



SUPPLY CHAIN MANAGEMENT WITH BIM

TOWARDS BETTER CONTROL OF
CONSTRUCTION LOGISTICS

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Report Master Thesis
Date Jun 2017

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The background of the image is a dark, textured surface, likely concrete, with numerous fine cracks and some larger, irregular fissures. The overall color is a dark charcoal or grey. Overlaid on this background is the text 'SUPPLY CHAIN MANAGEMENT WITH BIM' in a bold, white, sans-serif font. The text is arranged in three lines, centered horizontally.

SUPPLY CHAIN MANAGEMENT WITH BIM



PREFACE

Logistics have been a fascination of me for quite some time. In between my bachelors and masters, I took a gap year to be a full-time board member of Stylos, the study association of the Faculty of Architecture. One of the things I did that year was organising BkBeats, the biennial faculty party. There I discovered that my main interest was managing the logistics; being responsible for getting all the guests and crew to the right place at the right time. After that I started to look around more and focus on other logistical challenges, for instance on the construction of the train station in Delft. With all the construction traffic, regular traffic, cyclists and a lot of residents around the construction site this is a big challenge. Seeing all these challenges around me, my fascination grew and I decided I wanted to do something with it in my graduation research. Together with the NWO-project I could transform my ideas into a graduation research. Now, after an extensive research process, I am proud to present to you my master graduation thesis: *“Supply chain management with BIM: Towards more control of construction logistics”*.

With this thesis, there comes an end to seven years of studying at the Faculty of Architecture in Delft. A period which I enjoyed to the fullest, both studying and the student life. The past years were a series of positive experiences in which I gained a lot of knowledge and met a lot of new friends. Last year I dedicated to my thesis, but I could not have done this all by myself. Therefore, I would like to express my gratitude to a few people. First, I would like to thank my graduation supervisors. I would like to thank Ruben Vrijhoef for his support and his endless enthusiasm about construction logistics. I would also like to thank Alexander Koutamanis for his support and for sharing his extensive knowledge of BIM with me. In addition, I would like to thank all my colleagues at Waal for making me feel welcome and contributing to my research. Special thanks to the project team of Bètatoren, Joost de Korte, Jorg van Schadewijk and Dennis Adegeest, for sharing all your knowledge and experience with me and participating in what seemed an endless number of interviews. I would also like to thank Albert Gils, Martin van Leeuwen, Johan Noteboom and Mark Lammertink for their participation in this research. Furthermore, I would like to thank everyone involved in the NWO-project for sharing their knowledge and experiences during the meetings. Finally, I would like to thank my family and friends for their great support during the previous months. Thank you for patiently listening to all my graduation stories, dealing with me during deadline periods and offering me the necessary distraction. Special thanks to Marleen Meeuwsen, for showing your support during our many coffee breaks. Thanks to all of you I was able to successfully complete my graduation research and entire master track. I hope you enjoy reading my thesis.

Lisa Oosterwijk
Delft, June 2017

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SUMMARY

I. INTRODUCTION

Logistics can be defined as the organized movement of materials or people and is used throughout all different types of industries. The construction industry differs from other industries because the logistics are divided in the on-site logistics and the off-site logistics. This research focusses on the on-site logistics, which include all the various site services that support the main activity: the actual construction work (Lundesjö, 2015). Currently, the construction logistics on and around building sites often are not well organized, especially on building sites in dense areas. This inefficient construction logistics management leads to several problems, including overall time and budget overruns. It is assumed that one of the reasons of this inefficiency is that the main contractor does not have full control of the logistics. Research is therefore necessary to define how the main contractor can get control of the logistics.

For several years TNO has been conducting research about construction logistics. Their current research is a project led by NWO, but consists of a consortium of research facilities, educational institutes and construction companies. The project researches several logistic solutions implemented in different pilot projects, with the aim of making construction logistics

more efficient. One of these solutions is Building Information Modelling. BIM software can integrate logistic information with computational models and supports companies in managing their supply chain. However, there are still some technical and organisational issues that need to be solved before BIM can be used for supply chain management. Therefore, this research aims to solve these issues and research how the main contractor should manage the supply chain of a construction project with BIM. This research is part of the NWO-project and contributes to the overall research on construction logistics.

II. THE ESSENCE OF THE RESEARCH

The objective of this research is to show contractors how they can get control of their logistics with BIM, therefore the main research question is:

How does supply chain management with BIM help contractors to get control of the logistics of a building project?

The main research question consists of two parts: the first part focusses on how the main contractor should set-up the supply chain processes with BIM and the second part focusses on the acceptability by the third parties and the feasibility for the main contractor. The research will be conducted from an organisational perspective. The focus will be on how to organise the supply chain of a construction project with BIM in such a way that it gives the main contractor control over the logistics. Figure I shows the conceptual model of the research.

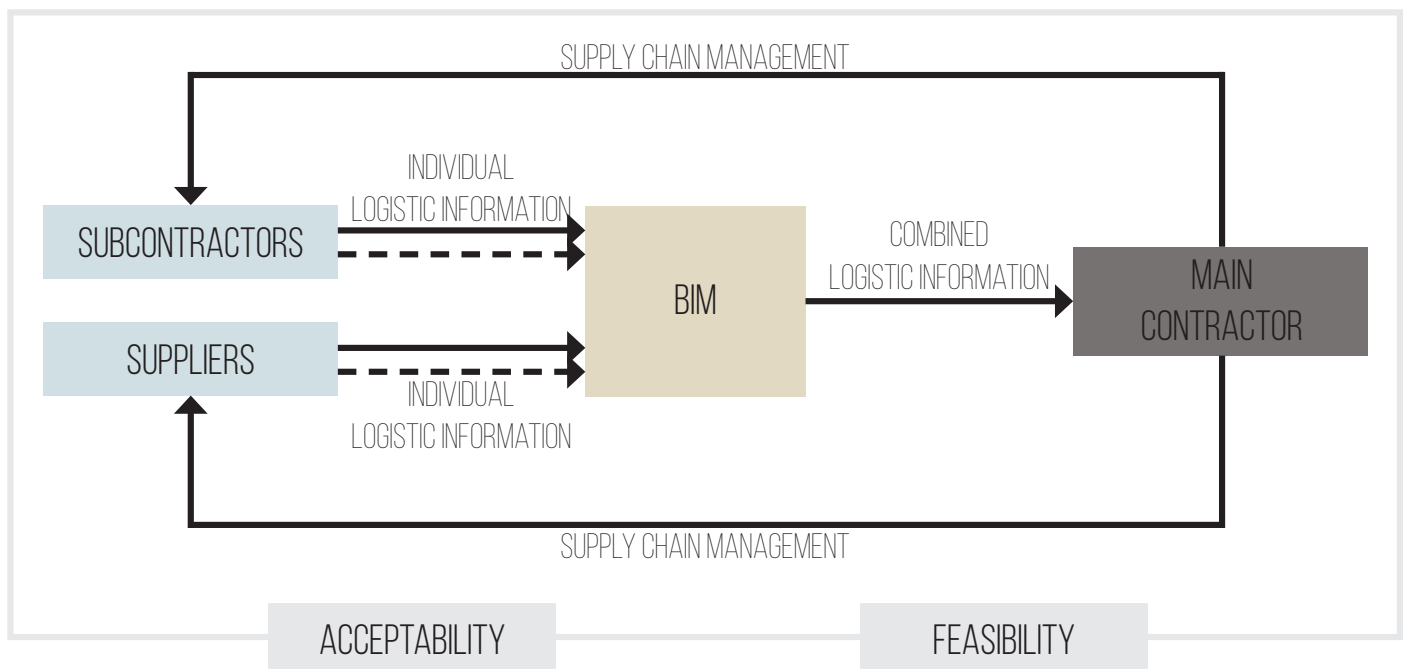


Figure I Conceptual framework (own illustration, 2017)

The model shows the information flows necessary for supply chain management with BIM. The research will focus on all these individual information flows to see how they should be organised in order to manage the supply chain with BIM. The sub-questions that are presented next reflect these different parts of the research.

1. How can a main contractor prepare the third parties for a new logistic system in order to get more control in the procurement phase?

2. What information of third parties is necessary in order to integrate logistic information in BIM software?
3. How does the main contractor need to use the BIM-model in order to get control of the logistics in the execution phase?
4. How do third parties view supply chain management with BIM?
5. Is the implementation of BIM for supply chain management feasible for the main contractor?

III. THEORETICAL FRAMEWORK

To provide a basis for the empirical part of this research, an in-depth literature study has been conducted. This literature study follows the phases of the conceptual framework that was presented in Figure I. For each phase, a literature study has been conducted and all these together provide a theoretical answer to the main question.

BIM has been selected for this research because it is a very comprehensive tool that can be used to streamline the information flows and is relatively easy to implement due to the low impact for all involved parties and the low adoption costs. Research showed that there are several benefits and barriers with regards to BIM. Benefits of BIM are a reduction and/or more control of time and costs and improvements of the coordination, communication and quality (Bryde, Broquetas, & Volm, 2013). The main barrier is about so-called 'people issues', which are issues concerning people having to agree to certain software, cooperate with each other and share their data. With regards to supply chain management the link between BIM and scheduling software is very important. Research conducted on the use of 4D BIM for planning and controlling the logistic operations on a construction site shows very promising results such as reduced inventories and better control of the material flows. This research focusses on how the processes and the information flows should be organised per phase in order to achieve these results.

In the first phase the main contractor has to set-up the supply chain organisation and prepare the third parties. This phase is about the position of the main contractor in relation to the third parties. In this case the main contractor is the focal firm and therefore takes on the role as supply chain integrator. In that role, the main contractor must manage the supply chain, together with the information flows within it. He must actively lead the supply chain and demand collaborative behaviour from the subcontractors and suppliers. Next to this, the main contractor must prepare the third parties for supply chain management with BIM. He must provide a BIM-protocol beforehand and provide knowledge and assistance during the process. Communication is key, so the main contractor must have an integrated approach that combines technical structures with social practices. The hypothesis for this phase is that currently the link between BIM and supply chain management is missing in the set-up of the project, which leads to an incomplete BIM-model.

In the second phase the role of the subcontractors and suppliers is defined. Based on their role and tasks they must provide certain information that serves as the input for the BIM-model. In order to develop an efficient supply chain structure, some lessons can be learned from the aerospace and shipbuilding industry. In those industries, there is a high interdependency within the buyer-supplier relationship. Subcontractors and suppliers are involved from a very early stage and they carry a lot of responsibility. They are each responsible for their own product and the focal firm is responsible for the logistics and assembling the final product. Information exchange is also implemented on a high level: the subcontractors and suppliers

are highly involved in the construction process and exchange detailed information with the main contractor. All parties communicate intensively with the main contractor, but the third parties do not communicate with each other. This ensures the main contractor stays in control. The hypothesis for this phase is that the fragmentation of the construction industry is the main reason for the inefficient organisation of the supply chain.

In the third phase the main contractor has to manage the construction of the building and has to control the third parties. The main contractor can do this by making use of the logistic information that can be extracted from BIM. First, the main contractor has to add some general information to the BIM-model. Next he must make sure to coordinate and update the BIM-model, merge segregate models with model checker software and host BIM meetings to keep all parties up-to-date (Papadonikolaki, Vrijhoef, & Wamelink, 2015). During this process, the main contractor should also make sure to measure the performance of the third parties and provide them with feedback. In the end, he must evaluate the whole process with all third parties, so they can also give feedback to the main contractor. This will improve the supply chain management and the relationships between the involved actors. The hypothesis for this phase is that to be able to manage the logistics with BIM, the model must include complete information with regards to the dimensions, location and the planning.

Per phase has been stated how the main contractor and the third parties should act in order to achieve an organisational structure that enables efficient supply chain management with BIM. An overview of these information flows is shown in Figure II.

In the fourth phase, all former phases come together and the results of the changed supply chain are visible. Based on the results of the literature study it is stated that if BIM is implemented correctly within the right organisational structure it can give the main contractor more control of the logistics. This could lead to benefits for all involved parties. Therefore, the hypothesis of this phase is that the implementation of BIM for the management of the on-site logistics is feasible for the main contractor.

The hypotheses will be tested by the empirical research. The set-up of this research will be presented in the next chapter.

IV. RESEARCH FRAMEWORK

The empirical part of this research is conducted by the use of a case study. The case that is selected for this research is project Bètatoren. It is a medium-sized construction project that consists of the construction of 134 apartments and some commercial space within an urban part of Leiden. The construction started in January 2017, the finishing phase of the construction will start in June 2017 and the building should be completed in July 2018. The main contractor of the project is Waal. Waal is a medium sized contractor located in Vlaardingen. They have experience with BIM but mainly use it as a tool in the procurement phase. They do see the potential benefits and are willing to research how to use BIM for supply chain management.

Next to Waal, four involved parties of project Bètatoren are researched. These consist of two subcontractors and two suppliers, in order to see whether there are differences between these types of third parties. The two selected subcontractors are Breman and Tegel Idee. Breman is responsible for all mechanical installations and will be closely involved during the whole construction phase. Tegel Idee is responsible for all the tiling and will only be involved during the finishing part of the construction phase. The two selected suppliers are Calduran and Halfen. Calduran is responsible for supplying the limestone and Halfen is responsible for the delivery of wall supports and steel lintels. Both will only be involved in the shell construction phase.

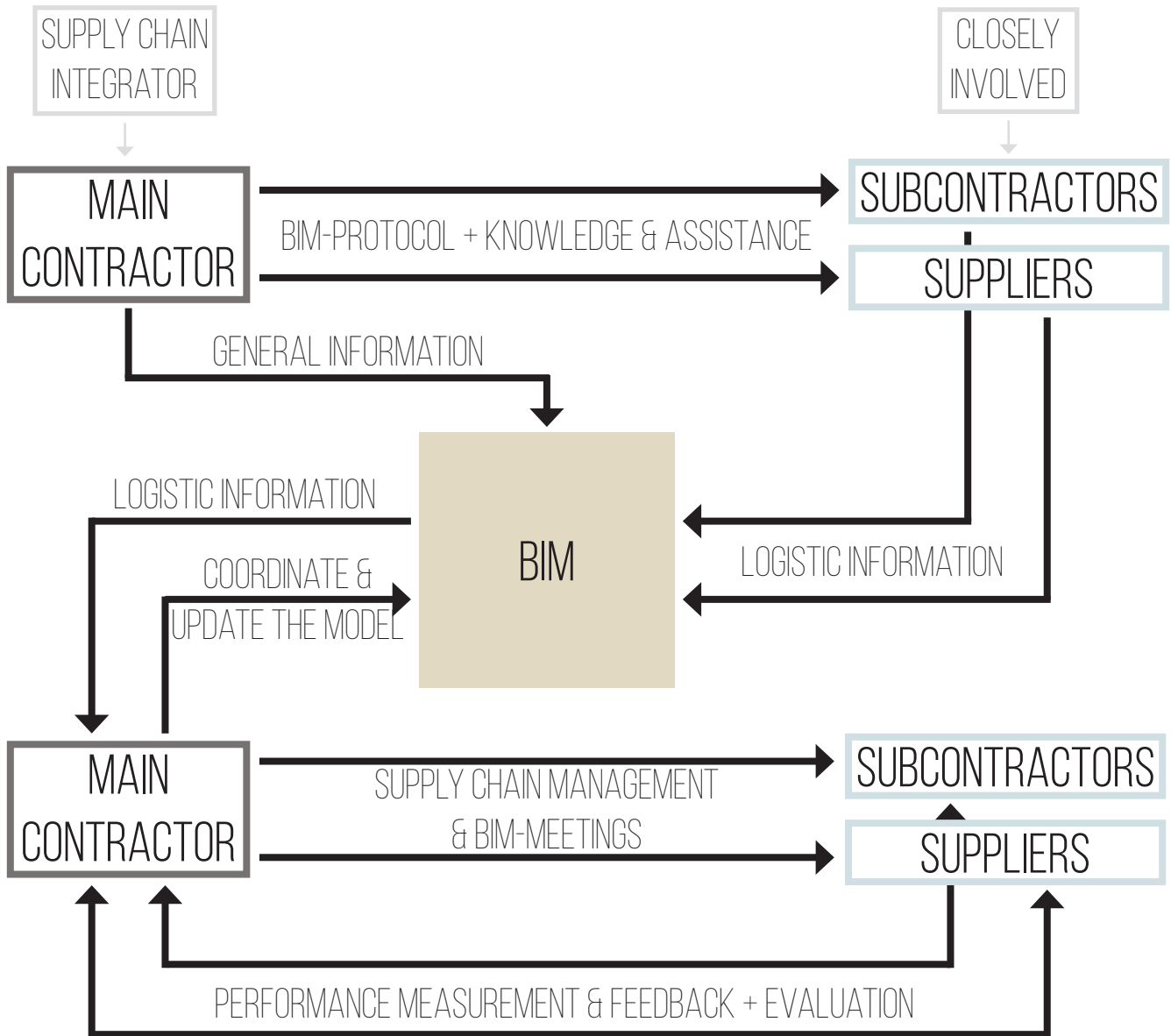


Figure II Information flows - theoretical framework (own illustration, 2017)

Next to the subcontractors and suppliers several BIM and supply chain experts will be involved in the research to give their opinion and validate the results.

V. CASE STUDY

This chapter describes the results of the empirical research. The research is conducted per phase, therefore each sub-chapter describes both the data collection and the data-analysis of one phase.

PHASE 1 - THE POSITION OF THE MAIN CONTRACTOR

The first phase of the conceptual framework takes place during the procurement phase of a construction project. This phase focuses on the position of the main contractor towards the third parties and the information the main contractor needs to provide to them.

Case study research showed that the information flow of the first phase currently consists of two main documents: the logistic agreement and the BIM-protocol. The logistic agreement is set-up by Waal and states which logistic measures will be taken during the project, how these

measures will be executed and what is expected from the subcontractors and suppliers. The BIM-protocol is also created by Waal and states the commitment and responsibilities of all parties with regards to BIM. The BIM-protocol is only send to the parties that will create their own BIM-model for the project. These parties also receive the central BIM-model of project Bètatoren, which was created by the architect. The BIM-protocol and the logistic agreement form the main part of the information flow that shows the third parties what is expected from them and how these expectations will be fulfilled. The plans and documents are set-up by Waal and quite compelling. Although there is some coordination with the third parties, everything happens on the initiative of the main contractor. Waal takes the lead and is responsible for setting up the plans, providing the right information and informing parties about their tasks and responsibilities. Even though Waal provides both information with regards to the logistics and information with regards to BIM, these documents are not linked. Therefore, BIM and the logistic information are disconnected in this phase.

In order for the main contractor to get more grip on the logistics, changes need to be made to the information flow at the start of the procurement phase. These changes aim at making the information flow smoother, making it a more coherent process and focussing more on the final use of the BIM-model. The first change concerns the logistic plan. Instead of the unilateral approach that is currently used, the main contractor should involve the third parties in the set-up of the plan. This approach will increase the solidarity amongst the parties and the plan will be supported broader because everyone is able to give input. This will make it more likely that everyone signs the final agreement and sticks to it during the construction phase. The second change concerns BIM. In order to use BIM to manage the logistics of a construction project it is important that BIM is already implemented from the start of the project. After the logistic plan has been made, the main contractor has to define what the BIM-model needs in order to use it for the management of the logistics. The BIM-model should be adapted to this, after which it is provided to the third parties. The model will be send together with a BIM-protocol that states exactly how everyone should use the model, with a special focus on the logistics. The information flow is now complete and consists of a logistic plan and agreement, the BIM-model and a BIM-protocol. They all have a focus on the logistics and are set-up by Waal in accordance with the sub-contractors and suppliers.

PHASE 2 – THE POSITION OF THE SUBCONTRACTORS AND SUPPLIERS

The second phase of the conceptual framework also takes place during the procurement phase of a construction project. This phase focuses on the role of the subcontractors and suppliers and the information they need to provide for the BIM model.

Case study research shows that there is a mismatch between the production processes and the information processes. Some information is send in a traditional way, some information is send via BIM, but none of the information is connected to the production processes of the materials and the construction site. The main contractor provides the central model to all parties that are going to use BIM. They take this model as the basis but do not check the information in it and neither does the main contractor. Out of the total logistic information, only 41% is available in BIM. The missing information is either send in 2D (planning, drawings) or not send at all because the main contractor does not use it. Also, some of the information that is present in the BIM-model is send in 2D anyway. The main contractor controls the process but does not coordinate the information, neither does anyone else. This leads to a fragmented and uncoordinated information flow.

One of the main problems is the fragmentation. This could be solved by linking the central model and the aspect models. However, to be able to link the models it is important that the input is correct. The input should be based on the IFC-standards and the BIM basis ILS to make sure all models are built the same and can be linked. The main contractor should encourage

all parties to work with BIM and provide them with knowledge and assistance. All parties focus on creating their aspect-model and the main contractor is responsible for coordinating the aspect-models and linking them all together. The third parties are responsible for providing the correct data with regards to the dimensions and other logistic information, while the main contractor is responsible for the data regarding location and planning. The main contractor is responsible for both the production processes on the construction site as the information processes. Therefore, the main contractor must make sure to coordinate both and ensure there is a match between them. This is done by coordinating the processes and guiding the subcontractors and suppliers in providing the right information in the right way.

PHASE 3 – SUPPLY CHAIN MANAGEMENT WITH BIM

The third phase of the conceptual framework takes place during the execution phase of a construction project. During this phase, the main contractor has to manage the construction of the building and has to coordinate the third parties.

The results of the case study show that the logistic information and BIM are almost completely disconnected in this phase. The main contractor does perform a quality control on the aspect-models, but since they do not fully check the coordination model there could still be a mismatch. The missing logistic information in BIM makes the model incomplete, which makes it impossible to manage the logistics from BIM. The logistic information that is present is extracted in 2D and then used to manage the actual logistics on the construction site, together with the 2D-information that was received directly from the subcontractors and suppliers. This creates an information flow that is completely disconnected from BIM.

In order to be able to manage the supply chain with BIM, the logistic information and BIM must be connected. First, the main contractor should check the coordination model of the procurement phase and compare it with the aspect-models received from the sub-contractors and suppliers. Secondly, the BIM-model needs to be linked to the planning. Adding the time factor to the BIM-model is crucial for the management of the logistics. Thirdly, the main contractor must find a way to manage the inventory. The BIM-model must include a detailed overview of the layout and the use of the construction site and a way to manage the materials. Several frameworks, such as those of Cheng and Kumar (2015b) and Chau, Anson, and Zhang (2004), have been designed for this purpose and can be linked to the BIM-model. Adding such a framework would give the main contractor better control of the material flows on the construction site. Overall, these steps should make it possible for the main contractor to manage the on-site construction logistics. However, this research mainly focussed on the management of large components. Fasteners and construction components from the shell construction phase are more difficult to manage in BIM, because we are not used to model them completely. This will be possible in the future, once contractors are familiar with 4D modelling and construction logistics management. Overall, it is important that all the information is linked to BIM and that the main contractor takes control in managing and coordinating this information.

PHASE 4 - VIEW OF SUBCONTRACTORS AND SUPPLIERS

In the fourth, and final, phase everything comes together. In this phase, the results of the changed supply chain management are visible. Because the main contractor cannot change the whole supply chain without the supply chain partners, the view of the subcontractors and suppliers on supply chain management with BIM was researched. None of the interviewed subcontractors and suppliers were supportive of the idea of overall supply chain management by the main contractor. They fear that they will lose control of their own activities and that the main contractor takes on more than he can handle. Almost the same goes for supply chain management with BIM. Apart from Calduran none of the parties had a positive view on the

use of BIM to manage the logistics. They fear that it will cost them extra time and energy, which they are not willing to spend. BIM does have some benefits but these benefits do not outweigh the costs for them.

PHASE 4 – FEASIBILITY FOR THE MAIN CONTRACTOR

Next to the view of the subcontractors and suppliers, it is important to know what the impact is for the main contractor. If changing the traditional process into a supply chain with BIM is not feasible for them, it will not be implemented. This research only focusses on the feasibility of the implementation process. The feasibility is divided in three types: financial feasibility, organisational feasibility and social feasibility. For each type, a small study was conducted based on the case study, the experience of the project team of Waal and literature.

The adoption of BIM comes with several costs. Even though the costs are substantial and should be seen as a serious investment, especially for smaller companies, this should not be a barrier. The price of the most used BIM-software packages is similar to that of common CAD-software, and if a company already uses 3D-BIM software it is a relatively minor upgrade to 4D or 5D BIM (Bryde et al., 2013). The investment should be seen in perspective with the (long-term) benefits. Especially when BIM is adopted by all parties in the supply chain these benefits will be substantial and outweigh the costs, making the adoption of BIM financially feasible.

The organisational feasibility focusses on whether it is feasible for the main contractor to coordinate the BIM-implementation process. The adoption of BIM requires a whole new organizational process, companies cannot just adopt new software, they have to adopt the new processes and organizational structures too (Hardin & McCool, 2015). BIM-adoption does require some effort and changes from an organization, however the main contractor is used to coordinate processes and if they are open to changes they can achieve a smooth implementation process and reap the benefits of BIM. Therefore, the adoption of BIM is organizationally feasible.

Finally, the social feasibility focuses on the interrelationships between supply chain partners and whether it is feasible for the main contractor to implement BIM with all the different parties. One of the ways to convince the third parties to cooperate is to show them the benefits of a BIM-process. Next to that it is important that more awareness about BIM is raised within the whole construction sector and that people improve their skills (Bryde et al., 2013). Finally, it is important that the contractor focusses on integration and communication (Khalfan, Khan, & Maqsood, 2015). For a smooth implementation of BIM, it is important that all parties cooperate and the main contractor has several options to get them to. Even though it could be difficult, the adoption of BIM is therefore socially feasible.

Overall, Joost de Korte, Dennis Adegeest and Jorg van Schadewijk all think that the implementation of BIM for supply chain management is feasible for the main contractor. Joost de Korte (personal communication, April 25, 2017) does state that it depends on the size of the project and the contractor. For large projects or large contractors, it is much easier to take the risk of implementing BIM. Dennis Adegeest (personal communication, April 24, 2017) adds to this that the implementation process should be set-by-step, giving the organizations the chance to adapt to the new situation before something changes again. In general, they all state that the adoption of BIM is worth the effort.

VI. VALIDATION

The validation is based on the experience of several BIM and supply chain experts from Dura Vermeer, Boele & van Eesteren and TNO.

As for the first phase the case study results showed that the subcontractors and suppliers

should be involved in the set-up of the logistic plan and the BIM-model. The experts slightly disagree on this. Although they emphasize the importance of cooperation, they do see the main contractor as the leader in the process who decides how the logistics will be organised. Contractors should always strive for innovation, even if it has a negative impact on the cooperation with the third parties. The negative consequences are only short-lived, on the long-term innovation will have a positive effect on their organisation.

The results of the second phase showed that the information flows were fragmented and uncoordinated. According to the experts, the main contractor is responsible for controlling and coordinating all the data. They believe contractors are able to fulfill this role. However, they must take into account that taking on such a role will cost them a lot of extra time and effort, especially in the procurement phase. They must make sure to allocate sufficient amounts of time, people and financial resources to this process. If they do not invest enough, their yield will be insufficient.

The results of the third phase pointed out that the main priority is to link the BIM-model to the planning. The experts agree that this is the way to go, but underline that it is an extensive process. They also pointed to the so-called 'people issues'. However, contractors should not be affected by resistance from their employees or third parties. Change must be seen as an opportunity to strengthen the business by aligning operations with strategy and the contractors must make sure their employees and the third parties also see it this way (Strebel, 1996). This can be achieved by, inter alia, educating them about the changes and communicating about the consequences it has for them (Kotter & Schlesinger, 2008). This will improve the implementation process and helps to make sure the adoption of BIM is supported broader within the supply chain.

