for example an hour at the hub before delivery is possible, this has to be prevented. Getting the ducts as fast as possible at the 9th floor is most important.

The concept of lean planning is good. The concept of lean planning is talking with other sub-contractors and acknowledge each other's problems and try to solve them together. However how lean planning is executed in practise is not good. In practice it seems that the only goal is to let sub-contractors build faster, the lean planning meeting is often too late in the process and it happened often that the project leader enters the room when the planning is finished and then he picks up a few notes and sais this has to go faster and then he leaves again. This is not the idea behind lean planning. Besides that, the planning is often not executed because when there is a delay somewhere the foreman works with his own planning.

After explanation of the LPS Johan thinks that the use of LPS is a way forward, this means that there will be better coordination and that the plan will be executed better. It will probably lead to some resistance because the culture is that it is too far away to plan six weeks ahead.

The main problem Gebroeders Meijer encounters at the construction site is a late change in plan, this happens often in the construction industry. If this can be prevented there is nothing that hinders the Gebroeders Meijer from perfming the job as planned. Gebroeders Meijer keeps its planning in control by realistic planning. The plans are made based on years of experience.

Gebroeders Meijer is not able yet to draw in BIM models. They are able to read them though. The production cannot be controlled yet by BIM models; this is being developed at the moment and will probably be finished within two years. But this is too late for the Groninger Forum. BIM modellers are too expensive at the moment to be hired by the Gebroeders Meijer. Johan thinks that in the future there will be businesses specialized in drawing BIM models, so the models are not made by BAM or by the sub-contractors but by a third party. Communication through the BIM model will be the key till success.

To become partners with BAM there must be a click between the partners and trust will be very important. Gebroeders Meijer is not negative towards becoming a partner of BAM. The reason why partnering is a topic now is because there are now possibilities because of the BIM model.

BAM is a good party to work for, BAM is always looking to innovate and Johan likes that about BAM.

Appendix F: Summary interview Brema-Air

The interview with Brema-Air was held on the 6th of December with the commercial director Henry Passon and with Fred de Rooy who is also working for Brema-Air.

Brema Air is going to deliver JIT by lifting a container with the tower crane and empty that container as fast as possible and work that day with the ducts from the container. The hub can be useful for Brema Air to wait there till the tower crane is ready and to use it as storage location. They can bring a full truck load to the hub and go with parts of the full truck load to the construction site.

Brema Air likes the idea of lean planning of involving all parties in the planning but the execution is not wright. The goal in practice is always to shorten the plan. After explanation they like the idea of the lookahead planning, instead of weekly meetings they see an extra advantage in short daily meetings. Those meetings can be 5 minutes but it would improve the coordination a lot.

When BAM keeps the plan as it was designed Brema Air can do its job better. Now decisions are made as late as possible and communicated as late as possible as well. Collaboration would also improve if BAM does not only look at price but takes other things in mind as well. Brema Air produces the ducts and delivers them immediately after production so a late change in plan is very bad for them. The planning made by Brema Air itself is a realistic planning based on Experience.

Brema Air offers different prices at different contractors; those are based on experiences from the past with that contractor. Brema Air arranges the transportation of the ducts itself, there is no fixed price it depends on the amount of deliveries. Not possible to give an indication of a percentage.

The earlier involvement is good for the construction process and results in lower costs. The selection process can be improved by making the decision earlier and not let three parties compete for two months. BAM is a pioneer in the industry they are the first contractor who is trying this. It is not perfect yet but keep talking with all parties is important and BAM is doing that. Brema Air does not know another way to improve the collaboration; they say that this is the way. A way to improve the freedom of selecting and of getting better or cheaper products the role of the advisors should be minimized. In the specification they often demand products of certain brands. A disadvantage of earlier involvement is that extra coordination is needed. The collaboration can be improved by selection the same team for five or six projects, when the members of the teams are used to each other and their way of working the construction will be a lot faster. Parties need to keep talking to reach this situation.

BAM should change the process of selection if it wants to create a better collaboration. BAM is still looking but it is happening now. It is all about smart solutions.

A better contract form for a successful collaboration would be to insert a shared interest for the involved parties in the contract. In this way there will be worked towards a successful result. The concept of “eenheidsprijzen” should be removed from the contract.

The concept of partnering is now open for discussion because of the recession and because of the possibilities coming from the BIM model.

Brema Air can read BIM models and also has a few modellers. The production cannot yet be controlled by BIM, this will happen in a few years but not yet for the Groninger Forum.

Appendix G: Summary interview with planner about BIM

The interview was held with Mark de Vries who is a planner at the Groninger Forum. The interview was held on the 29th of January 2014. The goal of the interview was to get insight in the possibilities of BIM and how BAM uses BIM.

Because of BIM it is easier to prefabricate parts of construction projects. Because in the Groninger Forum is not much repetition the Groninger Forum is not very suited for prefabrication.

Slack can be calculated by the current software BAM uses but this is not done. When there is slack and the executors know this they will use the extra time for sure. The software can also cope with uncertainty but you have to enter the chances yourself. So it is not very smart software in that way, it is just as easy to calculate it yourself when you know the chances.

BAM uses a 4D model at the Groninger Forum; a 5D model is not used. With a 4D model it is possible to see peeks in delivery, this is not taken into account. With the 4D model it is also possible to visualize the critical path this would be useful according to Mark but it is not used. The progression of construction compared to the plan can be seen as well with the 4D model but this does not have added value according to Mark.

In the planning the amount of construction workers from BAM are inserted to prevent peeks at the construction site. The information from sub-contractors is not taken into account so the information from BAM only is not very useful.

It would be good to keep up information about deliveries this is not done yet. The only thing that is known in advance is if the hub is used for a product and at what entrance of the construction site the delivery will be made.

The packaging materials are not added to products in the BIM model. It is not clear yet of this will be done. By far the most packaging materials are used at the fit-out phase. This phase is still over a year away so there is enough time to think about this.

Adding the reach of the two tower cranes to the BIM model has no added value. A 2D drawing is more than enough for planning the tower cranes.

The biggest problem with adding extra information to the BIM model is keeping the data up to date. There will always change things during the construction, this should than also be changed in the BIM model.