The experts were also asked about their opinion on the financial, organizational and social feasibility of the implementation process of BIM for supply chain management. All experts agree that the implementation of BIM is financially feasible for the main contractor, however there are some remarks. It depends on the current BIM-level of the contractor, the amount of extra data that is needed and the logistic costs of the third parties. Overall, the experts agree that the implementation of BIM requires a serious investment of a company, however these costs will be outweighed by the benefits, especially on the long term.

The experts also agree on the organizational feasibility. The main contractor already has a coordinating role and should already be responsible for managing the processes. Therefore, not much changes when BIM is implemented. The overall conclusion is therefore that the implementation of BIM for supply chain management is organizationally feasible for the main contractor.

All experts also agree that the adoption process is socially feasible, although they are less convinced. It depends largely on the experience of the third parties and on what the contractors asks of them. They state that the main contractor should focus on showing the benefits to the third parties, once they experience those they will become more cooperative.

Overall, all experts think that the implementation of BIM for supply chain management is feasible for the main contractor. They do emphasize that the contractor must have the right people and resources. They also think that supply chain management with BIM will become mainstream in the future. The construction sector is already experimenting with 4D and 5D BIM so it is only a matter of time before they start to manage their logistics with BIM.

VII. CONCLUSION

This chapter presents the answers to the sub-questions and the main research question. The final conclusion will be presented in the form of a framework.

The hypothesis of the first phase is: "Currently the link between BIM and supply chain management is missing in the set-up of the project, which leads to an incomplete BIM-model." Case study research showed a disconnection between BIM and the logistics in the first phase. Because the responsibilities and expectations with regards to both BIM and logistics are not well defined at the start, there will be problems with the BIM-model later on because it is not clear who is responsible for which information. The hypothesis of the first phase is therefore true. The sub-question of the first phase is: "How can a main contractor prepare the third parties for a new logistic system in order to get more control in the procurement phase?" The research showed that the main contractor should involve the third parties in the set-up of the logistic plan, which should also include in what way BIM is used for the management of the logistics. Next to that the BIM-model should be adjusted for supply chain management and provided to the third parties together with a BIM-protocol. All documents should focus on the link between BIM and logistics and should be set up in accordance with the subcontractors and suppliers.

The hypothesis of the second phase is: "The fragmentation of the construction industry is the main reason for the inefficient supply chain organisation." Case study research showed that there is a mismatch between the production processes and the information processes. One of the reasons for this is the fragmentation of the construction industry. The information and material flows are not bundled but spread across different parties within the supply chain. The hypothesis is therefore partly true. The sub-question of this phase is: "What information of third parties is necessary in order to integrate logistic information in BIM software?" The research showed that the subcontractors and suppliers are responsible for the information with regards to their own materials. They have to make sure their aspect-models include all the right information with regards to volumes (including packaging), weight, storage location and all other information that is important for the logistics. The information about the location and the planning is the responsibility of the main contractor. All parties must also make sure that not only the content is correct, but that the information also complies to the IFC-standards.

The hypothesis of the third phase is: "To be able to manage the logistics with BIM, the model must include complete logistic information with regards to the dimensions, location and the planning." The results of the case study show that the logistic information and BIM are almost completely disconnected in this phase. The logistic information in BIM is not complete, which makes it impossible to manage the logistics with BIM on site, which therefore has to be done in 2D. The hypothesis of the third phase is therefore true. The sub-question of this phase is: "How does the main contractor need to use the BIM-model in order to get control of the logistics in the execution phase?" First, the main contractor should check the coordination model of the procurement phase and compare it with the aspect-models received from the sub-contractors and suppliers. These must match with each other and comply with the standards. Secondly, the BIM-model needs to be linked to the planning. Thirdly, the BIM-model must include a way to manage the inventory on the construction site. There are several frameworks that can be used to manage the on-site logistics, including the site usage and the material flows. Once this is done, the BIM-model can be used to manage the logistics. If a BIM-model needs to be used for the overall supply chain management with BIM, the model must be designed for this from the start. Also, good agreements need to be made between the main contractor and the third parties to make sure the logistics have been excogitated into the smallest details. If this is done the information flow of the logistics will be completely connected to BIM.

The fourth phase is divided in two parts: the opinions of the third parties and the feasibility for the main contractor. The first sub-question related to the fourth phase is: "How do third parties view supply chain management with BIM?" Almost none of the interviewed subcontractors and suppliers were supportive of the idea of supply chain management with BIM. They fear

that they will lose control of their own activities and that the main contractor takes on more than he can handle. They also fear that it will cost them extra time and energy, which they are not willing to spend. BIM does have some benefits but these benefits do not outweigh the costs for them.

The second sub-question is: "Is the implementation of BIM for supply chain management feasible for the main contractor?" Research based on the case study, the opinions of experts and literature research showed that the adoption of BIM for the management of on-site construction logistics is both financially, organizationally and socially feasible. The hypothesis of this phase is: "The implementation of BIM for the management of the on-site logistics is feasible for the main contractor." Overall, this research concludes that the implementation of BIM for supply chain management with BIM is feasible for the main contractor. Therefore, the hypothesis is true. However, there are a few remarks. For large projects or large contractors, it is much easier to take the risk of implementing BIM. Also, the main contractor must have the right people and resources. Finally, the implementation process should be step-by-step, giving the organizations the chance to adapt to the new situation.

Overall, the research showed that there is one main conclusion with regards to the current status of supply chain management and BIM: the logistic information and BIM are disconnected. No one takes responsibility and therefore the current information processes are fragmented and uncoordinated. There are two main reasons for this. First, the contractors have little insight in their own information processes and have a conservative attitude. Even though BIM is implemented in the company they tend to set-up the information processes in the same way as they did before BIM. Secondly, the contractors are afraid to take the risk of using BIM to manage their logistics. They have very little insight in the logistic costs of the subcontractors and suppliers, so the margin of profit is unclear. This makes them hesitant to take the risk. Although they are convinced that overall the benefits of supply chain management with BIM outweigh the costs, they are reluctant when they need to put it into practice. This results in a fragmented and uncoordinated information flow. The disconnection resulting from this makes it not feasible to manage the logistics with BIM currently. The question is then, what changes should be made to the information processes to make the implementation of BIM for supply chain management feasible? The answer to this is the answer to the main question: "How does supply chain management with BIM help contractors to get control of the logistics of a building project?" First, the main contractor must take the responsibility and control the changes in the process. The main contractor must make sure he has extensive knowledge of BIM and also have experience with modelling. He must also make sure to get insight in his own information processes and be willing to change these. Secondly, the main contractor must make sure that the information processes and BIM are connected, and that the logistic information is incorporated in both. Also, the BIM-model should be upgraded to at least 4D, by adding planning software. Thirdly, the case study research showed that the main contractor must make sure that the BIM-model aligns with the logistics on the construction site. Finally, the main contractor must also measure the performance of the third parties and provide them with feedback during the process. Based on the results of the literature study and the case study research, the final framework for supply chain management with BIM has been defined, see Figure III.

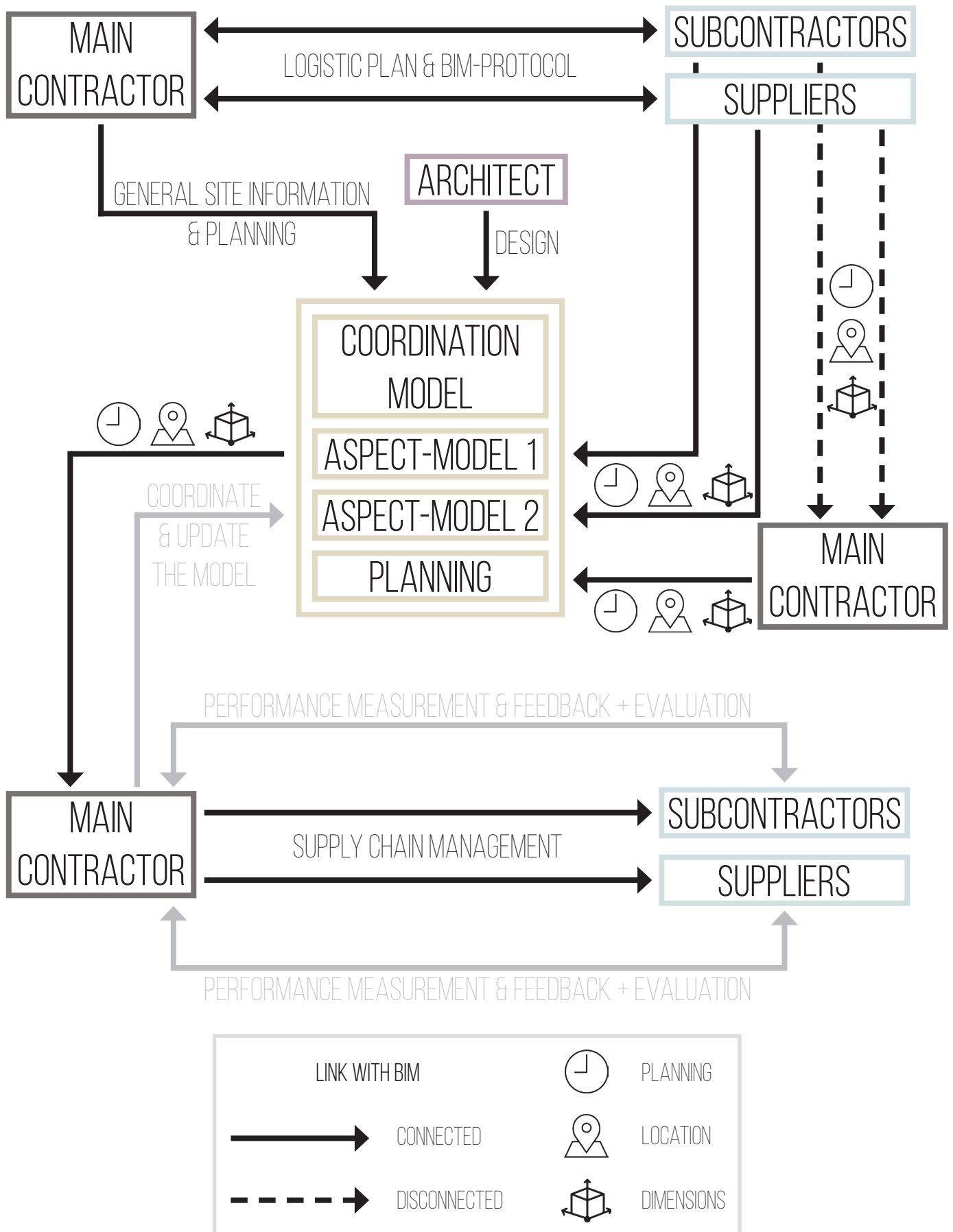


Figure III Total information flow (own illustration, 2017)

Next to the information flows, this research also focused on providing more clarity on the processes in BIM. Figure IV summarizes the structure of BIM from the design phase to the execution phase, with the goal to manage the logistics on site with BIM.

The information flows and the BIM-structure should be connected to make supply chain management with BIM feasible. Overall, both the case study research and the theoretical framework state that if the main contractor takes control, actively coordinates and structures the information flow and focusses on connecting the logistic information and BIM, he can get control of the logistics.

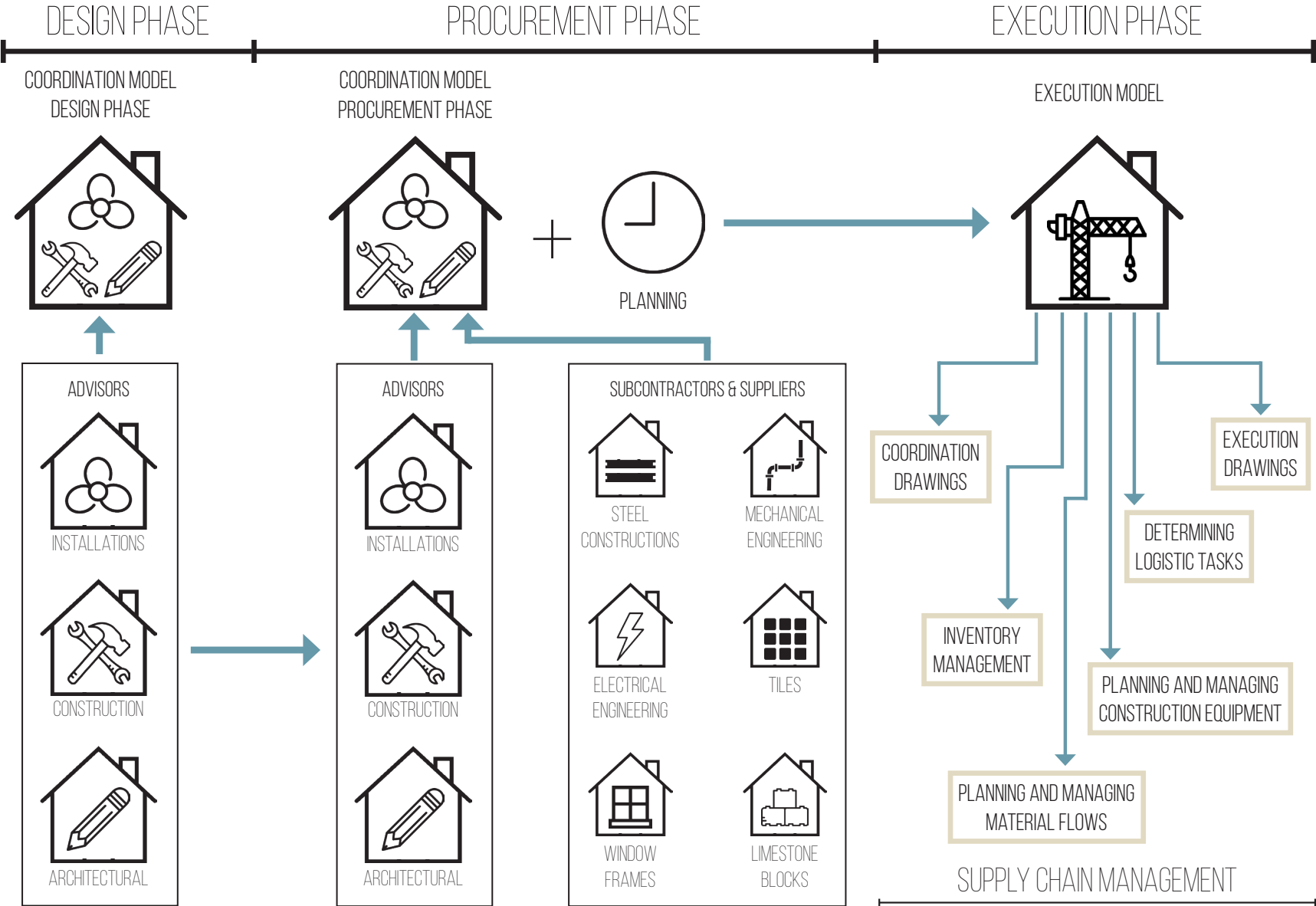


Figure IV Structure BIM-models (own illustration, 2017)

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PART I



This part of the research consists of the basis of the research. First, the background of the research will be presented, including an introduction of the research subject and the main structure of the research. Secondly, the results of the literature study will be presented, which form the theoretical framework of this research. Thirdly, the research framework will be presented. This consists of a case study protocol, which describes the set-up of the empirical research. The data collection and results of the empirical research will be described in Part II.

CHAPTER 01 | RESEARCH BACKGROUND

CHAPTER 02 | THEORETICAL FRAMEWORK

CHAPTER 03 | RESEARCH FRAMEWORK

01

RESEARCH BACKGROUND

This chapter describes the background of this graduation research. This background starts with an extensive problem analysis on the subject construct logistics and an introduction of the NWO-project, a large research led by TNO that this research is part of. Then the problem statement is presented, together with the research questions. Subsequently, the research goal and the final product will be explained. Finally, the organisation of the research will be described.

1.1 CONSTRUCTION LOGISTICS

Logistics is a common term that is used throughout all different types of industries. There are several different definitions of logistics, but most are quite alike the official definition of the Council of Supply Chain Management Professionals (2013) who state that *“Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers’ requirements”*. Basically, logistics is the organized movement of materials or people. However, several aspects need to be taken into account with logistics management.

Lundesjö (2015) describes logistics as the 'five rights', which means that logistics management is the process of ensuring that the materials or people are:

- in the right place;
- at the right time;
- in the right quantity;
- at the right quality;
- at the right price.

These definitions apply to logistics in all industries, but can be specified for specific industries. The construction industry differs from other industries because the logistics are divided in the on-site logistics and the off-site logistics. The on-site logistics focus on everything that happens on the construction site. This includes for instance the management of the materials on site, the vertical lifts, storage, walkways, the construction equipment but also the welfare of the staff. Summarizing, the on-site logistics focus on all the various site services that support the main activity: the actual construction work (Lundesjö, 2015). The off-site logistics focus on everything that happens outside of the construction site. This includes for instance the transportation of materials and their manufacturing processes. Since construction logistics mainly focus on the on-site logistics, that is also the scope of this research.

Currently, the construction logistics on and around building sites often are not well organized, especially on building sites in dense areas. This leads to several problems. Ineffective logistics management affects the efficiency of the workforce and reduces the overall labour productivity (Usman & Ibrahim, 2015). Because the employees spend a lot of time on dealing with the logistics, they have less time to spend on constructing the building. A result of this is that the average labour productivity on a building site is around 40 to 50% (Platform Logistiek in de Bouw, 2014). A large contributor to this very low percentage are the ineffective building logistics: the employees simply spend a lot of their time waiting on other people or materials (Welten, 2008). With the labour costs being approximately 60% of the total costs, contractors are largely benefited by an increase of the labour productivity (Platform Logistiek in de Bouw, 2014).

Other problems have to do with the procurement and the planning on site. These are often not well connected which results in storage problems on site. Contractors order approximately 10 to 20% more materials than needed in order to be able to deal with changes (Platform Logistiek in de Bouw, 2014). This is a problem because all these extra materials need to be transported and stored on site, which requires additional work from the employees. Also, quite often materials are ordered before they are needed so materials lay around the building site quite long and get lost or broken whereby new materials need to be ordered. All of this causes extra truck deliveries, which is bad for the environment, it contributes to the inefficient logistics and it causes higher costs for the contractors. With material costs being approximately 25% of the total construction costs, it would benefit the contractors a lot to decrease the number of materials (Platform Logistiek in de Bouw, 2014).

These examples show that there is a problem with construction logistics management. The inefficient management leads to time and budget overruns. It is assumed that one of the reasons for this inefficiency is that the main contractor does not have full control of the logistics. Research is therefore necessary to define how the main contractor can get control of the logistics. If contractors improve the management of the logistics, they could increase their overall project productivity (Usman & Ibrahim, 2015).

1.2 THE NWO-PROJECT

TNO, a large research organisation, has been researching construction logistics for several years. These research studies were mainly of smaller scale and in cooperation with companies or municipalities. An example is the research on construction logistics in urban areas, focusing

on the centre of Amsterdam (Quak et al., 2011). This research analysed the construction logistics of three cases, defined a list of logistic measures that could solve the issues and gave a recommendation to the municipality on how the construction logistics should be managed. The analysis showed that the logistics were often neglected within construction projects, leading to poor results. Possible solutions according to Quak et al. (2011) are making use of a hub, outsourcing the logistics to a third party or combining different material flows at the source. One of the main recommendations was that the construction industry should focus on becoming more standardised, because the fragmented nature plays an important role in the inefficiency of the logistics (Quak et al., 2011).

This, and other, research formed the basis of the TKI-project. In this project several companies, educational institutions and organisations worked together under the guidance of TNO to gain more practical experience about logistics. In the first round of the project one company was involved and one case was researched: the public transport terminal of the central station in Den Haag. The research analysed several logistic measures to find out which ones had the best effect on the construction logistics. Also, an analysis of the overall project and the mutual relationships between the parties was made. The outcome of the research showed that even in large, complex, urban projects the construction logistics were neglected (Dogger et al., 2012). All the subcontractors and suppliers were responsible for their own logistics and the main contractor was not able to manage all these flows. The final recommendation of the research was therefore that the main contractor should take charge by bringing the parties together, developing an integrated planning and managing the whole supply chain (Dogger et al., 2012). Making use of a hub and clustering staff transport were seen as the best logistic measures (Dogger et al., 2012).

These conclusions formed the basis of the second round of the TKI-project. The second round took place from mid-2014 until mid-2016 and focused on two cases: Hotel Amstelkwartier in Amsterdam and De Trip in Utrecht. In this round, more than ten construction companies were involved next to several colleges and the Technical University of Delft. An overview of the research was presented by Ludema and van Merrienboer (2016) and will be briefly described. The goal of this round was to conduct more in-depth research on logistic measures with a focus on 4C Control Towers. The final goal of the project is to implement a 4C Control Tower. Several logistic measures were applied to the two cases and the effects were measured by making use of key performance indicators. The results showed that the logistic measures were very beneficial. Managing the logistics with BIM and making use of a hub can lead to more than a halving of the truck rides, an increased loading capacity of the trucks and an increased labour productivity (Frazer, 2016). Using BIM also makes it possible for the main contractor to manage the materials much more efficient, which increases the time savings and decreases the amount of waste (Praat, 2016). At the end of the research, Ludema and van Merrienboer (2016) defined four important lessons for the future. The first is that the main contractor should make the benefits of logistic measures clear to the third parties in an early stage of the project. This will make the cooperation closer and makes it easier to adjust to one another. The second lesson is that a 4C Control Tower could make a large difference, but the system is not yet ready to implement. More research on for instance BIM needs to be conducted. The third lesson is that it is quite difficult to receive exact data from the cases. Measuring the KPIs was quite difficult because the involved parties often also did not have exact data. A final lesson is that the main contractor should evaluate the supply chain management at the end of the project with all third parties.

The third round of the project has started in September 2016 and builds on the former round. Within this round the organisational structure changed and the research is now led by NWO, which is the same consortium but under a new name. The focus is still on developing a 4 Control Tower but also on conducting more research on different measures that could help to

get more control of the logistics, such as an Urban Consolidation Centre (UCC) or BIM. This graduation research is part of the NWO-project and therefore contributes to retrieving data for this project.

1.3 BIM

There are several measures that can be taken that could help the main contractor to get more control of the construction logistics. One of these measures is Building Information Modelling (BIM). According to the National Building Information Model Standard Project Committee (2015) BIM is defined as *“a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onward. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder”*. This basically means that BIM is a 3D-database that includes all the data of a building, from the pre-design until the operations & maintenance phase. It is important to note that BIM is not just software; it is a process and software (Azhar, 2011). BIM is not only about using 3D-models but also requires significant changes in the workflow and project delivery processes (Hardin & McCool, 2015).

BIM-software can integrate logistic information with computational models and supports companies in managing their supply chain. BIM is currently mainly used in the design phase of a building project. However, one of the strengths of BIM is that it combines the data of all stakeholders into one 3D-model. This makes it very suitable to also use it for logistics. On the other hand, extra software might be needed to implement factors such as planning and location in the BIM-model. Research of Irizarry, Jalaei, and Karan (2013) has shown that one option is to integrate BIM with GIS (geographic information systems), making it possible to manage the logistics of a building project. Other research has shown that BIM can be used for material logistics planning (Cheng & Kumar, 2015b).

Next to additional research on the technical aspects of using BIM for logistics management, more research is also necessary for the organisational aspects. Information management is an important part of supply chain management and BIM could be a tool used to streamline the information flows (Bouwend Nederland, 2014). However, it currently is very difficult for a main contractor to get a grip on the information flows. BIM is seen as a black box that needs certain input from the main contractor and will provide certain output. How the main contractor should manage this is not defined yet. Therefore, this research focusses on how the main contractor should manage the logistics of a construction project with BIM.

1.4 PROBLEM STATEMENT

Currently, construction logistics are quite inefficient. This leads to both off-site problems, traffic jams and environmental pollution, and on-site problems: a low labour productivity and time and costs overruns. This research focusses on the on-site problems. It is assumed that one of the reasons for the inefficient construction logistics is that contractors do not have full control of their logistics and that full control would make their logistics more efficient. For this research, it is also assumed that BIM can help contractors to take control of their logistics. Currently, the logistic information is spread over different phases and different people, which do not connect well to each other. There is a gap between the procurement phase and the execution phase, and the logistics are often planned just before the start of the construction. Logistic information, such as information about materials or the site layout, is often not transferred properly. This happens both internal, between the project planners and the construction supervisor, and external: between the contractor and the subcontractors and suppliers. Information management could therefore help to streamline

the logistic information. BIM-software can integrate different types of information and can therefore be used as a tool to streamline the information flows and help contractors to get better control of their construction logistics. It is important to note that this research does not claim that BIM is the only option that could make construction logistics more efficient. There are other alternatives, however since previous research has shown the positive effects of BIM and additional research on the link between BIM and logistics is needed, this is the tool selected for this research. Therefore, this research focusses on how the main contractor can get control of the construction logistics by using Building Information Modelling. The scope of this research is limited to on-site construction logistics, of which all aspects are included: from information take-off to time-, site- and materials planning.

Within this research, several research subjects are combined, such as supply chain management and Building Information Modelling. There is a lot of research available on all of these subjects, however most literature focusses on one or two aspects instead of on the whole logistics. Peltokorpi and Seppanen (2016) examined several papers on construction logistics and concluded that some subjects, such as delivery reliability, have been extensively studied while other subjects, such as labour productivity, are still underexposed. This is also the case in research on using BIM for logistics management. Research such as that of Cheng and Kumar (2015b) and Bortolini, Formoso, and Shigaki (2015) shows how BIM can be used for site logistics and material logistics, but they both give little attention to labour productivity. Bryde et al. (2013) are one of the few to mention the human aspects of implementing BIM but leave out other aspects. This research aims at closing the gaps of the current research by focusing on all aspects of the logistics. Next to that it focusses on retrieving additional data for the NWO-project.

1.5 RESEARCH QUESTIONS

This research wants to explore how contractors can get control of the logistics of a building project with the use of BIM, therefore the main research question is:

How does supply chain management with BIM help contractors to get control of the logistics of a building project?

The main research question consists of two parts: the first part focusses on how the main contractor should set-up the supply chain processes with BIM and the second part focusses on the acceptability by the third parties and the feasibility for the main contractor. The research is conducted from an organisational perspective. The focus is on how to organise the supply chain of a construction project with BIM in such a way that it gives the main contractor control over the logistics. Figure 1.1 shows the conceptual model of the research.

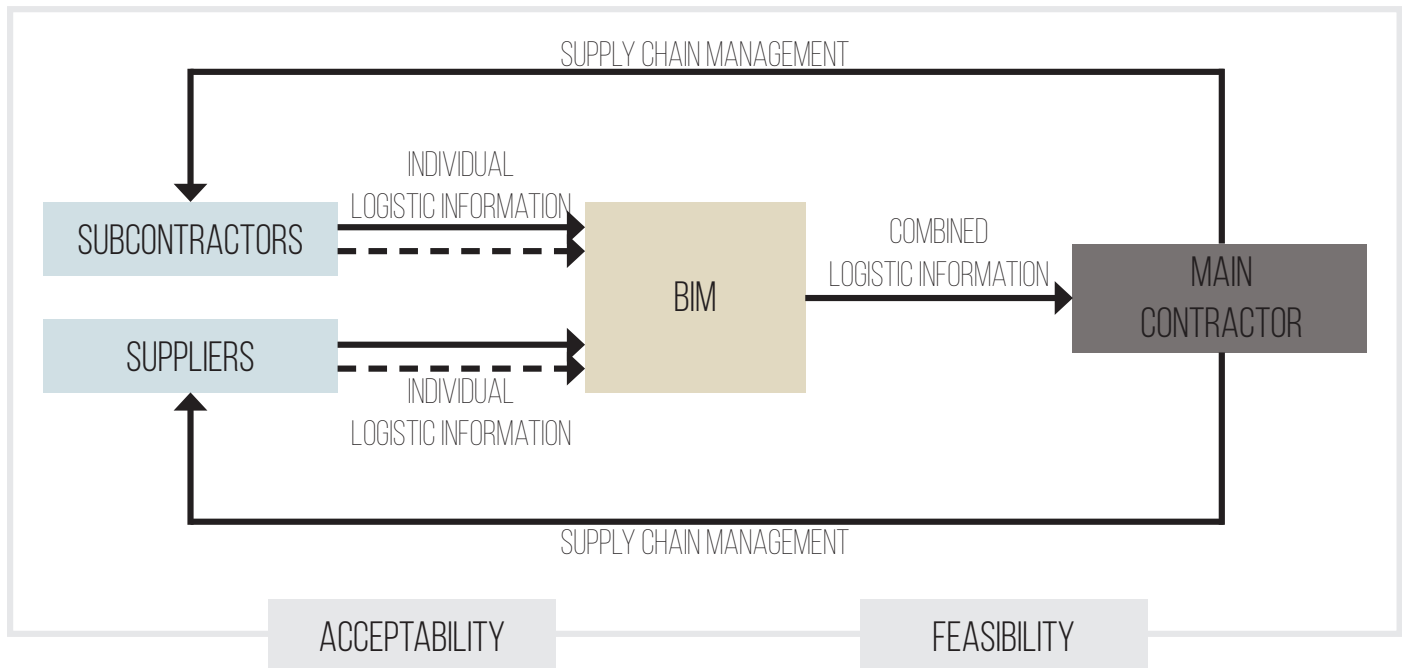


Figure 1.1 Conceptual framework (own illustration, 2017)

The model shows the information flows necessary for logistics management with BIM. The research focusses on all these individual information flows to see how they should be organised in order to manage the logistics with BIM. Also, the acceptability and the feasibility of the whole organisational model will be assessed together with the expected effects. The sub-questions that are presented next reflect these different parts of the research.

1. How can a main contractor prepare the third parties for a new logistic system in order to get more control in the procurement phase?

This sub-question is derived from the first phase in which the main contractor has to prepare the third parties for logistics management with BIM. The goal is to find out what the input of the main contractor to the third parties needs to be.

2. What information of third parties is necessary in order to integrate logistic information in BIM software?

This sub-question is derived from the second phase in which the main contractor needs certain output from the third parties to fill the BIM-model. The goal is to research what this information needs to be and how it should be implemented in BIM.

3. How does the main contractor need to use the BIM-model in order to get control of the logistics in the execution phase?

This sub-question is derived from the third phase in which the main contractor gets certain output from BIM and uses this to manage the logistics and the involved third parties. The goal is to find out what information can be extracted from BIM and how this information can be used to manage the on-site logistics.

4. How do third parties view supply chain management with BIM?

The fourth sub-question focusses on the fourth phase, which is the final phase. In this phase,

the circle is completed and the main contractor manages the logistics with BIM. The goal of this question is to provide an overview of the opinions of subcontractors and suppliers on supply chain management with BIM.

5. Is the implementation of BIM for supply chain management feasible for the main contractor?

The final sub-question also focusses on the fourth phase. The goal of this question is to assess whether the process of adopting BIM for the management of the on-site logistics is feasible for the main contractor. This is researched by an assessment of the views of the project team of Waal and literature research.

1.6 RESEARCH GOAL & FINAL PRODUCT

The objective of this research is to show contractors how they can get control of their logistics with BIM. The first part of the research focusses on how main contractors should set-up their supply chain processes with BIM. The corresponding product is a framework that contractors can use to change their logistic organisation in such a way that they can use BIM. This framework is built up from several parts, consisting of the final products of the first three sub-questions and the results of the literature study.

The second part focusses on what the feasibility is of the implementation process of BIM for the management of the on-site construction logistics. The corresponding product is an extensive assessment of the financial, organisational and social feasibility of this process.

The final framework shows how the main contractor should organise both the information processes and the BIM-model in order to successfully manage the logistics with BIM.

1.7 RESEARCH ORGANISATION

This MSc thesis research is carried out within one of the four domains of the master Management of the Built Environment: Design & Construction Management. This is shown by the focus on the organisational and managerial aspects of the supply chain. The focus on BIM is part of the second domain, which is a combination of Architectural Engineering, a domain of the master Architecture, and the fundamental Building Informatics which is part of the master Management of the Built Environment.

The first mentor is Ruben Vrijhoef from the department of Design & Construction Management. He is largely involved in the NWO-project and arranged this research to be a graduation topic. His experience with this subject forms the basis for the research that is proposed.

The second mentor is Alexander Koutamanis from the department of Architectural Engineering. He is also involved in the department of Design & Construction Management, mainly on the subjects computational design and information management. His knowledge of BIM complements the research.

The graduation company for this research is Waal, a contractor that is based in Vlaardingen. The case of this research is project Bètatoren, one of the housing projects of Waal. The project leader of this is Joost de Korte, who is also the supervisor during the internship.

02

THEORETICAL FRAMEWORK

The following chapter provides the results of an in-depth literature study that was conducted and presents the theoretical framework of the research. The literature study answers the main research question with a theoretical framework, which will function as the basis for the empirical research. Furthermore, it follows the phases of the conceptual framework that was presented in Figure 1.1. For each phase, a literature study was conducted and all together they provide a theoretical answer to the main question.

2.1 WHY BIM?

This research focuses on BIM as a tool to manage the logistics and exchange information with, in order to improve the logistics of a construction site. But why BIM, if there are several other measures a main contractor can implement to improve the logistics? This paragraph compares four large measures that are derived from previous research by TKI: making use of an Urban Consolidation Centre for the storage of materials, making use of BIM to organize the logistics, combining the traffic flows of employees and outsourcing the logistics to a logistics service provider. These measures were chosen because they are quite large, it takes time and effort to implement them, there are extra costs involved and the benefits are not

always clear. Each measure will be assessed on the following aspects: costs, benefits, impact on the main contractor, impact on the third parties and the applicability in various projects. In the end, it will become clear why BIM was chosen for this research.

2.1.1 URBAN CONSOLIDATION CENTRE

An Urban Consolidation Centre, or UCC, is a widely-used measure to improve logistics. UCC's are mostly used in dense areas, where there is no room for storage in the construction site. Suppliers deliver the materials to the UCC and the main contractor can then deliver them in the construction site just in time (Dogger et al., 2012). An UCC has several benefits: the travel time of the supplier decreases, there is a reduction in the waste of materials, the reliability of deliveries increases and so does the labour productivity of the construction workers (Ludema & de Vries, 2012). An UCC, however, is quite expensive. The building needs to be rented and secured. Also, logistic employees need to be hired to manage the UCC. Therefore, an exact cost-benefit analysis cannot be provided, as it is very project specific. Ultimately, it depends on, inter alia, the size of the UCC, the type of materials and the distance from the UCC to the construction site and the suppliers (Burlat, Faure, & Marques, 2015). Moreover, there is quite some impact on the main contractor as there is the need to arrange the UCC and manage the deliveries from the UCC to the construction site. With regard to third parties, the impact is very low, because for suppliers it does not matter whether they deliver the materials on site or on the UCC. Even though an UCC can be implemented in various projects, it is best used for projects in dense areas where there is a difficulty in access by freight traffic. However, an UCC can be combined with other logistic measures.

2.1.2 BIM

BIM is widely used as a tool for design management but is currently not yet common as a tool for supply chain management (Salazar, Mokbel, Aboulezz, & Kearney, 2006). However, it can be used to manage the information and material flows of a construction project (Papadonikolaki, Vrijhoef, & Wamelink, 2016). Isikdag, Aouad, Underwood, and Wu (2007) also state that BIM is very promising as a facilitator of integration, interoperability and collaboration. Using BIM has a lot of benefits for a project. According to Bryde et al. (2013) the use of BIM improves the overall coordination of the project and it improves the communication between the involved parties. The costs of BIM-software are similar to that of common CAD-software so it is accessible for all companies and projects. Nonetheless, BIM does not always cooperate well with other software for scheduling or supply chain management (Salazar et al., 2006). The impact of implementing BIM on the main contractor does differ. If the main contractor already uses BIM in the procurement phase, it is a relatively small step to add logistic software to the model. If the main contractor does not use BIM at all, this step is quite big. This also applies to third parties, as they might need to learn how to work with BIM software or have to provide extra information for the model.

2.1.3 CLUSTERING STAFF TRANSPORT

The transport of construction employees to the construction site accounts for the largest amount of transport movements belonging to a construction project (van Merrienboer, 2013). Vans can take up a lot of parking space around the construction site, which can be a problem, especially in dense areas. Combining the employees at one central point (an UCC or train station) and transporting them together to the construction site, saves a lot of commuting vans. Yet employees might need to bring tools with them, making it impossible in public transport (Quak et al., 2011). A solution, could be the placement of a small material container on the site for the storage of tools. This measure provides a very low impact on the main contractor, but a high impact on third parties. The third parties need to rearrange their transport and must be willing to do so (van Merrienboer, 2013). This measure can be applicable to all projects making use of an UCC or which are easily accessible by public transport.

2.1.4 OUTSOURCING

This measure concerns the complete outsourcing of the off-site construction logistics to a fourth party. The logistics provider can take care of the clustering of materials and provide fully loaded trucks just in time on the construction site (Dogger et al., 2012). Hence, decreasing the amount of truck rides and increasing labour productivity. The costs of outsourcing, however, are quite substantial. It depends on the size of the project and the logistics provider but outsourcing is a very costly measure. It does relieve the main contractor of all off-site logistic tasks and therefore has a very low impact on him. For third parties, the impact is quite high. It would relieve them of all the logistic tasks, which is very beneficial, however no more revenue in transport would exist. Also, they would have to rearrange their current material transport system to the new one. This measure is applicable to all projects, however there must be a logistics provider willing to take the job. This will be mainly the case with large projects.

2.1.5 CONCLUSION

Figure 2.1 shows the results of the logistic measures assessment. All measures are scored on the different aspects with 1 being the worst score and 5 being the best. Note that for costs and impact, a low score means high costs or impact, while for benefits and applicability, a low score means low benefits or applicability. Figure 2.1 shows that BIM is the best option because it provides high scores on all aspects. The use of an UCC is also a good option. On the other hand, the clustering of staff transport and outsourcing the logistics score quite poorly. In the case of outsourcing this is mainly due to the high costs, while for the clustering of transport it is mainly due to expected lack of cooperation from third parties.

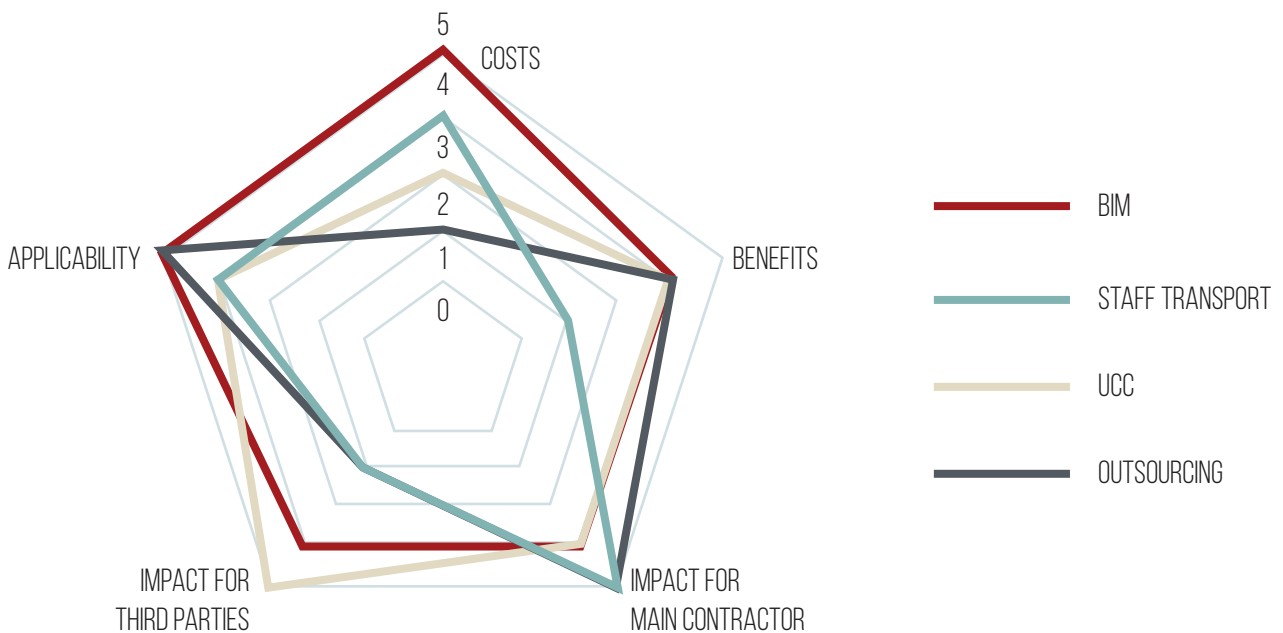


Figure 2.1 Overview of logistic measurement assessment (own illustration, 2017)

Because BIM is a very comprehensive tool that can be used to streamline the information flows and is relatively easy to implement, due to the low impact for all involved parties and the low implementation costs. Therefore, it was chosen as the focus of this research. This research focusses on BIM as a tool that streamlines the information flows and helps the main contractor get better control of the on-site construction logistics. The technical features of BIM are not included in the scope of this research. Although this research focusses solely on BIM, contractors could also decide to implement a combination of measures such as BIM and a UCC. BIM can easily be combined with other logistic measures, depending on what the contractor wants to achieve. The following paragraph provides a more comprehensive

overview of the current research on BIM.

2.2 THE BENEFITS AND BARRIERS OF BIM

As described in the introduction, BIM is a very comprehensive tool that can be used from the pre-design phase until the operations & maintenance phase. A lot of research has been conducted on the benefits of BIM for construction projects. Bryde et al. (2013) analysed 35 construction projects that used BIM to see which positive and negative benefits were obtained. The results showed that out of the positive benefits 'cost reduction or control' and 'time reduction or control' were the most frequent. Other positive benefits that occurred in at least a third of the projects were an improvement of the communication, an improvement of the coordination and an increase or control of the quality (Bryde et al., 2013). The main negative benefit, which occurred in 20% of the projects, were software issues. In some projects there were interoperability issues between different BIM-packages (Bryde et al., 2013). One of the main challenges is therefore solving the technical issues of BIM. Another challenge defined by Bryde et al. (2013) are so-called 'people issues'. These are issues concerning people having to agree to certain software, cooperate with each other while sharing their data and being willing to gain the knowledge needed to work with BIM. These results are confirmed by Yan and Damian (2008), who conducted a survey on the benefits and barriers of BIM with 70 construction professionals. They also found that the main benefits are reductions in the time and costs of a construction project. The main barrier that resulted from their study is also related to people. Companies were hesitant to implement BIM because they believe it would cost them lots of time and human resources to give all the employees the proper training (Yan & Damian, 2008). Yan and Damian (2008) also stated a lack of case study evidence proving that the use of BIM also saves costs, which makes companies reluctant when it comes to implementing BIM.

Next to the overall benefits and barriers of BIM, it is important to research the benefits and barriers that are related to supply chain management and logistics. One of the keys of successful supply chain management is the cooperation between the supply chain partners. Mondrup, Karlsøj, and Vestergaard (2012) conducted research on the use of BIM as a platform for communication and collaboration. They found that the key benefits were that BIM improves the project communication, it creates constant communication and it helps stakeholders to collaborate more effectively and more accurately (Mondrup et al., 2012). These findings are underlined by Isikdag et al. (2007) who state that BIM is very promising as a facilitator of integration, interoperability and collaboration. These benefits are of course very useful in supply chain management because for an efficient supply chain it is important that all parties communicate and collaborate closely with each other. However, Mondrup et al. (2012) encountered challenges such as the fact that BIM adoption requires extensive training and preparation of the employees and the fact that BIM implementation requires an integrated approach which combines technical structures with social practices. Hence showing that the challenges are mainly related to people. Furthermore, Papadonikolaki et al. (2016) conducted parallel research on BIM and supply chain management resulting in non-mutual dependency. It is important to note that BIM can support supply chain management by facilitating the management of both information and material flows. At the same time the informal supply chain setting can facilitate the BIM adoption process by offering a more trusting environment for collaboration (Papadonikolaki et al., 2016). This is confirmed by Salazar et al. (2006) who state that the use of BIM improves the communication process between different stakeholders and facilitates further coordination. However, BIM does not always cooperate well with scheduling or supply chain management software (Salazar et al., 2006).

The link between BIM and scheduling software is very important for the management of the logistics. In order to manage the logistics on site, the BIM-model needs to be linked to the

planning in order to create a 4D model. Bortolini et al. (2015) conducted research on the use of 4D BIM for planning and controlling the logistic operations on construction sites. The results showed the importance of using a hierarchical approach. The BIM-model becomes more detailed throughout the process. The results also showed that the use of 4D-BIM had a positive effect on the logistics because it supported the increase of the assembly productivity, reduced the inventories and helped to streamline the material flows (Bortolini et al., 2015). Cheng and Kumar (2015b) also conducted research on BIM and logistics planning. Their focus was on the planning of materials. They created a BIM-framework that can be used to manage the material logistics and site layout of a construction project (Cheng & Kumar, 2015b). This system helps contractors to take control of their logistics by allowing them to plan ahead and anticipate foreseen delays. The framework also improves the coordination between subcontractors and suppliers.

Overall, the literature research shows that BIM is an emerging tool that can be used throughout the whole life cycle of a building. Several different researches describe the key benefits of BIM which vary from a reduction in time and costs, to improved communication and collaboration. The main barriers are related to people having to change their common processes. BIM offers the possibility to link the model to the time planning, which enables planning and controlling logistic operations on construction sites. This seems very promising because research has shown that the use of BIM has several positive effects on the logistics, such as reduced inventories and better control of the material flows.

2.3 PHASE 1: THE POSITION OF THE MAIN CONTRACTOR

The first phase of the conceptual framework takes place during the procurement phase of the construction project, as shown in Figure 2.2. During this phase, the main contractor has to decide what logistic measures to take and how to organise the supply chain. He must also contract the subcontractors and suppliers, and prepare them for the logistic organisation.

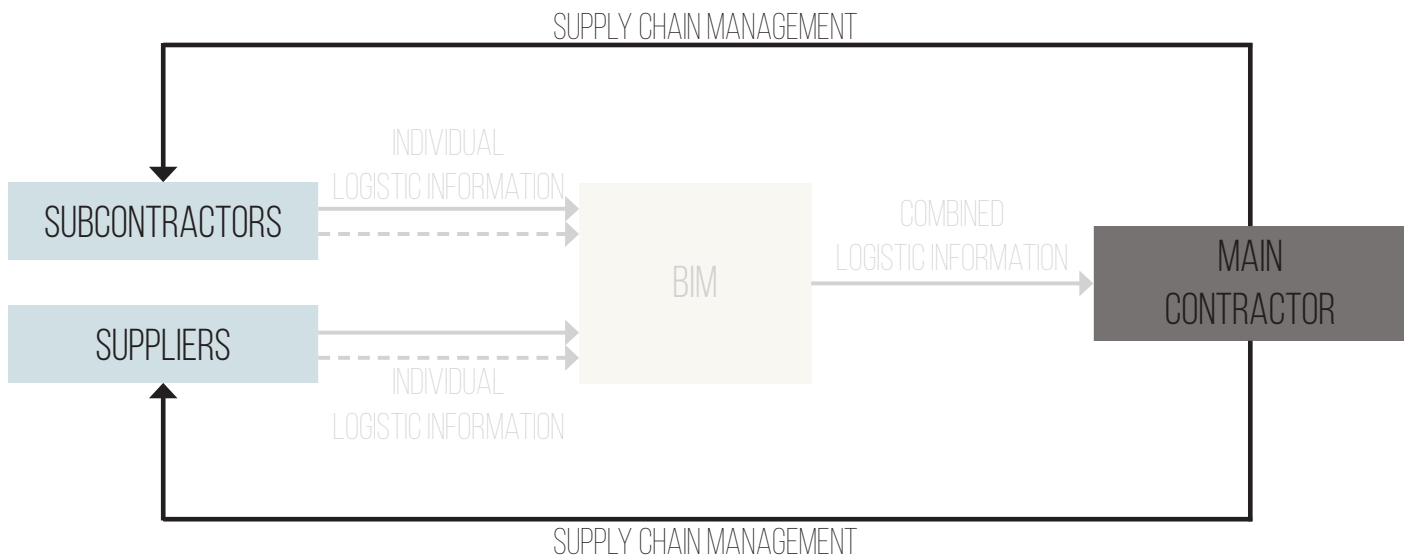


Figure 2.2 Phase one (own illustration, 2017)

Phase one focusses on the position of the main contractor. The first part focusses on the role of the main contractor in the supply chain, in relation to the other parties. The second part is about defining what kind of information a main contractor needs to provide to third parties in order to implement BIM in the supply chain. These two parts reflect the output from the main contractor to third parties as depicted by the black arrows in Figure 2.2.

2.3.1 THE MAIN CONTRACTOR AS THE SUPPLY CHAIN INTEGRATOR

According to Mentzer et al. (2001), supply chain management can be defined as *“the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole”*. Supply chain management has been successfully applied to several industries such as the retail, aviation and shipping industry (Akintoye, McIntosh, & Fitzgerald, 2000). However, the construction industry has been slower accepting the concept. This, because it differs from the other industries on some important aspects. First of all, the products of the construction industry differ from other industries. The standardization, repetitiveness and interchangeability of buildings are lower in the construction industry than in other industries (Noordhuis & Vrijhoef, 2011). Second, the construction industry is characterized by its informal nature, the large variety of informal structures and the project-driven focus (Noordhuis & Vrijhoef, 2011). The construction industry supply chain is very fragmented, while the supply chain of other industries is centrally controlled. It is, however, possible to apply such a structure to a construction supply chain. In most construction projects the main contractor is the focal firm in the supply chain, also known as the ‘system integrator’ who takes control of the integrated supply chain (Vrijhoef, 2011). The main contractor, as a system integrator, needs to integrate the whole supply system which includes economical, organisational and social aspects (Vrijhoef, 2011). The tasks of the main contractor in this role are twofold. On one hand, the tasks consist of the activities leading to the preparation of the production on site, involving construction clients and the design team (Akintoye et al., 2000). On the other hand the tasks consist of the activities regarding the delivery of construction products involving construction suppliers and subcontractors (Akintoye et al., 2000). Kanji and Wong (1998) underline that it is a difficult task for the main contractor due to the complicated nature of the industry. They do, however, also state that supply chain management in construction, together with total quality management, can solve the problems in the construction industry and lead to good results. Wong (1999) adds to this that as a system integrator the main contractor should develop an enabling structure and efficient communication system for effective relationship management. Next to this, the main contractor must promote collaborative behaviour from the suppliers and subcontractors in meeting quality objectives and must continually assess his relationships with the other supply chain members (Wong, 1999).

All aforementioned tasks apply to the main contractor in the first phase of the supply chain cycle. The main contractor must function as the system integrator and carry out the related tasks. He has to take control of the supply chain and the information flows within it.

2.3.2 INFORMING THE SUPPLY CHAIN PARTNERS ABOUT BIM

The former paragraph discussed the role of the main contractor as a system integrator. All tasks mentioned are conceived to improve the supply chain. In the case of managing the logistics with BIM there are some extra tasks that need to be carried out by the main contractor. This paragraph provides an extensive overview of the tasks a main contractor has to carry out as being the system integrator of a supply chain with BIM.

The first thing a main contractor needs to do is informing the third parties while contracting them, as they must know beforehand to what extent BIM will be used. Research of Papadonikolaki et al. (2016) has shown that the use of BIM does not largely influence the choice of third parties. Non-BIM users can easily join the project by following a traditional process or learning how to work with BIM on the job. The main contractor does need to make clear which parties use BIM for design development and which parties only use BIM for design communication (Cidik, Boyd, & Thurairajah, 2014). It is also useful for the main contractor to define to what extent the third parties are experienced with BIM. This can be

assessed by the use of a maturity model. With a BIM-maturity model an organisation can be assessed on the implementation of BIM on several levels (Siebelink, Adriaanse, & Voordijk, 2015). Stopel (2016) has compared several maturity models for BIM and concluded that the model of Siebelink et al. (2015) is the best fit for companies in supply chain management. When the parties are selected, the main contractor has to design a BIM-protocol and provide it to the third parties. This protocol is used to define the BIM-process, describing for instance the BIM-related project goals, modelling stages, deliverables and agreements for meetings (Papadonikolaki et al., 2016). Papadonikolaki et al. (2016) also state that BIM implementation requires close collaboration among multi-disciplinary professionals so it is advisable for the main contractor to organize several BIM meetings throughout the project where all parties can discuss their progress with a BIM-coordinator.

2.3.3 CONCLUSION

The main contractor is the start of the supply chain cycle as shown in Figure 2.2. In the first phase the main contractor must provide certain output to the supply chain partners. Since the main contractor is the focal firm, he takes on the role of the supply chain integrator. In that role, the main contractor must manage the supply chain together with the information flows within it. The main contractor must actively lead the supply chain and demand collaborative behaviour from the supply chain partners, in this case the subcontractors and suppliers.

Additionally, there are also a few aspects that are important for a main contractor to prepare third parties for logistics management with BIM. The main contractor must provide a BIM-protocol that describes the BIM-process together with what is expected from the third parties. The main contractor should also provide knowledge and assistance to parties that are less experienced with BIM. Several research studies, including Khalfan et al. (2015) and Mondrup et al. (2012), state that communication is key in BIM-implementation. The main contractor must have an integrated approach that combines technical structures with social practices.

2.4 PHASE TWO: THE POSITION OF THE SUBCONTRACTORS AND SUPPLIERS

The second phase of the conceptual framework, Figure 2.3, also takes place during the procurement phase of a construction project. During this phase, the role of the subcontractors and suppliers is defined. Based on their role and tasks they must provide certain information. This information forms the input for the BIM-model with which the logistics can be managed.

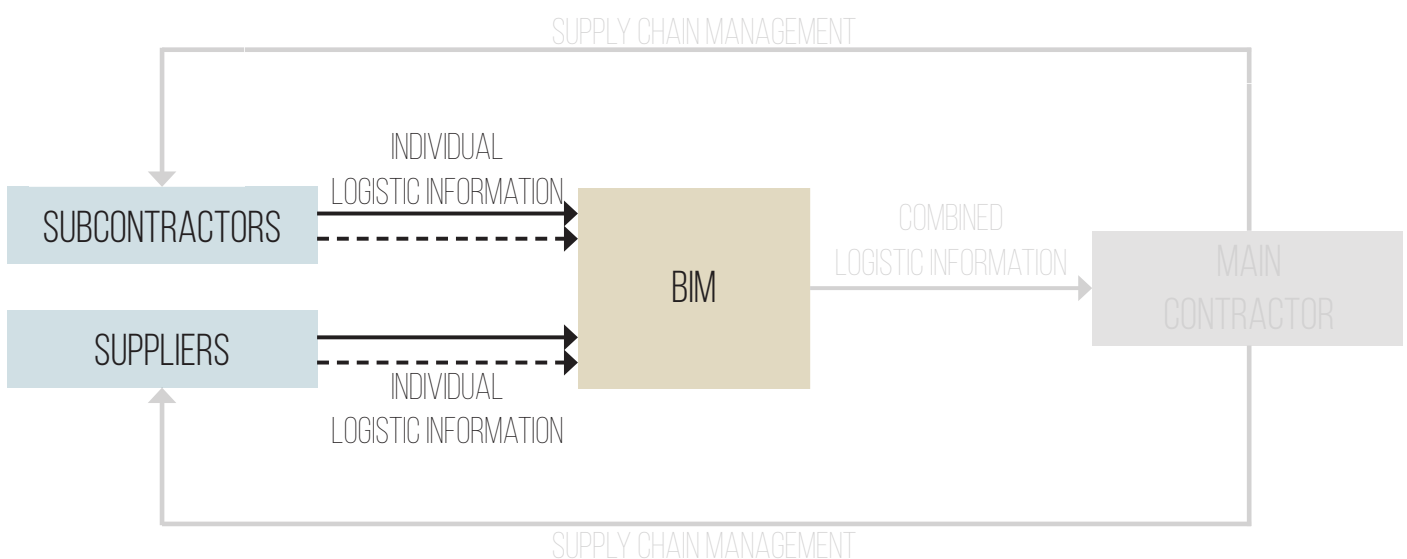


Figure 2.3 Phase two (own illustration, 2017)

The literature study for this phase focusses on the position of the subcontractors and suppliers in the supply chain. As explained before, the construction industry is very fragmented and partly therefore slow in adapting new ways of supply chain management. Some other industries that also deal with a lot of third parties, however, do manage to apply a more efficient supply chain structure. Examples of this are the aerospace industry and the shipbuilding industry. The construction industry could learn from these, and other industries (Vrijhoef, 2011). Below, two cases focusing on the position of the subcontractors and suppliers are analysed. One in the aerospace industry and one in the shipbuilding industry. These analyses show the best practices that could be used in the construction industry.

2.4.1 AIRBUS

Airbus is one of the leading companies in the industry of aircraft producers. They are responsible for designing and producing the Airbus A380, the largest airliner that is currently in use (Airbus, 2016a). For production, Airbus makes use of a lot of different suppliers. To streamline this, the supply chain is divided in several platforms. Airbus has multiple production sites on different locations, each being responsible for a specific part of the airplane (Airbus, 2016b). The supplies needed are sent to the production site where they are assembled. If needed, the part will then be brought to another production site where it is then placed in a larger part. When all parts are finished, they are transported to Toulouse, France, where they are assembled and the whole plane goes through final tests (Airbus, 2016b).

One of the strengths of this supply chain is the modularity. Every aircraft type consists of its own established modules that are produced exactly the same every time. This approach incorporates significant commonality and the aircrafts can be built on a common assembly line (Airbus, 2016b). Modular design and production could also be the basis for an improved supply chain in construction (Voordijk & Vrijhoef, 2003). The different parts of a building could be prefabricated and assembled on site. The main difference, and difficulty, is that the assembling location differs per project while Airbus can use the same assembly hall for every aircraft (Voordijk & Vrijhoef, 2003). This type of production highly depends on the subcontractors and suppliers. Therefore, these parties are largely involved in the design and production (Johnsen & Lewis, 2009). Because of the close collaboration with each other, the partnerships in this type of supply chain are often long-term. The suppliers and subcontractors receive a lot of responsibility but often also share in the risk (Johnsen & Lewis, 2009). These interdependencies strengthen the relationship between the client and the third parties.

Within Airbus' system, each supplier has its own task. All suppliers work in parallel, communicating a lot with Airbus but not with the rest of the suppliers (Vrijhoef, 2011). Airbus is responsible for making sure that all the parts are delivered at the right place and at the right time. They have an electronic system which makes it possible for Airbus and the suppliers to exchange information. This system enables both parties to place orders, manage the orders, exchange documents, etc. (Vrijhoef, 2011).

The position of the suppliers and subcontractors in the case of Airbus can be summarized as follows: the suppliers and subcontractors have a lot of responsibility while the large parties share in the risk. They can do so since they are involved from an early stage and have a large influence in the design. Each supplier then focusses on its own product while having little communication with the other suppliers. They are responsible for their own information exchange and for the quality of the final product. Airbus is responsible for the logistics, getting the product at the right place at the right time.

2.4.2 DAMEN SHIPYARDS

Damen is one of the leading companies in the shipbuilding industry. They build all sorts of

ships, from tugs to large freight ships and luxury yachts. The company operates worldwide, owning 32 shipyards in different continents (Damen, 2015). Similar to the aerospace industry the shipbuilding industry deals with a lot of different suppliers. Damen employs the same method as Airbus, where they have several suppliers responsible for a specific part of the ship and the whole ship is then assembled in one place (van Dijk, 2009). This structure is representative for most supply chains in the shipbuilding industry (Wei, 2012). The difference with Airbus is that at Damen much of the engineering, work preparation, purchase and logistics is done at the main location in Gorinchem, the Netherlands (van Dijk, 2009). However, the actual assembling of the ship is done at the yard closest to the final destination of the ship.

Damen is known for introducing modular production in the shipbuilding industry (Damen, 2015). Similar to Airbus, they have developed standard designs for each type of vessel. These standard vessels can be equipped with a large range of options and be modified to meet the customer's wishes (Damen, 2015). What is also unique about Damen, is that they also have vessels in-stock. Instead of only producing on contract-basis, they also have finished vessels of their standard designs in-stock at different ship yards across the world. This highly increases their delivery time, allowing them to immediately deliver when an order arrives.

Because of the dependency on subcontractors and suppliers, it is important for Damen to have a good relationship with these parties. To make sure the final product meets all quality standards, the subcontractors and suppliers are involved from the engineering phase (Fennema, 2014). Suppliers and subcontractors go through a very thorough selection process before they are contracted and are often engaged in long-term partnerships (van Dijk, 2009). The relationship between Damen and the subcontractors and suppliers is very close. Because a lot of the engineering and work preparation is done at one place, the subcontractors and suppliers communicate with each other on a lower level than with Damen. Damen remains in charge of the supply chain and is therefore responsible for making sure all the parts are at the right place at the right time.

The position of the subcontractors and suppliers in the case of Damen can be summarized as follows: the subcontractors and suppliers cooperate and have a high level of commitment to Damen, which indicates a relatively high interdependency within the buyer-supplier relationship (Fennema, 2014). They are involved from an early stage to ensure an optimal fit of their product within the final product. The subcontractors and suppliers communicate with each other but focus on their own product, while Damen is responsible for the overall logistics of the supply chain.

2.4.3 CONCLUSION

The subcontractors and suppliers are responsible for providing certain information that can be used to manage the supply chain as shown in Figure 2.3. The difficulty in the construction industry is the fragmentation and the large number of subcontractors and suppliers. In order to develop an efficient supply chain organisation structure, one can learn from other industries. For this literature study two cases in the aerospace and shipbuilding industry were analysed. Research has shown that there is a high interdependency within the buyer-supplier relationship. Furthermore, subcontractors and suppliers are involved from a very early stage and they carry a lot of responsibility. They are each responsible for their own product, while the focal firm is responsible for the logistics and assembling the final product.

The construction industry could also benefit if a more modular production system would be applied. The subcontractors and suppliers should only focus on their own product and strive for optimal quality. They should closely communicate with the main contractor while communicating on a lower level with the other third parties. Information exchange is also implemented on a higher level: the subcontractors and suppliers are highly involved in the

construction process by exchanging detailed information with the main contractor. This information, the red arrow in Figure 2.3, represents detailed information of the product, including the logistic information. This can be used by the main contractor to manage the overall supply chain, which is dealt with in the next chapters.

2.5 PHASE THREE: MANAGING THE LOGISTICS WITH BIM

The third phase of the conceptual framework, Figure 2.4, takes place during the construction phase. During this phase, the main contractor has to manage the construction of the building and has to control the third parties. The main contractor can do this by making use of the logistic information that can be extracted from BIM.

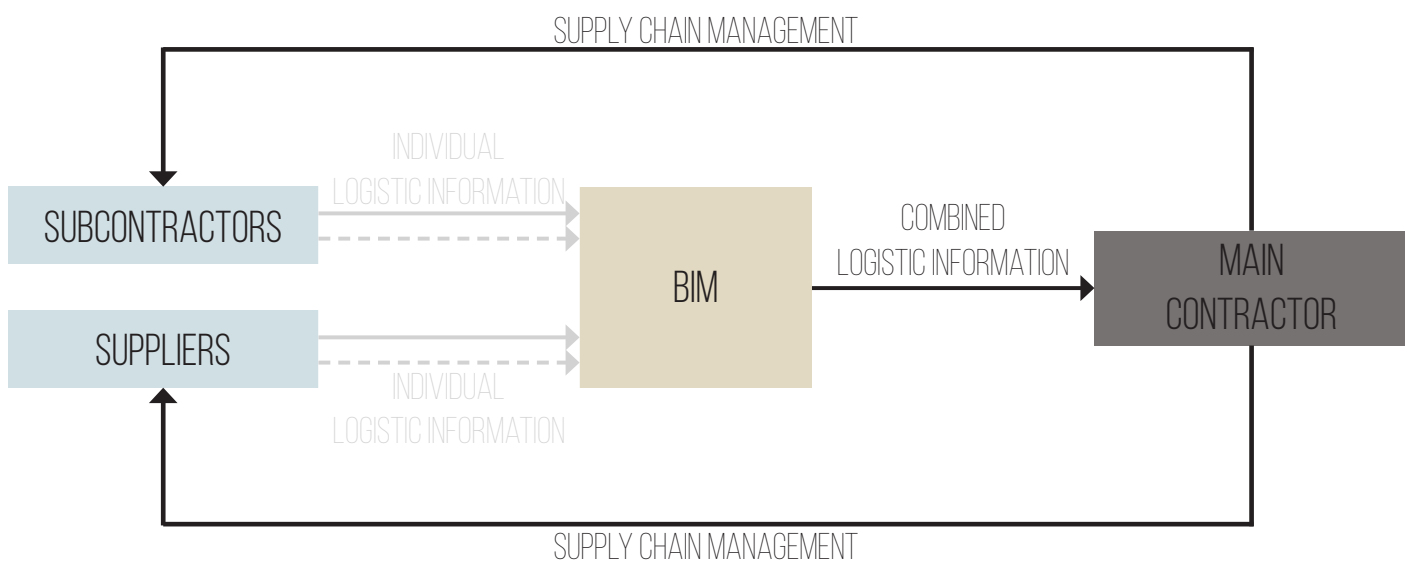


Figure 2.4 Phase three (own illustration, 2017)

This part of the literature study consists of a recommendation for the main contractor on how to manage the suppliers and subcontractors. First, the information the main contractor needs to add to BIM in order to complete the model will be presented. It will then be followed by how the main contractor should manage the third parties.

2.5.1 BIM

In the former paragraphs an overview was presented of the information that the third parties need to provide to the main contractor in order for the BIM-model to function properly. This information is very specific, since the third parties only provide information of their specific product. The main contractor is responsible for providing general information regarding the construction site. First, the main contractor must define the rules for site layout planning. These rules contain information about fences, possible locations for a tower crane, safety distances between objects, etc. (Schwabe, König, & Teizer, 2016). Secondly, the main contractor must assess the amount of storage space (both inside and outside the building) and update this regularly in the model (Cheng & Kumar, 2015b). This will make sure all storage space is used optimally. Thirdly, the main contractor must provide an overview of all the site equipment that is present on site. This contains elements such as large machinery, office equipment, traffic areas and transportation routes. (Schwabe et al., 2016). Although the technical details are beyond the scope of this research, it is worth mentioning that Cheng and Kumar (2015a) have designed a framework which can create dynamic site layout models in BIM. They have also designed a framework for material logistics planning (Cheng & Kumar, 2015b). These frameworks can be used for the technical input in BIM.

2.5.2 SUPPLY CHAIN MANAGEMENT

The fragmentation in the construction industry that was mentioned earlier in this literature study also leads to difficulties when it comes to supply chain management. The main contractor is responsible for managing the supply chain and must function as an integrator of all involved parties. This does come with some difficulties. The main contractor must make sure to obtain a regular workload that is profitable for himself, but at the same time needs to manage the subcontractors and suppliers who are fighting for their own survival (Ireland, 2004). King and Pitt (2009) conducted a research on supply chain management in construction from a main contractor's perspective. Their best practices will be discussed. The most important aspect for the main contractor is to focus on long-term relationships with the third parties. If managed, this could lead to several benefits for both parties, although both parties must have a shared concern for each other's interests. Also, the main contractor must make sure the client's interests are served and must create an environment suitable for long-term collaborative partnerships. King and Pitt (2009) also found that it is best for the main contractor to focus on a small group of high performing third parties, instead of a large group. The main contractor should try to engage with these parties for the long-term and cooperate with them on several projects. This increases the mutual trust and the eventual benefits. Also, the main contractor must focus on an effective information flow. An effective information flow is one of the key factors of an efficient supply chain. Moreover, the main contractor must facilitate and stimulate the interchange of information (Briscoe & Dainty, 2005). Finally, the main contractor should measure the performance of the third parties during construction and provide them with feedback (King & Pitt, 2009). Afterwards the experiences of all parties should be evaluated so the lessons learned can be applied to the next project.

These best practices should be implemented by the main contractor. The level of implementation however depends on the level of collaboration. In a project with very close collaboration, the main contractor can focus better on a long-term relationship than in a project where the distance between parties is quite large. This is also reflected in the BIM-based collaboration between the parties. Papadonikolaki et al. (2015) define three levels of BIM-based collaboration in supply chain management. The first type is 'ad hoc' where the main contractor is responsible for the model and only some third parties use BIM. The second type is 'linear' where most third parties use BIM and the main contractor is responsible for the model and has individual BIM-sessions with the other parties. The third type is 'central' where almost all parties use BIM, the main contractor updates the model weekly and there are regular joint BIM-meetings with all the involved parties. The way the main contractor manages the supply chain depends on the level of implementation of BIM. An ad hoc collaboration would lean more towards a traditional process than a central collaboration. However, despite the type of collaboration, a main contractor must make sure to coordinate and update the BIM-model, merge segregate models with model checker software and host BIM-meetings to keep all parties up-to-date (Papadonikolaki et al., 2015). This, together with the information of the main contractor and the third parties that is implemented in the model, will make sure the main contractor can manage the logistics much more efficient.

2.5.3 CONCLUSION

The main contractor is responsible for putting general information in the BIM-model, extracting the total amount of information and managing the logistics of the construction project with this information. How a main contractor should best do this, depends on the level of collaboration between the parties. However, despite the type of collaboration, a main contractor must make sure to coordinate and update the BIM-model, merge segregate models with model checker software and host BIM-meetings to keep all parties up-to-date (Papadonikolaki et al., 2015). Next to this, the main contractor should focus on developing long-term relationships with the third parties. Approaching the collaboration as a long-term relationship instead of a short-term will increase the mutual trust and the eventual benefits (King & Pitt, 2009). The

main contractor should also make sure to measure the performance of the third parties during the process and provide them with feedback. Finally, it is also important to evaluate the whole process. Also, all parties should discuss the outcome with each other, so third parties can also give feedback to the main contractor. Developing long-term relationships with close collaboration eventually will lead to the best situation for both parties.

2.6 PHASE FOUR: THE RESULTS

The fourth, and final, phase of the conceptual framework, Figure 2.5, consists of the finishing part of the construction phase. This is the phase in which all former phases come together. In this phase, the main contractor is still in charge of managing the construction and controlling the third parties, but he should also be able to see the results of the changes in the logistics. This phase is also used for evaluation among all involved parties.

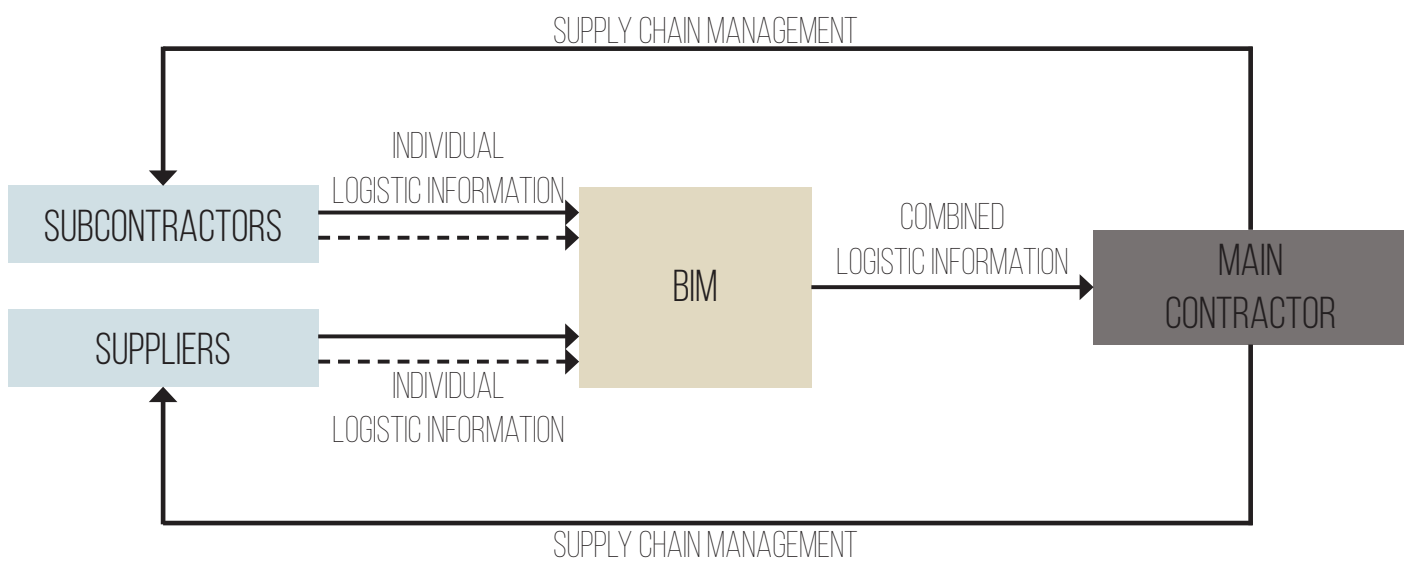


Figure 2.5 Phase four (own illustration, 2017)

This phase mainly focuses on the results of the changed supply chain management. As explained in Paragraph 1.2, previous research on supply chain management in construction, has been conducted by TNO. It was shown that there were large benefits for the parties involved. However, besides the effects it is also important to know how the involved parties view supply chain management with BIM. Their opinion is of importance to the feasibility for the main contractor. This literature study provides an overview of previous experiences of subcontractors and suppliers that dealt with supply chain management and BIM. This will be combined with the expected effects to provide an expectation of the feasibility for the main contractor.

2.6.1 EXPERIENCES OF THIRD PARTIES

Next to the feasibility of supply chain management with BIM, it is also important to know how the third parties experienced the supply chain management with BIM. A main contractor depends largely on its suppliers and subcontractors, hence it is important that they are cooperative. This part of the literature study explores what the current experiences of third parties are with BIM in order to see what could be expected in project Bètatoren.

Due to the fact that the findings in the literature on the experiences of third parties with BIM and supply chain management are limited, this part of the literature study is mainly based on the research conducted by Siebelink et al. (2015). This research showed the level of BIM

integration in over 50 organisations, divided into seven subdivisions. Because the empirical research focuses on subcontractors and suppliers, so will the literature study.

The subcontractors in this research are divided into construction firms that focus on residential and office buildings and installation companies. The research of Siebelink et al. (2015) showed that all construction firms recognized that the developments regarding BIM in construction, go very fast and that a lot of companies adopt BIM. However, they do not all see themselves as a leading company when it comes to BIM. A lot of the interviewed companies thought they were somewhere in the middle. The firms state that there are a lot of positive aspects on using BIM, such as decreasing failure costs, streamlining processes and improving the information management (Siebelink et al., 2015). The research however also showed that BIM was mostly implemented within the larger companies and projects. The installation companies largely differ from the construction companies. Some of the interviewees saw themselves as average performers, while other saw themselves as stragglers (Siebelink et al., 2015). None of them saw themselves as a leading company. This shows that experiences with BIM are much more limited amongst installation companies. This is also reflected in the drivers for these companies to adopt BIM. Many stated that they adopted BIM because the client demanded this in the contract, and not because they immediately saw the benefits themselves (Siebelink et al., 2015).

According to Siebelink et al. (2015) most suppliers assess themselves as a leading company when it comes to using BIM. However, due to the large diversity in types of suppliers one needs to be careful in interpreting these results for all suppliers. Mainly concrete and steel suppliers were experienced in using BIM (Siebelink et al., 2015). But although many companies see themselves as leaders when it comes to BIM, they are not very positive about the use. Almost every company uses BIM because the client demanded it and a lot of them had negative experiences with BIM (Siebelink et al., 2015). A main argument is that BIM currently is not very suitable for managing the planning and logistics, which is of course an important aspect for a supplier.

2.6.2 CONCLUSION

Previous research on supply chain management in construction has shown that logistic measures such as a UCC or using BIM can lead to large benefits for the involved parties. These benefits include a halving of the truck rides, an increased loading capacity of the trucks, an increased labour productivity, overall time and money savings and a decrease in the amount of waste (Frazer, 2016; Praat, 2016). In order to get a complete overview of the effects and fully implement BIM in construction logistics, more research is necessary. Next to some technical difficulties there are also some organisational difficulties, which mainly concern the role of the main contractor as the focal firm in the supply chain. Solving these issues will benefit all parties in the supply chain and it will bring the development of a 4C Control Tower one step closer.

Research of Siebelink et al. (2015) showed that amongst subcontractors the experiences largely differed from positive (construction companies) to a bit less positive (installation companies). The suppliers were also on the negative side. These conclusions however differ from those of Papadonikolaki et al. (2015), who conducted a case study about BIM-integration in supply chain management. According to Papadonikolaki et al. (2015) subcontractors are very efficient with BIM and also suppliers are adapting BIM on a high pace. These differences are probably caused by the wide range of companies. All companies differ in type, size, etc. and therefore also in their opinion about BIM. It is therefore very difficult to establish a general conclusion. Nevertheless, the empirical research will give more insight in the opinions of the third parties involved in project Bètatoren.

2.7 CONCLUSION & HYPOTHESES

This conclusion provides a theoretical answer to the main question:

How does supply chain management with BIM help contractors to get control of the logistics of a building project?

The main question consists of two parts: how should the main contractor organise the supply chain in order to manage it with BIM and what is the feasibility of this implementation process. The first part will be based on the sub-conclusions of phase one, two and three. The second part will be based on the sub-conclusion of phase four.

In the first phase the main contractor has to set-up the supply chain organisation and prepare the third parties (Figure 2.2). This phase is about the position of the main contractor in relation to the third parties. In this case the main contractor is the focal firm and therefore takes on the role as supply chain integrator. In that role, the main contractor must manage the supply chain, together with the information flows within it. He must actively lead the supply chain and demand collaborative behaviour from the subcontractors and suppliers. Next to this, the main contractor must prepare the third parties for supply chain management with BIM. He must provide a BIM-protocol beforehand and provide knowledge and assistance during the process. Communication is key, so the main contractor must have an integrated approach that combines technical structures with social practices. The hypothesis for this phase is that currently the link between BIM and supply chain management is missing in the set-up of the project, which leads to an incomplete BIM-model.

In the second phase the role of the subcontractors and suppliers is defined. Based on their role and tasks they must provide certain information that serves as the input for the BIM-model (Figure 2.3). In order to develop an efficient supply chain structure, some lessons can be learned from the aerospace and shipbuilding industry. In those industries, there is a high interdependency within the buyer-supplier relationship. Subcontractors and suppliers are involved from a very early stage and they carry a lot of responsibility. They are each responsible for their own product and the focal firm is responsible for the logistics and assembling the final product. Information exchange is also implemented on a high level: the subcontractors and suppliers are highly involved in the construction process and exchange detailed information with the main contractor. All parties communicate intensively with the main contractor, but the third parties do not communicate with each other. This ensures that the main contractor stays in control. The hypothesis for this phase is that the fragmentation of the construction industry is the main reason for the inefficient supply chain organisation.

In the third phase the main contractor has to manage the construction of the building and has to control the third parties. The main contractor can do this by making use of the logistic information that can be extracted from BIM (Figure 2.4). First, the main contractor has to add some general information to the BIM-model. Next he must make sure to coordinate and update the BIM-model, merge segregate models with model checker software and host BIM meetings to keep all parties up-to-date (Papadonikolaki et al., 2015). During the process, the main contractor should also make sure to measure the performance of the third parties and provide them with feedback. In the end, he must evaluate the whole process with all third parties, so they can also give feedback to the main contractor. This will improve the supply chain management and the relationships between the involved actors. The hypothesis for this phase is that to be able to manage the logistics with BIM, the model must include complete information with regards to the dimensions, location and the planning.

Per phase, it has been stated how the main contractor and the third parties should act in order to achieve an organisational structure that enables the main contractor to get control of the

logistics with BIM. An overview of these information flows is shown in Figure 2.6.

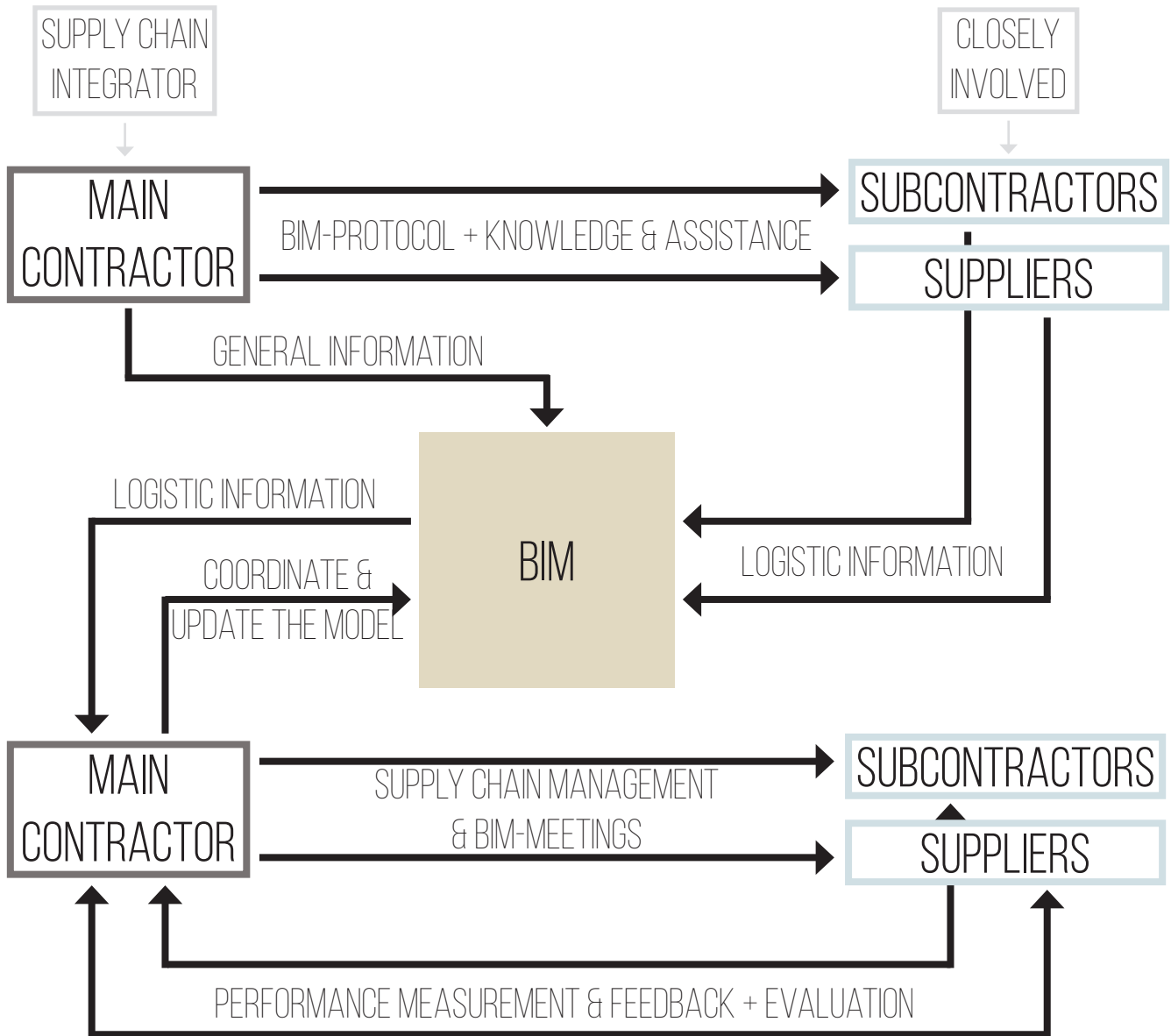


Figure 2.6 Information flows - theoretical framework (own illustration, 2017)

In the fourth phase, all former phases come together and the results of the changed supply chain are visible (Figure 2.5). Previous research on supply chain management in construction has shown that logistic measures such as a UCC or using BIM can lead to large benefits for the involved parties. However, more research is necessary to get a clear overview of the effects. Also, more research is necessary to overcome the current difficulties that arise when BIM is implemented in supply chain management. Previous research has also shown that the experiences of third parties with BIM largely differ, which makes it difficult to establish a general conclusion. However, based on the results of the literature study it is stated that if BIM is implemented correctly within the right organisational structure it can give the main contractor more control of the logistics. This could lead to benefits for all involved parties. Therefore, the hypothesis of this phase is that the implementation of BIM for the management of the on-site logistics is feasible for the main contractor.

The empirical research will test the hypotheses to see whether they are true or false. A detailed overview of the set-up of the empirical research is presented in the next chapter.

03

RESEARCH FRAMEWORK

As explained in Chapter One, the empirical part of this study is conducted by the use of a case study. This chapter presents the case study protocol for the empirical part of the research including a detailed overview of each sub-question and the pertaining research methods. This protocol is based on the template of Brereton, Kitchenham, Budgen, and Li (2008).

3.1 RESEARCH DESIGN

In order to conduct a research, a research design must be chosen. A research design, according to Bryman (2012), provides a framework for the collection and analysis of data. For this research, the data will be mainly collected within a construction project. This type of research design is called a case study. According to Bryman (2012), a case study entails the detailed and intensive analysis of a case. Within case studies there are single- and multiple-case study designs. For this research the choice was made to conduct a single-case study, for which the reasons will be further explained. Yin (2014) presents five rationales under which the single-case study is an appropriate design. One rationale is that the case represents a critical test of existing theory (Yin, 2014). Hereby, the single-case is used to determine whether the hypothesis is true or whether some alternative set of explanations might be more relevant

(Yin, 2014). Based on previous research there are several expected effects of supply chain management with BIM. If the organisation is set-up and managed according to the literature the outcome should be positive for all involved parties. Conducting a single-case study will test this and see if this hypothesis is true or false. Another argument for conducting a single-case study instead of a multiple-case study is that within the overall NWO-project several projects need to be researched. Because this needs to be thorough, it is better to focus on one case instead of multiple. Also, because this research is conducted within the (short) timespan of a graduation research the choice for a single-case has been made.

Within the single-case study design there are two types: embedded and holistic. An embedded design occurs when, in a single case, attention is also given to a subunit or subunits (Yin, 2014). If the single-case study focusses on the organisation as a whole it is a holistic design (Yin, 2014). The scope of this research concerns the on-site construction logistics. The main party is the main contractor, the focal firm of the supply chain. There is, however, also a focus on several subunits, namely the subcontractors and suppliers. Next to these subunits attention is also given to individuals, specific employees of the involved companies. Because the research is conducted within all these different levels an embedded single-case study design has been chosen.

3.2 CASE SELECTION

The case that is selected for this research is project Bètatoren, a construction project in Leiden. The selection criteria for this case are based upon previous research of TKI and the criteria of the TU Delft regarding a graduation project. Based upon the timespan of the research, the case needed to entail a construction project of which the construction phase took place in the first half of 2017. This construction project needed to have an urban nature and needed to deal with some logistic difficulties. Because the research focusses on supply chain management with BIM, the main contractor needed to be willing to use BIM. It also would be an advantage if BIM was already used in the design phase of the project. Another criterion is that the construction project needed to be large enough to involve several subcontractors and suppliers that could be researched. Some of them need to have BIM-experience and others do not. Because this research is part of the overall NWO-project, the case also needed to be part of it. This would ensure the case matches the other involved cases and can therefore contribute better to the overall conclusion. Also, by being part of the NWO-project the research can benefit from the knowledge and funding that is available from NWO.

Project Bètatoren meets all the requirements. It is a medium-sized construction project that consists of the construction of 134 rental apartments and some commercial space within an urban part of Leiden. The building is developed by Green Real Estate in cooperation with Bogor Projectontwikkeling and will be turnkey delivered by Vesteda, who is the client (Waal, 2017b). The architect of the project is Kolpa Architecten and the main contractor is Waal. Other involved parties are TW&P, the constructor, and M3e, the building physics consultant. Project Bètatoren is part of the transformation of the Lammerschanstriangle, a former industrial area that will be transformed into an attractive residential area within the coming years (Waal, 2017b). The apartments are relatively spacious and are intended for the mid-section of the free rental sector. The location of the project is easily accessible. The project is located at the Bètaplein, close to the train station of Leiden Lammerschans. The nearby highway, the A4, is also easily accessible. The building consists of 19 floors and houses 134 apartments of approximately 80 m² per apartment. The total gross floor area is 16.000 m². The ground floor and the first floor consist mainly of storage spaces. The ground floor also has 400 m² dedicated to commercial space and a small part of the ground floor consists of the general bicycle storage. The second until the eighteenth floor consist of apartments. The construction of the foundation started in January 2017. The ground floor and some walls of the ground

and first floor are composed of cast in-situ concrete. The floors of the first and second floor consist of wide slab floors. For the construction of the apartments in-situ concrete cast by tunnel forming is used. The finishing phase of the construction will start in June 2017 and the building should be completed in July 2018. Because project Bètatoren meets almost all criteria, this project is chosen as the case for this research.

Most data is collected from Waal, the main contractor. Waal is a medium sized contractor located in Vlaardingen. Their main focus is on housing, both apartment complexes and semi-detached housing. Waal is involved in the third round of the NWO-project and part of the pilot projects. They focus on innovation and improving their supply chain. BIM is an important part of that. They have experience with BIM but mainly use it as a tool in the procurement phase. They do see the potential benefits and are willing to research how to use BIM for the management of their logistics. The current vision of Waal with regards to BIM and supply chain management is that they want to function as a platform, they want to be the connecting element between all the partners in a construction process (Raaijmakers, 2017). BIM plays an important role in this. Waal wants to make better use of what BIM has to offer. They want to use BIM not only in the procurement phase but also in the construction phase (Raaijmakers, 2017). An important part of this is being able to create a planning in BIM, which is one of the goals of Waal. This is also highlighted in the BIM-vision of Waal, which can be found in Appendix A. The BIM-vision states the most important goals of Waal with regards to BIM. Planning with the BIM-model and using the model to control the construction process are part of these goals (Waal, 2017a). Their main goal is to be the centre of the BIM-network and to exchange information with their supply chain partners on a high level (Waal, 2017a). These goals are closely related to supply chain management with BIM. Due to the fact that the vision of Waal closely relates to the research subject, they are part of the NWO-project and project Bètatoren meets all the requirements for the research case, Waal is selected as the graduation company for this research.

Next to Waal, four involved parties of project Bètatoren have been researched. These consist of two subcontractors and two suppliers, in order to see whether there are differences between these types of third parties. The two selected subcontractors are Breman and Tegel Idee. Breman is responsible for all mechanical installations and will be closely involved during the whole construction phase. Tegel Idee is responsible for all the tiling and will only be involved during the finishing part of the construction phase. The two selected suppliers are Calduran and Halfen. Calduran is responsible for supplying all the limestone and Halfen is responsible for the delivery of wall supports and steel lintels. Both will only be involved in the shell construction phase. These four parties are selected because they give a divers overview of the parties involved in a construction project: subcontractors and suppliers, shell construction phase and finishing phase, highly and little involved.

Although the main focus is on the case of project Bètatoren, there are also some external parties involved in the research. In order to validate the data, it is important to receive input from parties outside the case. Therefore, two other contractors, Dura Vermeer and Boele & van Eesteren, are involved in this research. Dura Vermeer is a large contractor with a broad specialisation such as housing and infrastructure (Dura Vermeer, 2017). They also are quite experienced with using BIM. Boele & van Eesteren also is a relatively large contractor that focusses mainly on housing and non-residential construction (Boele & van Eesteren, 2017). These contractors are selected because they are also involved in the NWO-project and are researching different solutions to make construction logistics more efficient. Their knowledge and experience on that subject is highly relevant for this research. Another external party that will be involved in this research is HFB, a BIM-agency from Rotterdam. They are experts in BIM and are a step ahead of most construction companies. Their knowledge and experience will be used to explore the possibilities of logistics management with BIM. The last external party involved in this research is TNO.

3.3 RESEARCH METHODS

This paragraph presents a more detailed overview of the deliverables and research methods of each sub-question.

3.3.1 SUB-QUESTION 1

The deliverables for this sub-question consist of:

- An assessment of the BIM implementation within the third parties.
- An overview of the different options a main contractor has to manage the logistics.
- An analysis of the information flow between the main contractor and the third parties, including a recommendation for the information a main contractor needs to provide to the third parties about the organisation of the logistics.

The research methods used to collect data to answer this sub-question are:

- *Questionnaires* which are filled in by Waal, Breman, Tegel Idee, Calduran and Halfen. These questionnaires consist of the BIM-maturity model of Siebelink et al. (2015) that was mentioned in Paragraph 2.6.1 and uses the Likert-scale to answer the questions. This questionnaire can be found in Appendix B.
- *Interviews* with Joost de Korte, Jorg van Schadewijk and Dennis Adegeest from Waal. They are the project team of project Bètatoren. The interviews will be about the logistic measures they want to take and how they provide logistic information to their third parties. The interviews are semi-structured, the interview guide can be found in Appendix C.
- *Interviews* with Breman, Tegel Idee, Calduran and Halfen. These interviews focus on what the third parties need to know before the start of construction to prepare themselves for supply chain management with BIM. The interviews are semi-structured, the interview guide can be found in Appendix D.

3.3.2 SUB-QUESTION 2

The deliverables for this sub-question consist of:

- A social network analysis of project Bètatoren that focusses on both the information flows and the material flows.
- An overview of the logistic data of project Bètatoren, focusing on which data of the third parties is present and which data is missing in the BIM-model.
- An analysis of the information flow between the third parties and BIM, including a recommendation for what information should be implemented in BIM by the subcontractors and suppliers.

The research methods used to collect data to answer this sub-question are:

- *Documentary research* to analyse the logistic information in the BIM-model of project Bètatoren. Documentary research treats documents as a source of primary data. In this case the BIM-model will be this source of data, as BIM can be seen as digital communication (Denscombe, 2014).
- An *interview* with Alex Sagius, a BIM-specialist at HFB in Rotterdam. The interview will be about the information that is necessary to put into BIM to manage the logistics. The interview is semi-structured; the interview guide can be found in Appendix E.
- *Interviews* with Joost de Korte, Jorg van Schadewijk and Dennis Adegeest from Waal. The interviews will be about the set-up of the BIM-model for project Bètatoren. The interviews are semi-structured, the interview guide can be found in Appendix F.
- *Interviews* with Breman, Tegel Idee, Calduran and Halfen. These interviews are conducted to receive the data needed to make the social network analysis. The interviews will also focus on the logistic information the parties provide to the main contractor and how this information is send. The interviews are semi-structured; the interview guide can be found in Appendix G.

3.3.3 SUB-QUESTION 3

The deliverables for this sub-question consist of:

- A recommendation for how the logistic information that was extracted from the BIM-model of project Bètatoren can be used to manage the logistics.
- An analysis of the information flow between BIM, the main contractor and the third parties, including a recommendation for how the main contractor should extract the information from BIM and use this to manage the logistics in practice.

The research methods used to collect data to answer this sub-question are:

- *Documentary research* to analyse how the logistic information that was extracted from the BIM-model can be used in the construction phase.
- An *interview* with Alex Sagius from HFB. The interview will be about the logistic information that can be extracted from BIM and used to manage the on-site logistics. The interview is semi-structured; the interview guide can be found in Appendix E.
- *Interviews* with Joost de Korte, Jorg van Schadewijk and Dennis Adegeest from Waal. The interview will be about the way they manage the logistics with BIM. The interviews are semi-structured, an example of the interview guide can be found in Appendix H.
- *Interviews* with Breman, Tegel Idee, Calduran and Halfen. The interviews focus on the logistic measures chosen for project Bètatoren. The interviews are semi-structured; the interview guide can be found in Appendix I.

3.3.4 SUB-QUESTION 4

The deliverables for this sub-question consist of:

- A review of the views of the third parties on supply chain management with BIM. An overview of what they think are pros and cons together with their recommendation for future projects.

The research methods used to collect data to answer this sub-question are:

- *Interviews* with Breman, Tegel Idee, Calduran and Halfen. These interviews are conducted to receive the opinion of the third parties on supply chain management with BIM. The interviews are semi-structured; the interview guide can be found in Appendix J.

3.3.5 SUB-QUESTION 5

The deliverables for this sub-question consist of:

- A feasibility study that focusses on the financial, organisational, social and overall feasibility of the implementation of BIM for the management of the on-site construction logistics.

The research methods used to collect data to answer this sub-question are:

- *Interviews* with Joost de Korte, Jorg van Schadewijk and Dennis Adegeest from Waal. The interview will be about their opinions on supply chain management with BIM. The interviews are semi-structured, an example of the interview guide can be found in Appendix K.
- *Documentary research* to conduct a small literature study on the implementation process of BIM.

3.4 DATA ANALYSIS

As explained in the previous paragraph, each sub-question has several deliverables that are used to answer the question. These answers give insight in how the corresponding phase of the sub-question should be organised and managed.

The case study findings will be analysed from the perspective of the main contractor. Within this case the main contractor acts as the focal firm and is responsible for organising and managing

the supply chain. Therefore, the feasibility study will be conducted from the viewpoint of the main contractor. If the results would show that supply chain management with BIM is feasible, it means it is feasible for the main contractor, not necessarily for the third parties. However, the main contractor is very dependent on his third parties so if the situation is not feasible for them and they are unsatisfied, it is unlikely the outcome would still be feasible for the main contractor.

The overall results will be tested against the hypotheses that were derived from the literature study in Chapter 2. This will show whether the theoretical framework also works in practice or whether changes need to be made. This will lead to a new or revised framework which is the final product of this research. This can be used by contractors to re-organise their processes in such a way that they can use BIM and get control of their logistics.

3.5 RESEARCH PHASING

Figure 3.1 shows the phasing of this graduation research. Step one (problem statement) until step five (case selection) are all part of the first half of the research. This is the set-up part of the research in which the problem statement is formulated and the research proposal is designed and finalised. Part of this is a detailed literature study on several relevant topics that relate to the research. The outcome of this literature study is the basis of the hypotheses. The hypotheses are the conclusions of each phase. They will be tested in the second phase: the empirical part of the research. In this phase data will be collected and analysed in order to find an answer to the main question. The results of the case study will be validated by a group of experts. It is important to validate the research to ensure the overall reliability and validity. Once the results are validated the conclusions and recommendations are defined and tested against the hypothesis to see whether the hypothesis holds.

3.6 PLAN VALIDITY

It is important that the quality of the research design is good enough to conduct a correct case study, therefore the design needs to be tested. There are four tests that are commonly used to establish the quality of empirical social research (Yin, 2014). Of each step, a short overview will be presented of how the research meets the requirements.

The first test is construct validity, in which has to be shown that the research consists of a sufficiently operational set of measures (Yin, 2014). There are multiple ways in which this can be proven. The first is that multiple sources of evidence are needed. Next to project Bètatoren data will also be collected from other contractors that are involved in the NWO-project. Also, two subcontractors and two suppliers with different roles within the supply chain will be involved in the research to ensure a variety of data. A last source of evidence is TNO, who have a different view on the subject as they are not a contractor but a research facility. The second is that multiple methods for data collection should be used. The main research method will be conducting interviews, however other methods such as direct observation and documentary research will also be used. Finally, it is important that key informants review the draft of the case study report. The results of the case study research will be discussed with some of the project leaders of other pilot projects. They are all experienced with supply chain management in construction and therefore are able to provide a well thought judgement of the results.

The second test is internal validity, in which a causal relationship between the outcomes and the intervention has to be shown (Brereton et al., 2008). This, however, only applies to explanatory or causal case studies and is therefore not necessary for this research.

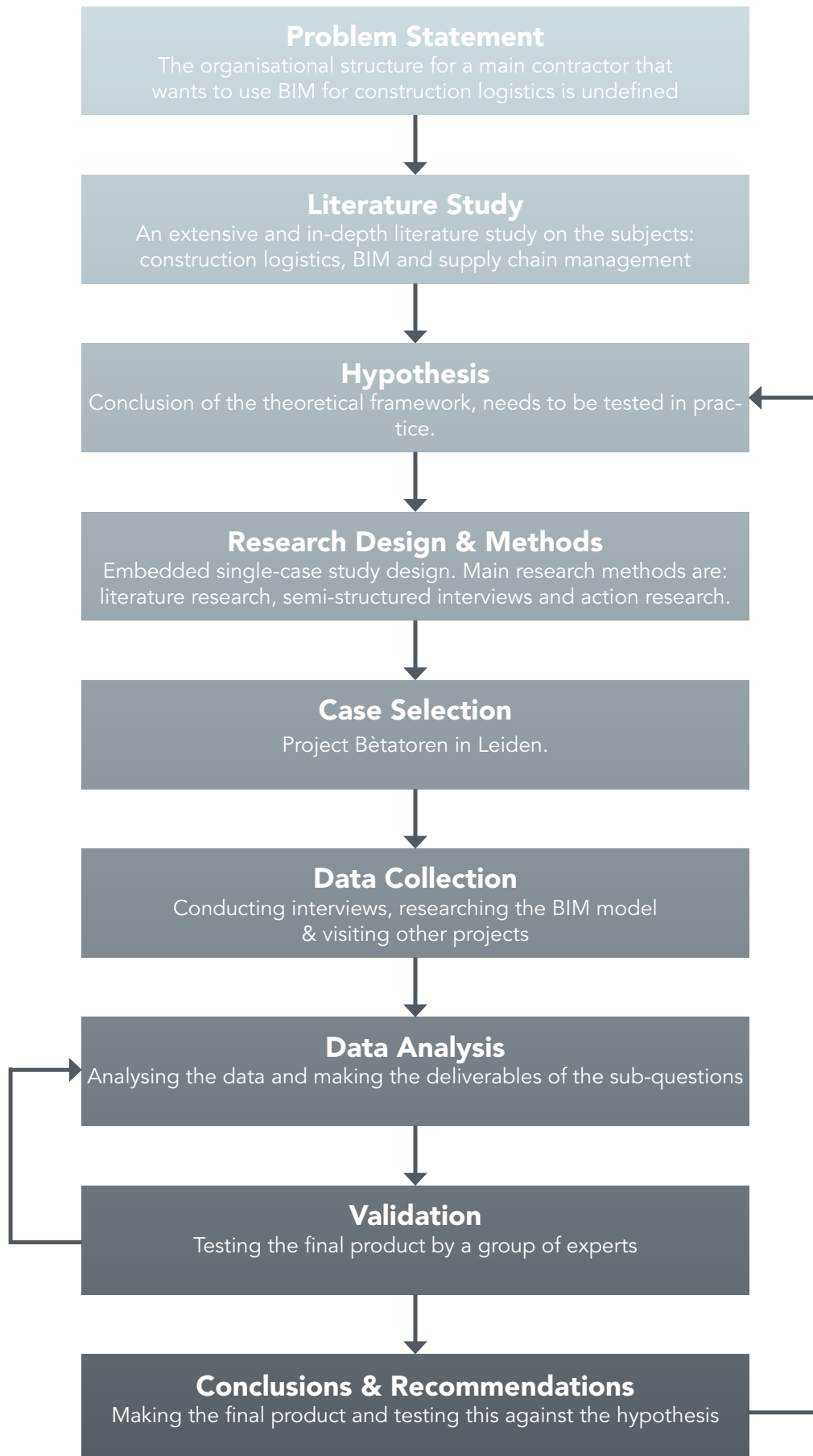


Figure 3.1 Research phasing (own illustration, 2017)

The third test is external validity, which is about showing that the study's findings can be generalized beyond the scope of the case (Yin, 2014). This can be proven by using theory that shows the broader scope. For this research, the theory is used for the literature study and to conduct the hypothesis.

The fourth test is reliability, which means that if another researcher would conduct the exact same case study in the future the results and conclusions would be the same (Yin, 2014). This can be achieved by using a case study protocol for the set-up of the research, as is done for this research.

3.7 STUDY LIMITATIONS

A potential limitation could be the close involvement of Waal in the case study research. It is important to involve Waal largely in the research because most data will be collected from employees of Waal or third parties that are contracted by Waal. However, a careful approach is needed to make sure this close involvement does not influence the results. The research should not depend fully on Waal, in case there is a problem with the data collection this data should be collected from other pilot projects of the NWO-project. Another potential limitation is that Waal is mainly interested in results that are specifically useful for them, not in a general outcome. This research, however, needs to generalize the outcome and not produce a final product specific for Waal. It is therefore important to take this into account during the data collection and analysis and to check that the external validity is ensured.

3.8 REPORTING

As explained in Paragraph 1.2 this research is part of a large research that is conducted by NWO. This overall research consists of three rounds and focusses on supply chain management in the construction industry. This research is part of the third round and focusses specifically on supply chain management with BIM, one of the focal points of the NWO-project. One of the goals of this research is to retrieve extra data for the NWO-project, to help build a database of experiences and knowledge of supply chain management in the construction sector.

The target audience of the research therefore consists of all the involved companies in the NWO-project, but also contractors in general. The main target group are contractors that are carrying out building projects from the position of the main contractor. They have to take the lead to change the organisational structure in order to implement BIM. The designed framework will be of direct use to them. Other involved actors are subcontractors and suppliers. Subcontractors and suppliers have an influence on the main contractor and vice versa, therefore it is important to include them in the research. Also, some subcontractors and suppliers might also want to implement BIM and can use the framework of this research.

PART II



This part of the report consists of the elaboration of the empirical research. The chapters are divided per sub-question, and each sub-question is linked to a phase. Each chapter presents the outcome of the research that was conducted for the corresponding sub-question. Within the chapters there is a clear structure. Each chapter starts with, if necessary, some extra knowledge regarding the corresponding phase. This knowledge is obtained from literature, empirical research or both. Subsequently, the chapter continues with a detailed overview of the case. This part is a more practical elaboration of the BIM-model of project Bètatoren, to show how it functions during the corresponding phase. Finally, the chapter ends with a comparison. The current situation within the phase is described, based upon the case study findings. This is compared with the theoretical framework and new findings, in order to state what should be the situation. This final paragraph describes what the process should be in order for the main contractor to get more control of the logistics. Each chapter thus describes both the data collection and the data analysis of a phase.

After the elaboration of the sub-questions there are three more chapters to complete this part of the report. Chapter eight consists of the validation of the plan, chapter nine consists of the conclusions and the final chapter consists of the discussion and recommendations. Together all these chapters provide a complete and detailed overview of the empirical research.

CHAPTER 04 | THE POSITION OF THE MAIN CONTRACTOR

CHAPTER 05 | THE POSITION OF THE SUBCONTRACTORS AND SUPPLIERS

CHAPTER 06 | MANAGING THE LOGISTICS WITH BIM

CHAPTER 07 | THE FEASIBILITY

CHAPTER 08 | VALIDATION

CHAPTER 09 | CONCLUSION

CHAPTER 10 | DISCUSSION & RECOMMENDATIONS

04

THE POSITION OF THE MAIN CONTRACTOR

The first phase of the conceptual framework, Figure 2.2, takes place during the procurement phase of a construction project. This phase focuses on the position of the main contractor towards the third parties and the information the main contractor needs to provide to them. The sub-question related to this phase is:

How can a main contractor prepare the third parties for a new logistic system in order to get more control in the procurement phase?

This sub-question is divided in three parts. The first part is an assessment of the level of BIM of all involved parties, in order to know what the starting point is. The second part is about the main contractor who has to decide what kind of logistic measures to take during the project. The third part concerns the information the main contractor needs to provide to the third parties about the organisation of the logistics. All parts together form the answer of the sub-question.

4.1 BIM-ASSESSMENT

In order to define the baseline for the research it is necessary to assess the level of BIM of Waal and the four subcontractors and suppliers. It is important to know their current use of BIM in order to know what can be expected of them during the project. For the BIM-assessment a BIM-maturity model is used. This model is designed by Siebelink et al. (2015) based on their research in the construction industry. The BIM-maturity model consists of six categories that each consist of several statements. For each statement, a score can be assigned ranging from 0 (not present) to 5 (fully present and continuously improving). The average of the scores shows the level of BIM-implementation within the company. An example of a BIM-maturity model can be found in Appendix B.

4.1.1 WAAL

Within Waal six people filled in the BIM-maturity model. Three models were filled in by the project leader and two project planners from project team E. Team E is responsible for project Bètatoren and focuses in general on large housing projects in the form of apartment buildings. Two models were filled in by 3D-engineers from project team C. Team C is responsible for housing projects that consist of terrace houses and semi-detached housing. The last model was filled in by the supply chain manager of Waal.

The total score of Waal is 289, which is an average of 3.4 (see Figure 4.1).



Figure 4.1 BIM-maturity score of Waal (own illustration, 2017)

A score of 3.4 means that BIM is implemented in the whole organisation, the course of implementation is defined and is actively managed. Although the overall score is quite high, the score largely differs per team. The average of team E is 3.6, close to the overall average, but the average of team C is 2.8, quite below the average. This is interesting because team C uses BIM much more than team E, and the maturity models for team C are filled in by BIM-experts. This difference can be explained by the way these teams use BIM. Team E does not use BIM very often and the people that filled in the models are not very experienced with BIM. Their assessment is mainly based on the BIM-vision of Waal. This is a long-term vision that states what BIM should be within Waal, but not necessarily what BIM currently is. They also have a lot of contact with external parties and it is important for them to present a good image of Waal. This, together with their inexperience, might lead to higher scores. Team C on the other hand uses BIM intensively every day, therefore they have a lot of experience with the software. They based their assessment solely on the current status of BIM within Waal. They do not have a lot of contact with external parties, only after contracts have been signed, so they are not inclined to give higher scores. The supply chain manager gives the highest score (4.1) out of everyone that filled in the model. This can be explained by his opportunistic view on the situation. He is the one in charge of implementing BIM in the organisation and he knows what they are currently doing and what they are going to do. With this in mind he filled in the BIM-model, assessing some aspects more on where they will stand in a few months than

on what their actual stand is right now. Overall, the scores combined do give a good view on the implementation of BIM within Waal. BIM is used within all the teams and although some teams use it more than others it is actively encouraged, both by the higher management and within teams, to get the most out of BIM.

4.1.2 SUBCONTRACTORS

The two subcontractors that were selected for this research are Breman and Tegel Idee. Breman is an installation company that takes care of the mechanical installation of project Bètatoren. They are responsible for the delivery and installation of the plumbing, the central heating and the mechanical ventilation. A few years ago, they started to use BIM, so they have quite some experience. They mainly use BIM for the design and coordination of several types of installations, such as the installations of project Bètatoren (R. Breman & M. van Leeuwen, personal communication, February 22, 2017). Breman will create a BIM-model for project Bètatoren. The BIM-maturity model of Breman was filled in by Martin van Leeuwen, the Breman project leader of project Bètatoren. He scored Breman with an average of 2.9, which means that BIM is implemented and the implementation is being managed (see Figure 4.2). However, the implementation is more bottom-up than top-down. For a full implementation of BIM both the software and the information processes within an organisation need to change. In order to make this change, the implementation of BIM must be supported broadly within the company. For this the support of the management is needed. A top-down approach can implement changes much faster than a bottom-up approach. Also, the implementation strategy needs to be evaluated and, if necessary, adjusted every once in a while. This is currently not happening at Breman.



Figure 4.2 BIM-maturity score of Breman (own illustration, 2017)

The second subcontractor is Tegel Idee, a tile company. They are responsible for the delivery and installation of all the floor and wall tiling of project Bètatoren. They do not have any experience with BIM because they have never used it. According to Johan Noteboom (personal communication, February 13, 2017), the director of Tegel Idee, contractors do not need 3D-models of the tiling and therefore it is not necessary for Tegel Idee to invest in implementing BIM. However, if contractors start to manage their logistics with BIM they also need 3D-models of the tiling. Given the current developments, it would be wise for Tegel Idee to start investing in BIM. For project Bètatoren they do not need to create a 3D-model because the drawings, planning and logistics will be managed in a traditional way. The BIM-maturity model was filled in by Johan Noteboom. Since BIM is not used the total score is 0, meaning that BIM is not present within the organisation (see Figure 4.3).

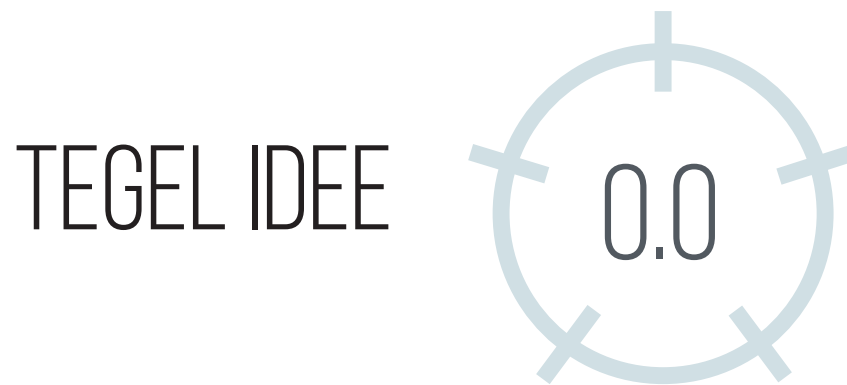


Figure 4.3 BIM-maturity score of Tegel Idee (own illustration, 2017)

4.1.3 SUPPLIERS

The two suppliers that were selected for this research are Halfen and Calduran. Halfen is specialised in mounting techniques. For project Bètatoren they are responsible for the delivery of wall supports and steel lintels. They have a lot of experience with BIM and use it for many of their projects. They started using BIM because it creates benefits for themselves and their customers (M. Lammertink, personal communication, February 13, 2017). It is the only company out of the selected four that initiates to use BIM in a project, the other companies only do so when the client asks them to. Halfen also has a significant part of their website dedicated to BIM. They have their own libraries, a BIM-protocol and several videos of their products modelled in BIM (Halfen, 2017). For project Bètatoren they will also create a BIM-model, that mainly focusses on the wall mountings of the façade. The BIM-maturity model was filled in by Mark Lammertink, the Halfen sales engineer of project Bètatoren. The average score of Halfen is a 2.8, meaning that BIM is implemented and the implementation is managed (see Figure 4.4). Although BIM is incorporated in a large part of the organisation, the organisation falls behind when it comes to the qualities and competencies of individual employees. More education and trainings are necessary for the whole company and the BIM-manager should be able to focus on BIM implementation as his main task (M. Lammertink, personal communication, February 13, 2017).

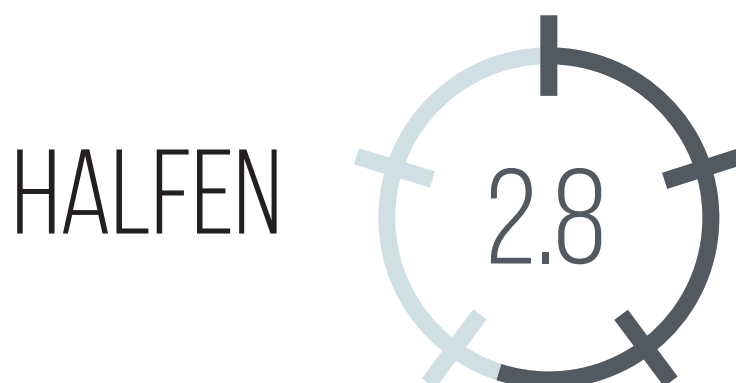


Figure 4.4 BIM-maturity score of Halfen (own illustration, 2017)

The second supplier is Calduran, who is specialised in limestone. For project Bètatoren they are responsible for the delivery of limestone, which they also produce themselves. They also have quite some experience with BIM. They see BIM as a method to create an efficient construction process. Their implementation is more top-down, they have started to invest in BIM because clients started to ask for BIM. However, they also have more information about BIM on their website, which states that they have their own library and use the IFC-standards (Calduran, 2017). For project Bètatoren they will not use 3D-engineering in BIM because they

only have to deliver a standard stock product and therefore BIM-modelling is not necessary (A. Gils, personal communication, February 7, 2017). The BIM-maturity model was filled in by Albert Gils, the BIM-manager of Calduran. The average score of Calduran is 2.8, the same as the score of Halfen (see Figure 4.5). The BIM-maturity model shows that the score for each statement is relatively the same, meaning that everything is managed but they are not improving themselves. The implementation can be taken to a higher level by putting more effort into it and making it an iterative process.



Figure 4.5 BIM-maturity score of Calduran (own illustration, 2017)

4.1.4 BIM-MATURITY MODEL AND SUPPLY CHAIN MANAGEMENT

Next to the overall score, the scores of two statements will be highlighted. The focus of this research is on logistics, so it is important that the level of BIM within the companies is sufficient for supply chain management with BIM. The two statements that are most important for the logistics are 'cooperation' and 'data exchange'. Cooperation is the extent to which the attitude of the company is aimed at collaboration (Siebelink et al., 2015). This is determined by aspects such as openness and transparency towards partners. Data-exchange is about sharing data with supply chain partners and increasing the quality of this data (Siebelink et al., 2015). Good data-exchange makes it possible to integrate data from multiple partners into one BIM-model. Successful supply chain management depends on close collaboration between supply chain partners. Mutual trust and good communication are therefore very important. In order for the selected parties to use BIM for supply chain management, their cooperation and data-exchange must be good.

Data-exchange is assessed relatively high by all parties. Halfen, Breman and Calduran all give their data-exchange a 4. The average score of Waal is 3.7, also quite high. Tegel Idee, of course, has a 0 because they do not use BIM. A 4 for data-exchange means that BIM-models are exchanged via open standards, such as the IFC. This improves the sharing of data and expanding the model based on the information of multiple supply chain partners (Siebelink et al., 2015). A company that has a 4 for data-exchange also is open and transparent towards other companies. The fact that all companies have a high score on data-exchange is a good starting point for supply chain management with BIM. It means that all parties are able to share data with each other.

Next to being able, all parties also must be willing to share data with each other. This is assessed in the aspect 'cooperation'. The score for this statement differs per company. Calduran assesses themselves with a 2, Halfen gets a 3 and Breman a 4. The average of Waal is 2.7. A score of 2 means that the importance of working together is recognized and that the cooperation via BIM is included in the set-up of the contract (Siebelink et al., 2015). A 3 means that there are joint activities with all the supply chain partners to coordinate structures, tasks and processes. A 4 means that external cooperation is part of the organisational strategy of

the company and that the mutual trust between supply chain partners promotes cooperation. The variation in the scores shows that this will be the difficult part in setting up supply chain management with BIM. The parties are able to change their traditional supply chain in a supply chain that uses BIM, however all parties need to accept that such a structure requires them to be fully open and transparent.

4.2 LOGISTIC MEASURES

In Paragraph 2.1 several logistic measures were described and BIM was selected as the most feasible option. After consultation with the project managers of project Bètatoren a new option was introduced: the material container. A material container is used for a systematic supply of the construction site while also increasing the labour productivity. The container is placed on the construction site and filled by the subcontractors and suppliers. This can be done at any time span, according to the planning. One option is to fill the container weekly. All subcontractors and suppliers make sure that their materials are placed in the container before the weekend. In the weekend, the materials are moved by runners. All materials are placed on the right place on the right floor and are also unpacked, the waste is taken out by the runners. When the subcontractors arrive on Monday morning they can start working immediately and do not lose time moving materials or unpacking. In this set-up, the runners can be deployed for moving and unpacking the materials, while the experts can focus on their specific task. The labour productivity of both will increase because there is no time lost moving the materials or waiting on the construction crane. Because waste is disposed of the construction site in the same movement, both time and money are saved. An example of this system is presented by BMN Bouwmaterialen (2017) who offer the BouwBewustBox as one of their services. The costs of using a material container are relatively low, because it mainly concerns the rent of the container and the labour costs of the runners. Also, since a decrease in costs is expected, arrangements can be made between the main contractor and the third parties. If the costs decrease, the profit made is shared between both parties equally. This way, all parties benefit from the system. The impact on third parties is relatively low, they have to rearrange their material supply to a weekly (or different, depending on the planning) supply. Also, they have to agree with sharing the profit made with the main contractor. This can be difficult, however it is explainable by the investment the main contractor needs to make. The main contractor takes on the risk of renting the container and extra staff and also takes on full responsibility for the logistic system. If there is no profit made, the third parties will not lose money but the main contractor will. Since the main contractor facilitates the logistic system and provides the third parties with insight in their logistics it is logical he shares in the profit. Together the parties can realise an optimisation of the logistics and an increase of the labour productivity. The material container will be used at project Bètatoren together with BIM. BIM will be used during the procurement, to create the planning for the container. In order to use the container an overview must be created of which materials are being placed in the container, how many materials are being placed and the volume they take up. This information can be retrieved from BIM. Then, a planning can be made that includes the number of containers and the number of runners needed to move the materials. The planning is created together with the third parties to make the logistics as smooth as possible. Together with the project team of project Bètatoren a document has been set-up to smoothen the implementation of this logistic measure. This implementation plan states all the details regarding the project, the logistic measures and the corresponding research. The plan was set-up for the NWO-project to document project Bètatoren, so it can be compared with other pilot projects.

4.3 THE INFORMATION FLOW

This sub-question focusses on the information flow from the main contractor to the third parties at the start of the project. Case study research of project Bètatoren has shown how

this information flow currently works in practice. However, this differs from how it should work in order for the main contractor to get control of the logistics. Both are compared to show what is necessary to go from the current situation to an improved situation, with the current resources.

4.3.1 HOW DOES IT WORK?

The information flow of the first phase consists of several steps that, in the end, lead to an overview of the tasks and responsibilities of the third parties. The first step is to secure the optimisation of the logistics during the procurement of the third parties. Waal has included a rule in all contracts that states that a logistic optimisation will take place during the project and that the parties are expected to cooperate, even though the precise details are not yet clear (J. de Korte, personal communication, January 18, 2017). The second step is to define these details and decide which logistic measures will be taken during the project. For project Bètatoren this consists of the use of a material container together with BIM, as discussed in Paragraph 4.2. The logistic measures are elaborated in a logistic plan. This logistic plan is set up by the project leader and the project planners of project Bètatoren, in cooperation with the construction supervisor of project Bètatoren. Because the construction supervisor is responsible for the actual construction of the project and will be in charge of the logistics, it is important he also agrees with the plan. As soon as the plan is complete, it is converted into an agreement which needs to be signed by the third parties. The agreement consists of a plan of action of the logistics during the construction phase, together with an overview of the responsibilities of both Waal and the third party. This logistic agreement is an important part of the information flow from the main contractor to the third parties. Another important part is the BIM-protocol. The BIM-protocol of project Bètatoren states the commitment and the responsibilities of all parties with regards to BIM. The BIM-protocol is very detailed and states for instance how the software should be used, what the output needs to be and how models are shared with each other. This ensures that all parties know how to use BIM. Detailed information about the logistics often is not exchanged during this phase and is also not included in the BIM-protocol. The main contractor often is not sure about the details of the logistics yet and agreements on this are made mostly just a few weeks before the start of construction. Therefore, there are currently no agreements made on how to use the BIM-model for the management of the logistics later on in the project. Once it is clear which parties are going to model, these parties receive the central BIM-model from Waal. This model is created by the architect in the design phase, based on the program requirements set-up by the client. After that the model is adjusted for the procurement phase. The BIM-model consists of the construction and the basic furniture (bathroom, kitchen, etc.). The parties can use this model as an underlay for their model.

The BIM-protocol and the logistic agreement form the main part of the information flow, that shows the third parties what is expected from them and how these expectations will be fulfilled. The plans and documents are set-up by Waal and quite compelling. Although there is some consultation with the third parties, everything happens on the initiative of the main contractor. Waal takes the lead and is responsible for setting up the plans, providing the right information and informing parties about their tasks and responsibilities. A schematic representation of this is shown in Figure 4.6.



Figure 4.6 Phase one - current situation (own illustration, 2017)

Even though Waal provides both information with regards to the logistics and information with regards to BIM, these documents are not linked. Therefore, BIM and the logistic information are disconnected in this phase.

4.3.2 HOW SHOULD IT WORK?

In order for the main contractor to get more grip on the logistics, changes need to be made to the information flow at the start of the procurement phase. These changes aim at making the information flow smoother, making it a more coherent process and focussing more on the final use of the BIM-model. Regarding the first phase, there are some small changes which should improve the processes. The first change concerns the logistic plan. Case study research shows that the logistic plan is set-up by the main contractor and then submitted to selected third parties. With some third parties, agreements have already been made and they are now forced to change these. This unilateral approach could also evoke resistance with the third parties because they feel the logistic plan is imposed onto them. It would be better if the main contractor set up the logistic plan with the third parties. As soon as all the relevant parties (installations, walls, floors, large furniture, etc.) are contacted, the main contractor should plan a meeting to discuss the logistics. The main contractor is the initiator and can bring up some ideas. The other parties can react to these plans and come up with new ones. This lean approach has several benefits. Lean can improve knowledge management and makes business processes more efficient (Melton, 2005). This approach will increase the solidarity amongst the parties and the plan will be supported broader because everyone is able to give input. Regular meetings with all supply chain partners also help to establish mutual trust and consensus-seeking orientation (Papadonikolaki et al., 2016). This will make it more likely that everyone signs the final agreement and sticks to it during the construction phase. The main contractor functions as the supply chain integrator, he actively leads the supply chain by initiating logistic changes and demanding collaborative behaviour from the third parties by involving them in this process.

The second change concerns BIM. In order to use BIM to manage the logistics of a construction project it is important that BIM is already implemented from the start of the project. Instead of making a model and then using the information in that model to manage the logistics, the use of the model should be the starting point. After the logistic plan has been made, the main contractor has to define what the BIM-model needs in order to use it for the management of the logistics. The BIM-model should be adapted to this. The main contractor is responsible for the coordination model of the procurement phase (also 'procurement model'), and has to provide this to the third parties. The procurement model is based on the design model and consists of the architectural model, the construction model and the installation model (see Figure 4.7).

These models were created in the design phase and can either be used immediately or need to be remodelled for the procurement phase. The main contractor can decide to do this himself, if the necessary knowledge is present within the company. Otherwise the choice could be made to outsource it to a modelling bureau. The procurement model will be provided to all parties, who are all expected to work with BIM. Only parties that have no relevance of using BIM, such as the plasterer or the painter, do not have to use BIM, although the materials they need have to be included in the model. The procurement model is provided to all parties, together with a BIM-protocol that states exactly how everyone should use the model. An example of this is the BIM-protocol of Pioneering (2013), a foundation focussing on innovative technologies in the construction industry. They have created a BIM-protocol, together with several large contractors and other construction experts. The BIM-protocol includes a complete guideline for the use of BIM in the procurement and execution phase. Pioneering (2013) emphasizes that it is important to define at the start of the procurement phase what the final use of the model will be and how the model needs to be adapted to this. The protocol should include all the agreements and responsibilities of all involved parties. It must also include exactly

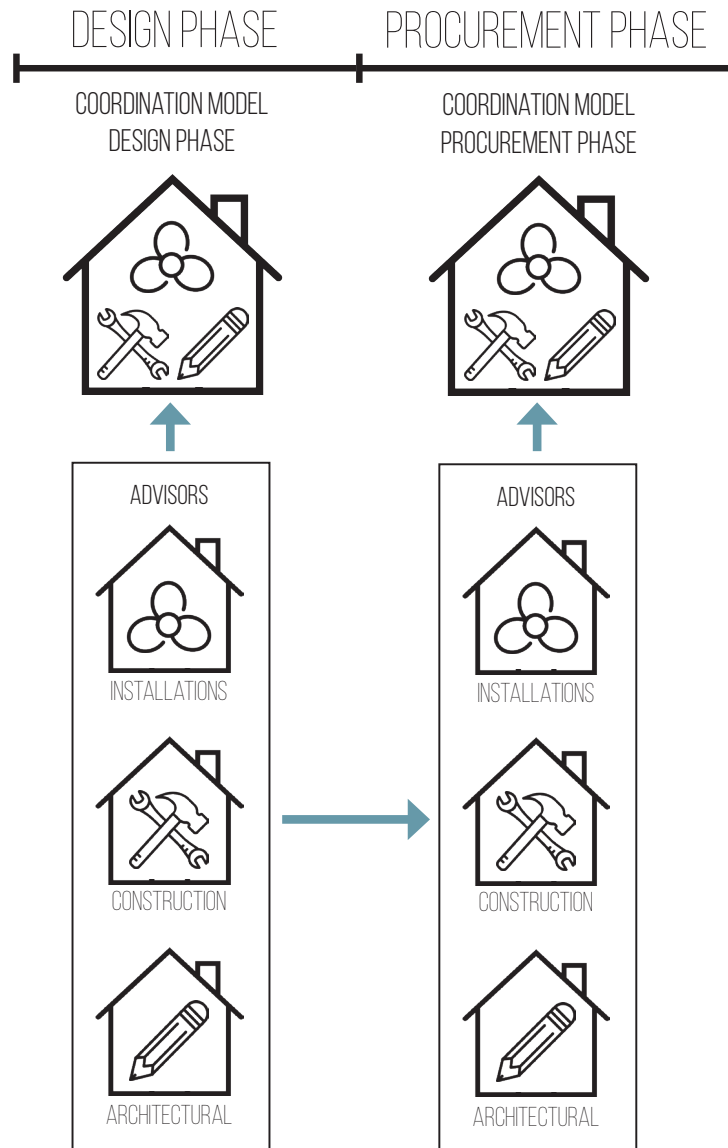


Figure 4.7 BIM – Phase one (own illustration (2017) based on Pioneering (2013))

how the elements should be modelled with regards to the logistics. This includes information about the volumes, packaging, location and planning. The information flow is now complete. It consists of a logistic plan and agreement, the procurement model and a BIM-protocol. These together form the information flow that comprises of information about the building, the logistics, the planning, finances, BIM and the tasks and responsibilities of all involved parties. A schematic representation of this is shown in Figure 4.8.



Figure 4.8 Phase one – improved situation (own illustration, 2017)

Now it is up to the third parties to check this information and add their particular information to the flow, which will be discussed in the next chapter.

05

THE POSITION OF THE SUB- CONTRACTORS AND SUPPLIERS

The second phase of the conceptual framework, Figure 2.3, also takes place during the procurement phase. This phase focuses on the role of the subcontractors and suppliers and the information they need to provide for the BIM-model. The sub-question related to this phase is:

What information of third parties is necessary in order to integrate logistic information in BIM software?

This sub-question is divided in three parts. The first part is a social network analysis of the four parties of project Bètatoren that were selected for this research. This analysis shows the interrelationships between the parties and Waal. The second part is an overview of the BIM-model of project Bètatoren. It states which information regarding the logistics is present and which information is still missing. The third part concerns the information the subcontractors and suppliers need to provide to the main contractor regarding the logistics. All parts together form the answer to the sub-question.

5.1 SOCIAL NETWORK ANALYSIS

In order to get more insight in what the information flows between all the parties should be and how the BIM-model should function, it is important to know which parties are involved and what their interrelationships are. A social network analysis (SNA) is a tool that can be used to identify and investigate the relations among a group of actors (Wichmann & Kaufmann, 2016). A SNA can be used to map all sorts of relations, such as communication, workflow or the exchange of goods among actors (Carter, Ellram, & Tate, 2007). This last aspect is useful in supply chain management. For this research, a SNA is conducted that maps the exchange of both information and construction materials between suppliers, subcontractors and the main contractor. Research of Ozkul and Barut (2009) provides an approach to conduct this SNA. First, the involved parties must be selected. For this research two suppliers and two subcontractors are selected next to the main contractor. Secondly, the interrelationships must be made visible. Graph theory is an extensively used method in SNA because it visualizes the network. Actors are represented as nodes, and relationships are represented as lines between nodes (Ozkul & Barut, 2009). A direction can be added to the lines to show the direction of the relationship and values can be added that represent the intensity of the relationships. An example of this is shown in Figure 5.1.

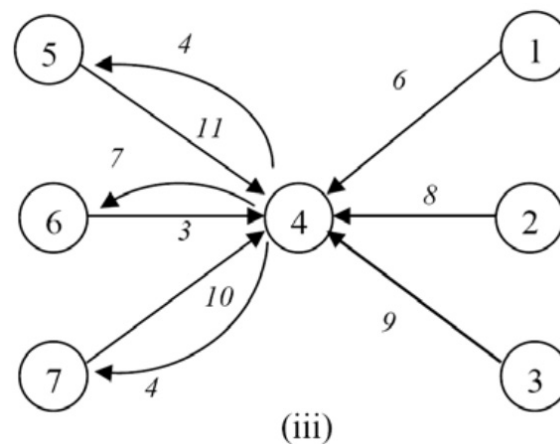


Figure 5.1 Example of a SNA for supply chain management (Ozkul & Barut, 2009)

For the social network analysis of project Bètatoren the interrelationships of the main contractor (Waal), two subcontractors (Bremán and Tegel Idee) and two suppliers (Halfen and Calduran) have been analysed. The result of the SNA can be found in Figure 5.2. The interrelationships have been analysed on two levels, based on interviews that are conducted with all the parties. First, the information flows have been analysed. These are reflected as the red arrows in the analysis. These arrows show which parties send information to which other parties. Secondly, the flows of the materials have been analysed. These are reflected as the green arrows in the analysis. These arrows show which party delivers materials to which other parties. Together they show which parties have a relationship and whether this is based on the exchange of information, the exchange of materials or both.

The social network analysis shows that Waal is the centre of all parties. Waal has to communicate with all the subcontractors and suppliers about the logistics and all the materials have to be brought to the construction site of project Bètatoren. Therefore, Waal is the centre of both flows. The information flows show the same pattern with almost all the third parties, only Calduran shows a different pattern. In the other cases Waal has direct contact with the subcontractor or supplier. They exchange information regarding the logistics, this information goes both ways because they both have to agree on the set-up of the logistics. Waal only has contact with Bremán, Tegel Idee and Halfen, not with their suppliers. When a contract has

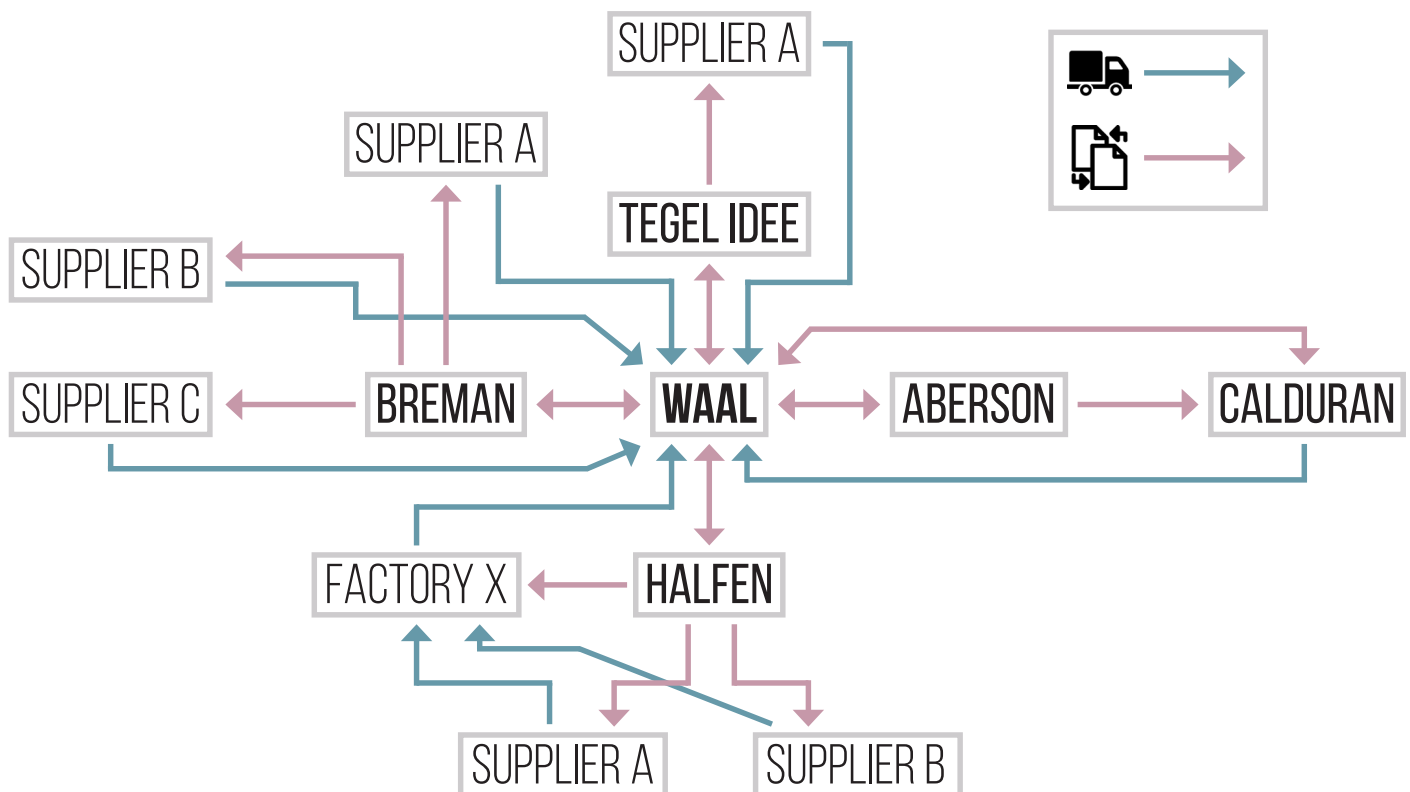


Figure 5.2 Social network analysis of project Bètatoren (own illustration, 2017)

been signed, these parties contact their suppliers and place their orders, which is mainly a one-way information flow. Calduran is different because there is another company involved: Aberson. Aberson is a brick company that works together with a lot of smaller companies, such as Calduran. Waal first contacts Aberson to discuss what types of materials they need. Aberson then directs Waal to the company that specialises in that type of material. In this case Waal needed limestone, which is produced by Calduran. Once Waal is in contact with Calduran they discuss everything with them and do not have contact with Aberson anymore. The material flows also show almost the same pattern at every party. Breman, Tegel Idee and Halfen have external suppliers that deliver materials to the construction site. The larger and more complex the contract is, the more external suppliers are involved. The material flows are all one-way flows; the suppliers only deliver materials to the construction site, they do not take anything back. Waal and the external suppliers do not have contact, all the contact goes via the subcontractor or supplier. Calduran is also different here, because they do not have an external supplier. Calduran produces and delivers the limestone themselves. Therefore, they are the only party that Waal has both a direct information and material flow with.

The social network analysis of project Bètatoren clearly shows the fragmentation of a construction project. Although only four subcontractors and suppliers are selected, the total of parties is already more than 10. With all the subcontractors and suppliers that are involved in a construction project, and all their external suppliers, this easily goes up to over 50 different parties. Next to that, the analysis shows that there is a difference in the parties that the main contractors make an agreement with and the parties that actually deliver the materials. In other words, there is a mismatch between the production processes and the information processes. The main contractor can make arrangements with the subcontractors and suppliers regarding the logistics, but has to trust them to arrange this with their external suppliers. The longer this chain, the higher the chance that something goes wrong, because information is not transferred properly or people do not agree with the arrangements made between other

parties. The analysis also shows that the subcontractors and suppliers do not have contact with each other, they only focus on their own product. Using BIM for the logistics could change this because all the parties would then work with the same model. This could benefit the parties by making it easier to align transports with each other. However, the fragmentation and differences in flows between the parties are important to keep in mind when setting up a new structure for supply chain management with BIM.

5.2 BIM-MODEL

This phase focusses on the information of the third parties that goes into the BIM-model. In order to find out which information is necessary to manage the logistics and whether this information is available for project Bètatoren, the BIM-model of project Bètatoren was analysed. An analysis has been made of the products of the selected subcontractors and suppliers, to see what kind of information is present and which information is missing.

5.2.1 BREMAN

Breman is responsible for the delivery and installation of all the plumbing. The plumbing consists of large furniture, such as sinks or bath tubs, but also smaller components, such as toilet paper holders. Breman is also responsible for the fasteners of all the plumbing. The analysis of the BIM-model is carried out with Autodesk Revit software. Research shows that only the large furniture is present in the BIM-model. In the bathroom, the modelled plumbing consists of a sink, a shower, a bathtub and a radiator. In the toilet, there are a toilet and a small sink. Extra furniture such as the panel of the toilet or the mirror above the sink are not modelled. An example of the properties of the plumbing can be found in Table 5.1.

General	
System Family	Plumbing Fixtures
Type	74_PF_wastafel-900mm
Constraints	
Level	07 zevende verdieping*
Dimensions	
Bakbreedte	400
Breedte	900
Phasing	
Phase Created	2. nieuwbouw
Identity Data	
Description	wastafel
Assembly Description	Vaste sanitaire voorzieningen standaard - sanitaire toestellen - normaal
Assembly Code	74.11

*parameter differs per element

Table 5.1 Properties of the bathroom sink (own illustration, 2017)

All products that are provided by Breman are documented in a product overview that they send to Waal. To see which information is present, a few steps need to be taken.

1. The first step is to make a schedule that shows an overview of all the plumbing. To be able to manage the logistics, three types of information are necessary: information regarding the dimensions of the component, information regarding the location of the component and information about the planning. As for the plumbing, this information is reflected in the level, the room number, the room name, the type, the description and the volume. Part of the schedule is shown in Table 5.2.
2. The second step is to see what errors come up after creating the schedule. The first error is that the volume is not available for any of the plumbing and also information

<Test_Plumbing Fixture Schedule>						
A	B	C	D	E	F	G
Room: Level	Room: Number	Room: Name	Type	Description	Count	Volume_packaging
07 zevende verdieping	07.01.2	toilet	74_PF_fontein-toilet	fontein	1	0.01 m ³
07 zevende verdieping	07.01.2	toilet	74_PF_toilet_wand	zwevend toilet	1	0.26 m ³
07 zevende verdieping	07.01.4	badkamer	74_douche-hoek_glas-01		1	
07 zevende verdieping	07.01.4	badkamer	74_PF_wastafel-900mm	wastafel	1	0.09 m ³

Table 5.2 Plumbing fixture schedule (own illustration, 2017)

about the length, width and height is missing for most components. This shows that information about the dimensions is not available. Secondly, most plumbing consists of one component; however, the showers only consist of a glass wall. Since these are modelled as a line or a group and not as plumbing, some of their properties do not include information about the location. Another error is that the room numbers are not separated. Room numbers are stated as 02.01.4 (second floor, first apartment, fourth room), which means it is impossible to filter on only the bathrooms (room 4). A final error is that the radiators are modelled within the family of generic models, which means they cannot be shown in a schedule that focuses on plumbing fixtures.

3. The third step is to solve the errors, which can quite easily be done for most of them. For instance, since all rooms also have a function (room 4 is always a bathroom) and they all have a level, one can filter on these in order to select only one type of rooms. Adding the dimensions is the most difficult error to solve. First, the parameter 'volume_packing' is added to all plumbing fixtures, which represents the volume including the packaging material. Then, the volume for each component needs to be calculated. For each piece of plumbing the volume is calculated including all the extra materials that come with it. The volume for the bathroom sink for instance consists of the sink itself, but also includes the mirror, the shelf, the faucet, the plug bottle trap and the angle valve. Every volume is increased by 10% to add packaging. A complete overview of the packaging calculations of all the plumbing can be found in Table 6.1. The volumes are then added to the BIM-model and visible in the schedule. Now, the volume of each room can easily be calculated. There is, however, one flaw. Although the volume is now calculated, the information about the dimensions is not fully complete. A volume of 0.012m³ looks really small, but it is in fact a shower enclosure of 2 meters high. It is really thin and therefore has a low volume, but one needs to take into account that the height asks for special measures when the element is transported.

5.2.2 TEGEL IDEE

Tegel Idee is responsible for the delivery and installation of all the floor and wall tiling. This consists of three types of tiling: wall tiles for the bathrooms and toilets, floor tiles for the bathrooms and toilets and floor tiles for the entrance of the building. An example of the properties of the tiling can be found in Table 5.3.

To retrieve the data that is available for the logistics and analyse this, three steps have to be taken.

1. The first step is creating a schedule. Since floor tiling is part of the family 'Floors' and wall tiling is part of the family 'Walls', two schedules need to be created. For both types, the schedule consists of the fields: level/base constraint, type, assembly code, description, function, area and volume. Part of the floor schedule is shown in Table 5.4.

General	
System Family	Floors
Type	43_FL_tegelvloer_300x300_10
Constraints	
Level	07 zevende verdieping*
Dimensions	
Perimeter	9720.0*
Area	5.220 m2*
Volume	0.052 m3*
Elevation at Top	21100
Elevation at Bottom	21090
Thickness	10
Construction	
Function	Interior
Phasing	
Phase Created	2. nieuwbouw
Identity Data	
Description	tegelvloer 10mm
Assembly Description	Vloerafwerkingen niet verhoogd - bekledingen
Assembly Code	43.22

*parameter differs per element

Table 5.3 Properties of the floor tiles (own illustration, 2017)

<Test_Floor Schedule>								
A	B	C	D	E	F	G	H	I
Level	Type	Area	Volume	Description	Function	Assembly Code	Comments	Assembly Description
11 elfde verdieping	43_FL_tegelvloer_300x300_10	1.0 m ²	0.01 m ³	tegelvloer 10mm	Interior	43.22		Vloerafwerkingen niet verhoogd - be
11 elfde verdieping	43_FL_tegelvloer_300x300_10	4.4 m ²	0.04 m ³	tegelvloer 10mm	Interior	43.22		Vloerafwerkingen niet verhoogd - be
11 elfde verdieping	43_FL_tegelvloer_300x300_10	4.2 m ²	0.04 m ³	tegelvloer 10mm	Interior	43.22		Vloerafwerkingen niet verhoogd - be
11 elfde verdieping	43_FL_tegelvloer_300x300_10	1.0 m ²	0.01 m ³	tegelvloer 10mm	Interior	43.22		Vloerafwerkingen niet verhoogd - be

Table 5.4 Floor schedule (own illustration, 2017)

- The main error is that it is not possible to select a room in the schedules for walls or floors. Walls and floors are not linked to a certain room and therefore they cannot be added to the schedule. This means it is not possible to filter on bathroom floors for instance.
- The error could be solved by dividing the tiles in two types: a bathroom type and a toilet type. The parameters would be completely the same except from the name, that either says bathroom or toilet. Then it would be possible to filter on just tiling for bathrooms or just for toilets. It would, however, be even better if the tiling could be linked to a specific apartment and room. Then it would be possible to filter for instance on all the tiling of apartment 1 on the second floor. This is very useful for the logistics because the tiles can then be divided per apartment. This is quite difficult, however. The floors can be linked to a specific room and apartment, because they are bound to them. This should preferably be done when setting up the model. For the walls, it is more difficult because they are not always bound to a room. Linking them to a room should be done while setting up the model. Still, even without a link to a specific apartment it is relatively easy to calculate the total number of tiles or the

number per floor. An overview of the calculations can be found in Appendix L.

5.2.3 CALDURAN

Calduran is responsible for the delivery of limestone. There are three types of limestone that they will deliver: regular limestone blocks (100 mm) for the corridors and shafts, chamfered blocks (100 mm) for the outer walls of the bicycle storage and smaller chamfered blocks (67 mm) for the inner walls of the bicycle storage. An example of the properties of the limestone can be found in Table 5.5.

General	
System Family	Basic Wall
Type	22_WA_kalkzandsteen_L100/198_100mm
Constraints	
Base Constraint	07 zevende verdieping*
Top Constraint	Up to level: 08 achtste verdieping*
Dimensions	
Length	19770.0*
Area	47.729 m2*
Volume	4.773 m3*
Construction	
Function	Interior
Material and Finishes	
Structural Material	Kalkzandsteen
Phasing	
Phase Created	2. nieuwbouw
Identity Data	
Description	kalkzandsteen 100mm
Assembly Description	Binnenwanden niet constructief - massieve wanden
Assembly Code	22.11

*parameter differs per element

Table 5.5 Properties of the limestone (own illustration, 2017)

The analysis of the data is carried out by means of the three steps.

1. A schedule is created for the walls, which is the same schedule that also includes the tiles of Tegel Idee. Part of the wall schedule is shown in Table 5.6.

<Test_Wall Schedule>						
A	B	C	D	E	F	G
Base Constraint	Type	Assembly Code	Description	Function	Area	Volume
06 zesde verdieping	22_WA_kalkzandsteen_L100/198_100mm	22.11	kalkzandsteen 100mm	Interior	14.8 m²	1.48 m³
06 zesde verdieping	22_WA_kalkzandsteen_L100/198_100mm	22.11	kalkzandsteen 100mm	Interior	34.6 m²	3.46 m³
06 zesde verdieping	22_WA_kalkzandsteen_L100/198_100mm	22.11	kalkzandsteen 100mm	Interior	7.2 m²	0.72 m³
06 zesde verdieping	22_WA_kalkzandsteen_L100/198_100mm	22.11	kalkzandsteen 100mm	Interior	0.8 m²	0.08 m³

Table 5.6 Wall schedule (own illustration, 2017)

2. The same error occurs here as happened with the wall tiling: it is not possible to select the room that the wall is bound to. Next to that there is another error. The small

chamfered blocks are 67 mm, however they are modelled as 70 mm. This difference however is so small that it is negligible.

- Here the same goes as for the wall tiling: it is difficult to link the walls to a specific room. However, for the limestone this is not necessary because they are constructed during the shell construction phase and do not need to be delivered per apartment. They can be filtered per floor, which is useful for the logistics. An overview of the calculations can be found in Appendix M. An important remark, is that the pallets and the amounts of blocks are rounded up, the remaining material that is left when the blocks are cut is included. One way to decrease the amount of leftover material is with the Uitgekiend Service of Calduran. With this service, they model the limestone with their own BIM software and calculate exactly how many blocks are necessary per floor (A. Gils, personal communication, March 14, 2017). Then they deliver custom pallets that are matched per floor, so it is not necessary anymore to move blocks from one floor to another. This makes the logistics much more efficient because all the materials are brought to the exact place at once.

5.2.4 HALFEN

Halfen is responsible for the delivery of the wall supports and steel lintels. They create their own BIM-model, based on the IFC-standards. This model can be linked to the procurement model of project Bètatoren. An example of the properties of the wall supports is shown in Table 5.7.

General	
System Family	Structural Framing
Type	Geveldrager 33749*
Constraints	
Top Elevation	+38.310*
Bottom Elevation	+38.355*
Dimensions	
Height	45 mm
Length	1295 mm*
Width	95 mm
Weight	8.200 kg*
Material and Finishes	
Finish	FV/P2 RAL
Phasing	
Phase Created	New construction
Identity Data	
Description	BLL45*95*6

*parameter differs per element

Table 5.7 Properties of the wall supports (own illustration, 2017)

Within the period this analysis was carried out only the preliminary version of the model was available. Therefore, it could be that certain errors that are identified during this analysis are solved within the final model.

- Since the model of Halfen was exported as an IFC-model, it needs to be imported in other software in order to read it. This is possible with for instance Autodesk Revit.

Because the model was made by Halfen and not by the architect, there are some differences in the models. The Halfen model is much more detailed, every aspect of the wall supports is modelled, including the screws. There is, however, no context. The wall supports are not modelled together with the building. Since all parts of the wall supports belong to the same family, Structural Framing, a schedule can be created. Part of this schedule is shown in Table 5.8.

<Structural Framing Schedule>								
A	B	C	D	E	F	G	H	I
Type	Level	Elevation at Bottom	Elevation at Top	Count	Volume	Weight	IfcDescription	NameOverride
Geveldrager				1	0.000 m³	11.10 kg	BLL45*95*6	Geveldrager
Geveldrager 1412				1	0.000 m³	11.10 kg	BLL45*95*6	Geveldrager
Geveldrager 1628				1	0.000 m³	11.10 kg	BLL45*95*6	Geveldrager
Geveldrager 1847				1	0.000 m³	5.60 kg	BLL45*95*6	Geveldrager

Table 5.8 Structural framing schedule (own illustration, 2017)

2. The schedule immediately shows the difficulty of this external model. There is almost no information available in the parameters. The types are visible but since the model is not linked to Bètatoren there are no levels. For some components, there are a top elevation and a bottom elevation or an offset. The next error concerns the lack of data regarding the dimensions. For only two types of components there is data available about the length, width, height and weight. For the other components, there is no information available. Another error is that for some components the material is not clear and the type also does not state what kind of material it is. This makes it very difficult to read the schedule.
3. The errors are very difficult to solve because they are made while building the model. Some of the errors (such as the levels) could be solved if the model was linked to the procurement model. For some components, there is simply information missing about the dimensions. The volume is not included as a parameter but could be easily added once the other dimensions are known. In order to use this model for the logistics there is too much information lacking, therefore it is not possible to make any calculations regarding the deliveries.

5.2.5 COMPARING THE MODELS

As shown in the analysis there are quite some differences in the availability of information regarding the different components. Appendix N shows an overview of all the modelled components and shows whether specific information is available in the parameters (checkmark), whether it is missing (cross) or whether the information is irrelevant (line). The information is divided in four categories: designation (what is it), dimensions (how big is it), location (where does it need to go) and time (when does it need to be delivered or constructed). None of the categories has the complete information available for all components, although the designation comes very close. Only some showers are lacking a family because they only consist of a line and not of a component. The category 'dimensions' largely differs. Weight is missing for almost every component, but the walls and floors have every other information available. For the plumbing, most information is missing and needs to be entered manually. Regarding the location almost all information, if necessary, is available. The main difficulty is concerned with the information about time. Although the information about phasing is present for all components, there is no information regarding the planning or whatsoever. The phasing only gives information about whether the component is part of the existing building or whether it is part of the new construction. It says nothing about when the component

needs to be constructed within the phase. What is interesting to see is that there is not much of a pattern concerning the type of party, the differences are mainly based on the component. Walls and floors are relatively complete, regardless of whether it concerns a subcontractor (Tegel Idee) or a supplier (Calduran). The other differences also cannot be reduced to the type of party.

The main reason for the incompleteness of the information is that the main contractor does not use the 3D-information and therefore does not ask the third parties to include this in the model. The main contractor receives the model from the architect, which includes some logistic information, but also lacks a lot as seen in the table of Appendix N. This information, however, is not checked nor completed. The main contractor does not check the logistic information and neither do the subcontractors and suppliers. Only the parties that create their own aspect-model check their information. Because the main contractor does not use the 3D logistic information for the management of the logistics currently, it does not matter to him whether the information is complete or not. Also, most information is send in 2D, so the information in the BIM-model is not even used. Of course, this needs to change in order to manage the logistics with BIM. To make this possible, all the information needs to be complete. An important remark here is that the model should not be completed afterwards (as is the case with Waal), but should already be designed for logistics management in the procurement phase. At the start of the procurement phase clear agreements must be made about what kind of information needs to be included in the model (volume, weight, usage information, etc.). This information can easily be included in the families of the components. These families should not be created by a modeller but by the manufacturers, since they have the detailed information. The families only need to be created once, and then can be used for every project. The situation of Waal with an incomplete BIM-model therefore could have easily been avoided if clear agreements had been made beforehand. These agreements include the allocation of the logistic data. The information about the dimensions is the responsibility of the subcontractors and suppliers, they have the most detailed knowledge of their products and therefore have to make sure all logistic information is complete. The information about the location is partly the responsibility of the main contractor and partly of the architect. The architect is responsible for the design of the building and often also creates the coordination models of the design and execution phase. The main contractor is responsible for the site layout. Together they are responsible for the location of the materials and components. The information about the planning is the responsibility of the main contractor, because he is responsible for the overall planning of the whole project.

5.3 THE INFORMATION FLOW

This sub-question focusses on the information flow from the third parties to the main contractor in the procurement phase. Case study research of project Bètatoren has shown how this information flow currently works in practice. However, this differs from how it should work in order for the main contractor to get control of the logistics. Both are compared to show what is necessary to go from the current situation to an improved situation, with the current resources.

5.3.1 HOW DOES IT WORK?

Case study research in project Bètatoren shows that the use of BIM is seldom chosen, most of the time the choice is made to send information in the traditional way. The responsibility for this lies with the main contractor. Even though most subcontractors and suppliers have started to work with BIM, they will not use it if the main contractor does not ask them to. All four selected parties stated that they do what the main contractor asks of them, irrespectively of what their own preferences are. If the main contractor demands BIM, they will do it as long as they have the resources. If the main contractor does not want BIM, they will not model even if it is more beneficial for them to do so (A. Gils, personal communication, March

14, 2017; M. van Leeuwen, personal communication, March 14, 2017; M. Nijboer, personal communication, March 14, 2017; J. Noteboom, personal communication, March 14, 2017). The main contractor has its own reasons not to ask parties to model. For some parties, they state that it is not necessary or it is too expensive. Some of the reasons stated by Waal are that: a lot of the drawings are also sufficient in 2D, a model will only be used for the procurement phase, the client does not see the benefits of BIM and some parties, for instance the installation companies, have such a high degree of autonomy that they should choose for themselves how they work, as long as the final product meets the standards (D. Adegeest, J. de Korte & J. van Schadewijk, personal communication, March 08, 2017).

The four subcontractors and suppliers were interviewed to research what kind of information they send to Waal during the procurement phase and how they send this. What is striking, is that there is very little communication regarding the logistics. Once the contract has been signed, Waal sends their planning to the subcontractors and suppliers with the starting date of their activities. The subcontractors create their own planning based on this date. They plan their own logistics, including the deliveries. A few weeks before the start they will communicate this with the construction supervisor at the construction site, other than that there is little to no communication about the logistics (A. Gils, personal communication, March 14, 2017; M. van Leeuwen, personal communication, March 14, 2017; M. Nijboer, personal communication, March 14, 2017; J. Noteboom, personal communication, March 14, 2017). Jorg van Schadewijk (personal communication, April 13, 2017) states that he has never had a question from a subcontractor during the procurement phase about how the logistics would be organised on the construction site. They simply assume that the main contractor will take care of it. The parties that use BIM also send their model to Waal, a few weeks before the start of the construction. These aspect-models are based on the IFC's of the architect and the construction engineer, which are provided by the main contractor (A. Gils, personal communication, March 14, 2017; M. van Leeuwen, personal communication, March 14, 2017; M. Nijboer, personal communication, March 14, 2017). If necessary, the parties check their model with the models of other parties to make sure there are no clashes. The mechanical installation company for instance compares their model with the model of the electrical engineer. They do not check their model with the procurement model. They only use that model as a basis for their model, but do not check the information in it (A. Gils, personal communication, March 14, 2017; M. van Leeuwen, personal communication, March 14, 2017; M. Nijboer, personal communication, March 14, 2017). The main contractor is responsible for checking the different models with the procurement model. However, there is no link between the procurement model and the aspect-models of the subcontractors.

This analysis emphasizes what was already concluded in the social network analysis: there is a mismatch between the production processes and the information processes. Some information is send in a traditional way, some information is send via BIM, but none of the information is connected to the production processes of the materials or the construction site. Out of the three types of logistic information, only the location is present in the BIM-model for most of the components. The dimensions are partly there: some components are modelled correctly while others are incomplete. The time factor is missing for all of the components because the planning is not linked to the BIM-model. The missing information is either send in 2D (planning, drawings) or not send at all because the main contractor does not ask for it. Also, some of the information that is present in the BIM-model is send in 2D anyway. The main contractor controls the process but does not coordinate the information, neither does anyone else. This leads to a fragmented and uncoordinated information flow. A schematic representation of this information flow is shown in Figure 5.3.

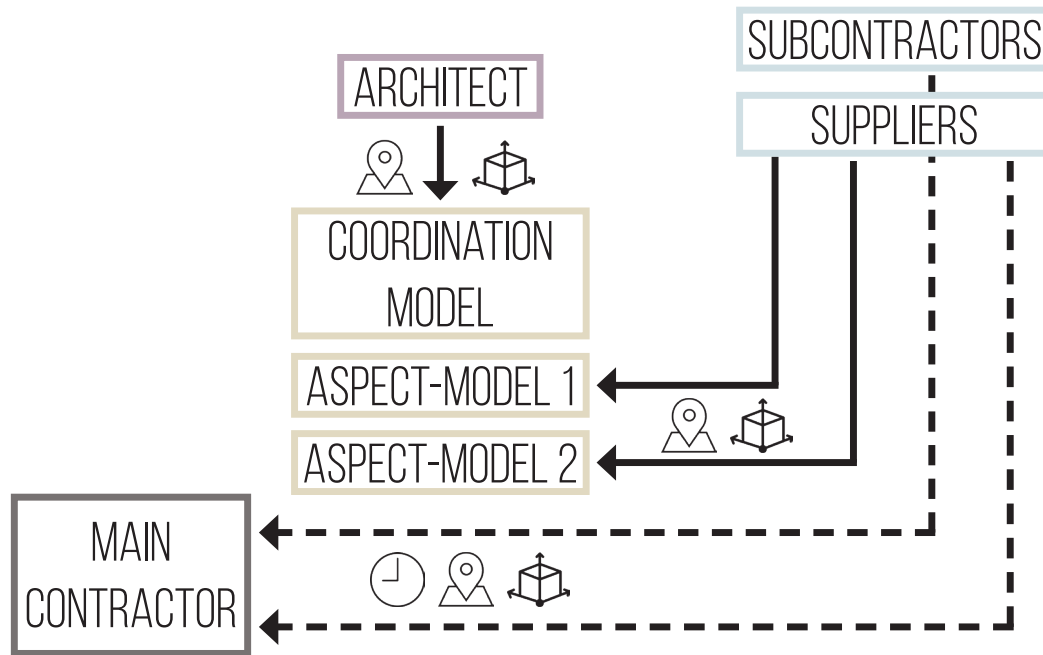


Figure 5.3 Phase two – current situation (own illustration, 2017)

5.3.2 HOW SHOULD IT WORK?

One of the main difficulties in this phase is the fragmentation. Some parties use BIM to create models and some parties do not. Some use BIM only for the procurement phase while others also use it for the logistics. The final product differs for each party, which makes it very difficult for the main contractor to align these with each other. This could be solved by linking the procurement model and the aspect-models. HFB, a BIM-agency in Rotterdam that specialises in creating BIM-models for complex projects, also works this way. They create one large model that consists of the coordination projects and all the aspect-models (A. Sagijs, personal communication, March 13, 2017). An example of this is shown in Figure 5.4.

For large projects this can go up to 52 aspect-models, which is still workable. However, to be able to create one large BIM-model it is important that the input is correct and that the main contractor has the necessary knowledge and skills to put the models together. The input should be based on the IFC-standards and the BIM basis ILS. The Industry Foundation Classes is a neutral and open file that can be used to exchange information between different types of software (BIM Loket, 2017b). A model created in, for instance, Autodesk, can be exported as an IFC-file. This IFC-file can then be send to another party and opened in for instance Solibri. This makes it possible for the whole supply chain to exchange information without data loss. The BIM basis ILS is an agreement between several construction companies about the specifications of information delivery. If all parties stick to the agreement, all the information will be exchangeable, structured, unambiguously, correct, complete and usable (BIM Loket, 2017a).

The main contractor should encourage all parties to work with BIM and provide them with knowledge and assistance. All parties focus on creating their aspect-model and the main contractor is responsible for coordinating the aspect-models and linking them all together. The aspect-models include all information regarding the design (drawings), construction, materials and the quantities. It is very important that all components are modelled properly. The subcontractors and suppliers are responsible for the information with regards to their own materials. They have to make sure their aspect-models include the right information with regards to volumes (including packaging), weight, storage location and all other information that is important for the logistics. The information about the planning is the responsibility of

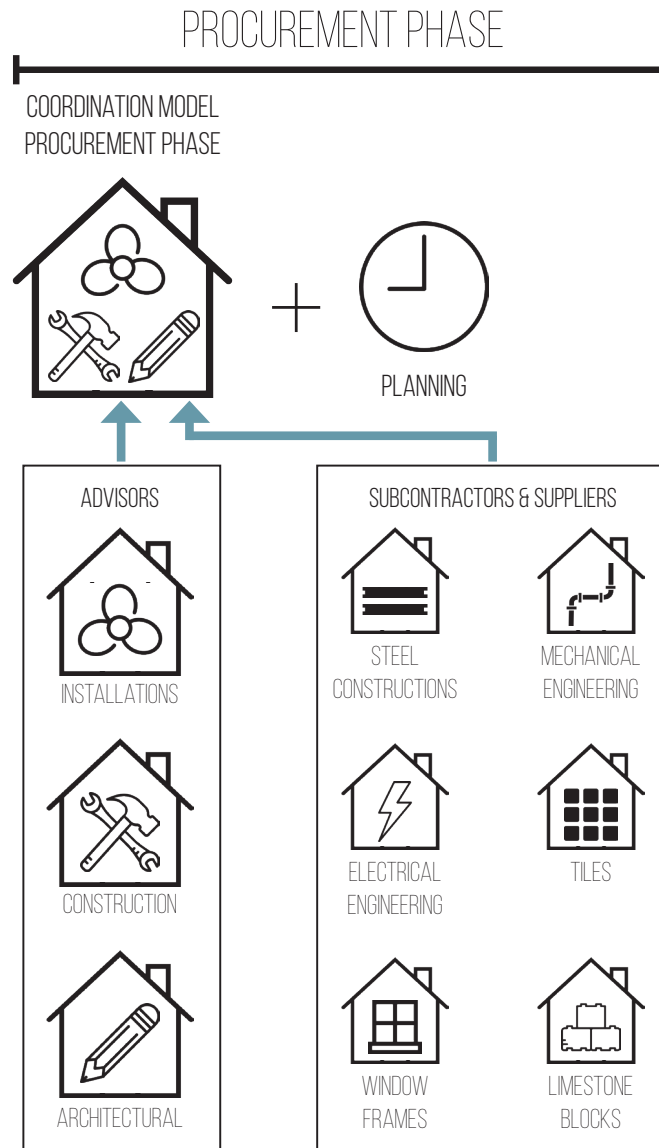


Figure 5.4 BIM – Phase two (own illustration (2017) based on Pioneering (2013))

the main contractor. They are always responsible for the overall planning of the project so they should also manage the planning in BIM. It is possible to plan with a BIM-model but it requires specific knowledge, extra software and a different structure of the model (A. Sagius, personal communication, March 13, 2017). Therefore, it is advisable that main contractors hire experts to do BIM-planning for them if their own modellers do not have the necessary skills. If these changes are made, the information flow should be streamlined and coordinated by the main contractor. A schematic representation of the information flow is shown in Figure 5.5.

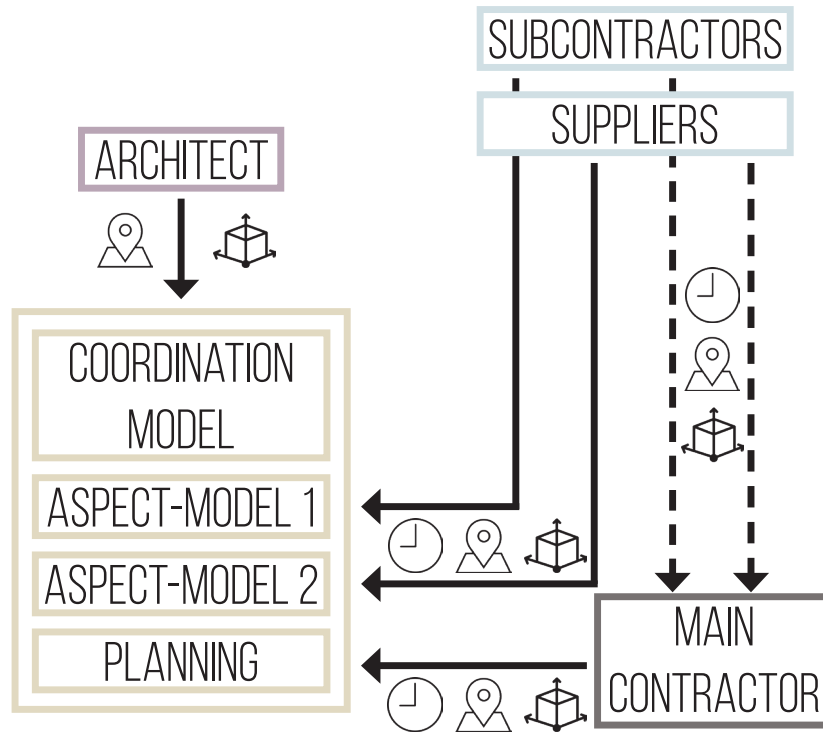


Figure 5.5 Phase two – improved situation (own illustration, 2017)

Once the information is put into BIM, the main contractor can use it to manage the logistics. This will be discussed in the next chapter.

06

MANAGING THE LOGISTICS WITH BIM

The third phase of the conceptual framework, Figure 2.4, takes place during the execution phase. During this phase, the main contractor has to manage the construction of the building and has to coordinate the third parties. The sub-question related to this phase is:

How does the main contractor need to use the BIM-model in order to get control of the logistics in the execution phase?

This sub-question is divided in two parts. The first part is an overview of the use of BIM for logistics management in project Bètatoren. It describes how the information that was analysed in phase two can be used to manage the logistics in the construction phase. The second part concerns a general picture of logistics management with BIM. It focusses on what kind of logistic information can be extracted from BIM, how this information is coordinated and how the logistics can and should be managed with it. All parts together form the answer to the sub-question.

6.1 MANAGING THE LOGISTICS OF PROJECT BÈTATOREN

In Paragraph 4.2 the logistic measures for project Bètatoren have been described, which consist of a material container in combination with BIM. In Paragraph 5.2 an overview was presented of all the information that was extracted from BIM. Now, these two need to be combined to show how the information from BIM can help to manage the logistics. For some subcontractors and suppliers an overview has been made of the volumes per apartment or per floor, based upon the information extraction and analysis from BIM. The material container will only be used in the finishing part of the construction phase, so both Halfen and Calduran will not be using it. Also, there is not enough logistic data from Halfen to give a good estimation of the volumes of their materials. Therefore, only Breman and Tegel Idee are included in this overview.

6.1.1 BREMAN

Project Bètatoren has a very repetitive floor plan. The first two floors consist of the entrance, bike storage and some commercial space. The apartments start at the second floor. The second until the ninth floor have the same floor plan and consist of ten apartments per floor. An example of one of these floor plans can be found in Appendix O. Out of the ten apartments there are eight without a bathtub and two with a bathtub. All other plumbing is the same. The tenth until the eighteenth floor also have the same floor plan and consist of six apartments per floor. An example of these floor plans can be found in Appendix P. Out of these six apartments there are five without a bathtub and one with a bathtub. Since all bathrooms are the same, the only difference is an extra bathtub, it is relatively easy to create an overview of the total volume of the plumbing. Table 6.1 shows an overview of the plumbing volumes of one apartment.

APARTMENT									
Toilet	Toilet	Toilet	0.37	0.53	0.4	110%	0.086	m3	
		Toilet flush mounting	1.2	0.6	0.2	110%	0.158	m3	
		Control panel	0.2	0.1	0.005	110%	0.000	m3	
		Toilet seat	0.37	0.53	0.05	110%	0.011	m3	
		Toilet brush holder	0.1	0.1	0.25	110%	0.003	m3	
		Toilet roll holder	0.15	0.1	0.12	110%	0.002	m3	
		Total					0.260	m3	
	Sink	Toilet sink	0.36	0.26	0.095	110%	0.010	m3	
		Plug bottle trap	0.18	0.26	0.05	110%	0.003	m3	
		Sink faucet	0.155	0.111	0.036	110%	0.001	m3	
		Total					0.013	m3	
	Total					0.273	m3		
	Bathroom	Sink	Sink	0.9	0.48	0.165	110%	0.078	m3
Sink angle valve			0.072	0.08	0.054	110%	0.000	m3	
Plug bottle trap			0.18	0.26	0.05	110%	0.003	m3	
Sink faucet			0.155	0.111	0.036	110%	0.001	m3	
Sink shelf			0.6	0.165	0.01	110%	0.001	m3	
Mirror			0.6	0.8	0.006	110%	0.003	m3	
Total							0.086	m3	
Shower		Shower faucet	0.298	0.162	0.1	110%	0.005	m3	
		Shower rod	0.15	0.5	0.1	110%	0.008	m3	
		Shower enclosure	1.95	0.895	0.006	110%	0.012	m3	
		Total					0.116	m3	
Bathtub		Bathtub	1.8	0.8	0.5	110%	0.792	m3	
		Bathtub faucet	0.298	0.162	0.1	110%	0.005	m3	
		Bathtub rod	0.15	0.4	0.1	110%	0.007	m3	
		Bathtub enclosure	1.5	0.8	0.006	110%	0.008	m3	
		Total					0.812	m3	
Miscellaneous		Radiator	0.5	0.9	0.15	110%	0.074	m3	
		Total					0.074	m3	
Total						1.088	m3		
TOTAL - WITHOUT BATHTUB							0.549	m3	
TOTAL - WITH BATHTUB							1.361	m3	

Table 6.1 Plumbing volumes of one apartment in project Bètatoren (own illustration, 2017)

The data for this table was partly retrieved from BIM and partly traditional. Data analysis in Paragraph 5.2.1 showed that a lot of information regarding the dimensions of the plumbing fixtures was missing. This data was retrieved from a product overview provided by Breman. This overview showed the types of plumbing that would be installed. Research on the website of the suppliers showed the exact dimensions. Altogether the volume of the plumbing could be calculated. The calculation shows that the plumbing volume is either 0.55 m³ (without a bath) or 1.36 m³ (with a bath). Appendix Q shows the total calculation of the plumbing volume. The volumes are stated per apartment, per floor and for the total building (93.91 m³). Now it must be checked whether the volumes fit in the material container according to the planning. The total plumbing volume of a floor plan with ten apartments is 7.12 m³. A standard cargo container has an average volume of 33.2 m³ (5.89 m x 2.35 m x 2.39 m), which means that it would be able to fit 4.7 floors of plumbing materials. However, the plumbing volumes are not perfect cubes. The shower and bathtub enclosures, for instance, are very large (up to 1.95 x 0.895 m) but very thin (6 mm). Their volume is about the same as that of the toilet sink, but the dimensions are completely different. To get more insight in de dimensions, a 3D view of the bathroom components in a container has been made (see Figure 6.1).

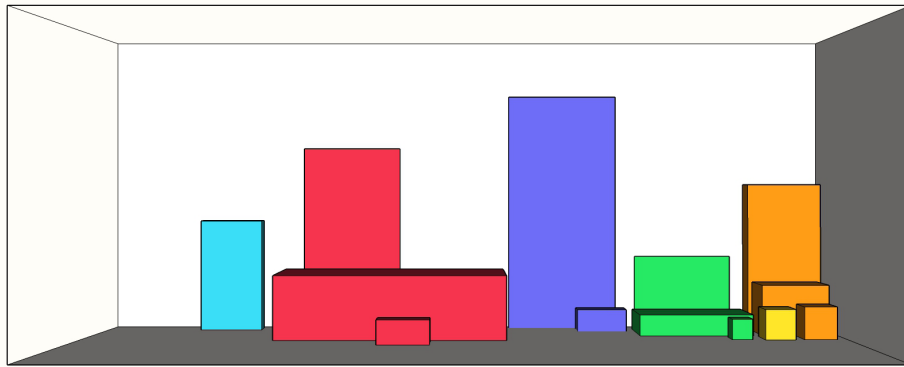


Figure 6.1 Front view of plumbing volumes in a container (own illustration, 2017)

The coloured blocks reflect the plumbing volumes of one apartment. The orange volumes belong to the toilet, the yellow volume is the toilet sink, the green volumes form the bathroom sink, the purple volumes form the shower, the red volumes the bathtub and the blue volume is the radiator. The very small volumes have been combined, because in practice they would also come in one box. The 3D-views (Figure 6.1 and 6.2) show that the plumbing of one bathroom easily fits in the material container.

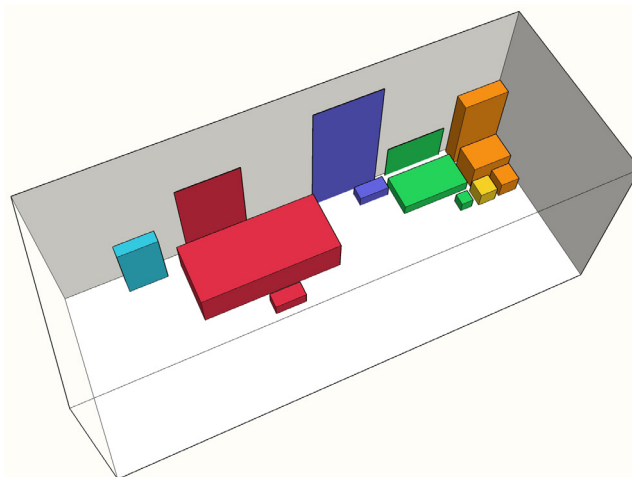


Figure 6.2 Top view of plumbing volumes in a container (own illustration, 2017)

Fitting 4.7 floors (or 47 bathrooms) in a container, however, might be a bit more difficult. Since not all components can be stacked on top of each other and there needs to be space to get the materials in and out, there is some space in the container that cannot be used. Looking at the container and the volumes it would be possible to fit around 2.5 to 3 floors (or 25 to 30 bathrooms) in the container. The current set-up of the logistic plan is divided per week. Every week the container needs to be filled with components and in the weekend the runners place these components on the right place on the right floor. The current planning aims at installing one floor per week. Based on the plumbing calculations this would easily fit. It is possible to place all the bathroom materials of one floor in the container, and there would be much space left for other materials, such as the window frames or tiles.

6.1.2 TEGEL IDEE

Tegel Idee is responsible for the tiling of the bathrooms and the toilets in the apartments. Both rooms have floor tiles and wall tiles, the type of tiles are the same for both rooms. The floor tiles are 30 x 30 cm and 1 cm high. The wall tiles are 15 x 30 cm and 1 cm high. The size of the bathrooms varies per apartment, but the toilets are almost the same size for every apartment. The tiles will be transported on pallets, which will be distributed per floor. It is therefore not necessary to know the number of tiles per room. As explained in the former paragraph, Bètatoren has a very repetitive floor plan so the number of tiles are the same for the 2nd to 9th floor and the 10th to 18th floor. The data of the total surface was retrieved from the BIM-model. For the 2nd until the 9th floor the 7th floor was selected as the reference floor and for the 10th until the 18th floor the 11th floor was selected as the reference floor. Since the floor tiles and the wall tiles have different sizes, the calculations for the logistics are also different. Table 6.2 shows an overview of the square metres of floor tiles that are needed, according to the BIM-model. The same goes for Table 6.3, which shows the overview of the wall tiles.

FLOOR TILES - BÈTATOREN		WALL TILES - BÈTATOREN	
Ground Floor	0.00 m2	Ground Floor	0.00 m2
First Floor	0.00 m2	First Floor	0.00 m2
Second Floor	61.70 m2	Second Floor	280.10 m2
Third Floor	61.70 m2	Third Floor	280.10 m2
Fourth Floor	61.70 m2	Fourth Floor	280.10 m2
Fifth Floor	61.70 m2	Fifth Floor	280.10 m2
Sixth Floor	61.70 m2	Sixth Floor	280.10 m2
Seventh Floor	61.70 m2	Seventh Floor	280.10 m2
Eighth Floor	61.70 m2	Eighth Floor	280.10 m2
Ninth Floor	61.70 m2	Ninth Floor	280.10 m2
Tenth Floor	35.30 m2	Tenth Floor	157.10 m2
Eleventh Floor	35.30 m2	Eleventh Floor	157.10 m2
Twelfth Floor	35.30 m2	Twelfth Floor	157.10 m2
Thirteenth Floor	35.30 m2	Thirteenth Floor	157.10 m2
Fourteenth Floor	35.30 m2	Fourteenth Floor	157.10 m2
Fifteenth Floor	35.30 m2	Fifteenth Floor	157.10 m2
Sixteenth Floor	35.30 m2	Sixteenth Floor	157.10 m2
Seventeenth Floor	35.30 m2	Seventeenth Floor	157.10 m2
Eighteenth Floor	35.30 m2	Eighteenth Floor	157.10 m2
TOTAL	811.30 m2	TOTAL	3,654.70 m2

Table 6.2 and 6.3 Overview of floor and wall tiles of project Bètatoren (own illustration, 2017)

The calculations for the logistics are based upon these overviews and can be found in Appendix L. The tiles will be delivered per pallet, and the calculations show the total number of pallets for the wall tiles (37.22) and the floor tiles (8.26). This would be the number of pallets if all tiles would be delivered at the same time, but that is not the case. With the use of the material container the tiles will be delivered per week, and according to the planning that would be one floor. The calculations also show the number of pallets needed per floor. For the 2nd until the 9th floor 0.63 pallets are needed for the floor tiles and 2.85 pallets for the wall tiles. These cannot be merged, so three pallets are needed. An overview of how much space these take up in the container is presented in Figure 6.3.

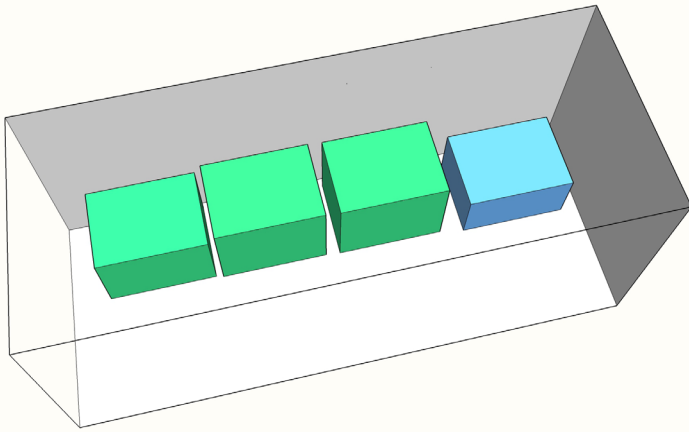


Figure 6.3 Top view of tiles in a container – 2nd to 9th floor
(own illustration, 2017)

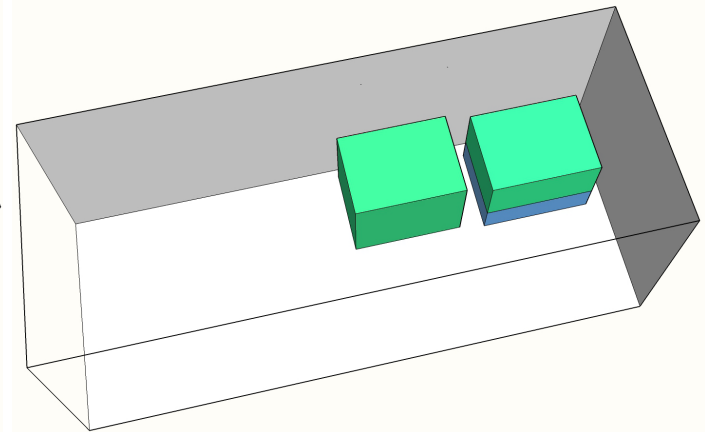


Figure 6.4 Top view of tiles in a container – 10th to 18th floor
(own illustration, 2017)

The blue volume is the pallet with the floor tiles and the green volumes are the pallets with the wall tiles. The overview shows that the volumes easily fit in the container, if necessary the pallets could also be stacked.

For the 10th until the 18th floor 0.36 pallets are needed for the floor tiles and 1.60 pallets for the wall tiles. These pallets can be merged, so only two pallets are needed. The tiles are all provided by the same supplier, so they can make sure to place the two types of tiles on one pallet. An overview of the pallets in a container is presented in Figure 6.4. Since these floors are smaller, the pallets take up much less space. For the 2nd until the 9th floor two containers might be needed if both Breman and Tegel Idee are going to use them. All the volumes of ten bathrooms and the tiles of one floor will probably not fit while making sure everything is stacked properly. For the 10th until the 18th floor the volumes will fit in one container. Two containers are also necessary if other subcontractors, for instance the window frame supplier, are also using the material container.

Based upon the previous calculations for Breman and Tegel Idee, the logistic plan of filling a material container per week seems relatively reasonable and enforceable because of the amount of materials and the planning. The difficulty, however, is getting the subcontractors and suppliers to also agree on this system. From the viewpoint of the main contractor using a material container is quite beneficial, however the third parties might have a different perspective on this. This will be covered in the next chapter.

6.2 THE INFORMATION FLOW

This sub-question describes the information flow from BIM to the main contractor and then back to the subcontractors and suppliers. It focusses on how the information that is extracted from BIM can be used to manage the logistics in practice. Case study research of project

Bètatoren has shown how this information flow currently works in practice. However, this differs from how it should work in order for the main contractor to get control of the logistics. Both are compared to show what is necessary to go from the current situation to an improved situation, with the current resources.

6.2.1 HOW DOES IT WORK?

The information flow of the third phase consists of two steps: in the first step the main contractor extracts all the necessary information from BIM and in the second step he uses this information to manage the logistics during the execution phase of the project. Within the first step the main focus point is the connection between phase two and three, which is what happens within BIM. The subcontractors and suppliers put certain information into BIM and the main contractor extracts certain information. However, it is very important that this information matches, otherwise the main contractor might base his logistics management on the wrong information. To perform a quality control on the received information is the responsibility of the main contractor, according to Dennis Adegeest, Joost de Korte & Jorg van Schadewijk (personal communication, March 14, 2017) from Waal. It is the task of the project planners to check the models of the subcontractors and suppliers with the coordination model. All the subcontractors and suppliers that make a model send the IFC-file to Waal. They can check that IFC-file with their coordination model in specialised software, such as Solibri. Solibri is a software program that specialises in checking models by performing clash detections, deficiency detections, BIM compliance and model comparisons (Solibri, 2017). It also has the possibility for a full information take-off, which is very useful for the project planners. What needs to be noticed is that, at least in project Bètatoren, the main contractor does not perform a full quality control on the coordination model. Once they receive the model from the architect, they perform an overall check to see if the quantities match their purchasing overview, but they do not check details such as the types or the dimensions (D. Adegeest, J. de Korte & J. van Schadewijk, personal communication, March 08, 2017). This increases the risk of failures in a later phase. Once the project planners have performed the quality control and the aspect-model matches the central model, they can extract the information they need. This information mainly consists of the drawings and the quantities of materials, other logistic information often is not included (D. Adegeest, J. de Korte & J. van Schadewijk, personal communication, March 14, 2017). The degree of information largely differs per party. The installation companies are very close involved in the project and have a high degree of autonomy. Their contract is based on performance, as long as they deliver a perfect product the main contractor does not interfere with how they do that. They check their own quantities, plan their own logistics, etc. With other parties a delivery schedule is set up so the main contractor has a general overview of who will be delivering what and when. During the construction, the construction supervisor is responsible for confirming the agreed dates. Subcontractors and suppliers that do not work with BIM provide their information in the traditional way by sending separate drawings, a separate planning, etc. These are all checked separately by the main contractor, which of course takes more time than checking a model with certain software (D. Adegeest, J. de Korte & J. van Schadewijk, personal communication, March 14, 2017).

Once all the information is extracted and analysed, it should be used to manage the logistics. This step is currently missing in project Bètatoren. The 3D-information in BIM is extracted as 2D-information and then used for the management of the logistics. One of the reasons is that there currently is no link between BIM and the planning. The first step in supply chain management with BIM is linking the central model to the central planning, and this currently does not happen at Waal (D. Adegeest, J. de Korte & J. van Schadewijk, personal communication, March 14, 2017). Next to that, Waal uses the same processes in the execution phase as they did before BIM. They are used to receive all the information in 2D and manage the logistic information with this 2D information. Adopting BIM did not change this, they still manage their logistics with 2D information.

To conclude, the logistic information and BIM are almost completely disconnected in this phase. The main contractor does perform a quality control on the aspect-models, but since they do not fully check the coordination model there could still be a mismatch. The logistic information in BIM is not complete, which makes it impossible to manage the logistics from BIM. The logistic information that is present is extracted in 2D and then used to manage the actual logistics on the construction site, together with the 2D-information that was received directly from the subcontractors and suppliers. This creates an information flow that is completely disconnected from BIM. A schematic representation of this information flow is shown in Figure 6.5.

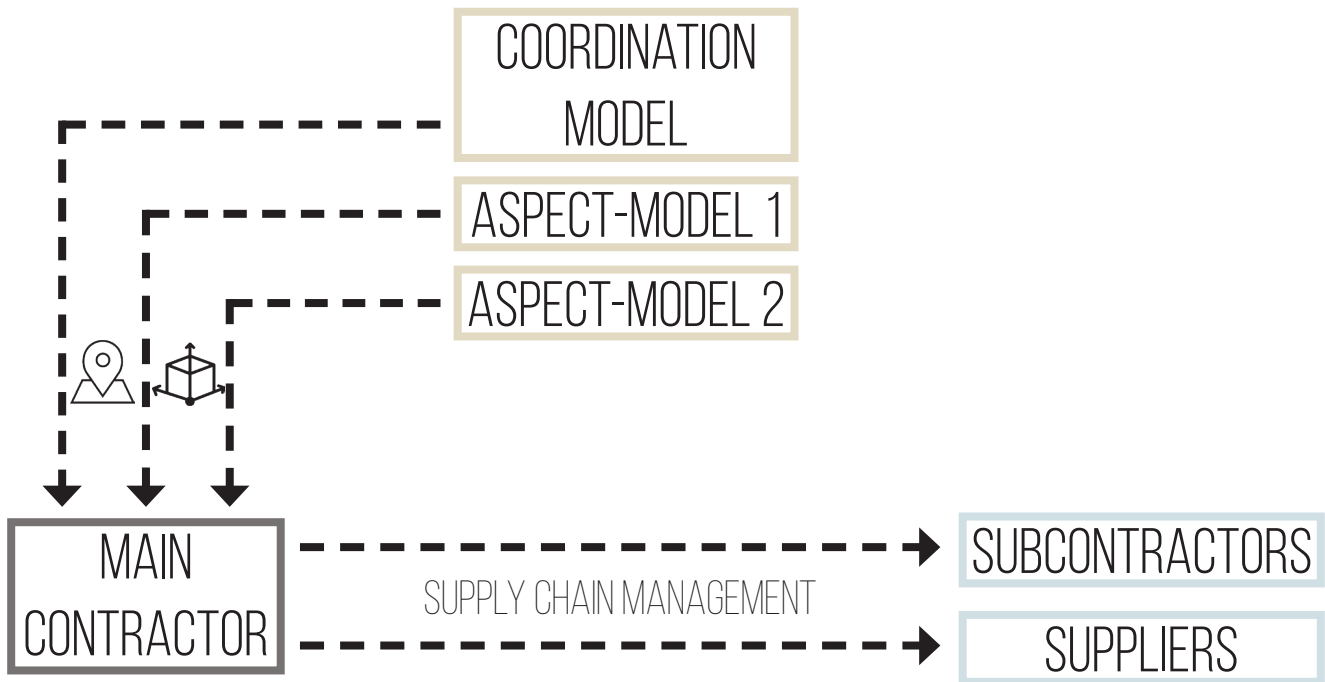


Figure 6.5 Phase three – current situation (own illustration, 2017)

6.2.2 HOW SHOULD IT WORK?

The former paragraph described the current status of supply chain management and BIM within project Bètatoren and Waal. Currently, the link between BIM and the logistics is missing in the construction phase. Therefore, certain things need to change before BIM can be used to manage the logistics. The first step is linking the BIM-model to the planning. The time factor is currently missing in the BIM-model, and this is crucial for supply chain management. With 4D simulation logistic operations can be analysed in detail beforehand, which helps to forecast possible problems and enhances the decision-making process (Bortolini et al., 2015). The second step is finding a way to manage the inventory. In order to make BIM useful for the construction supervisor he must be able to manage all the material supplies on the construction site. To do so, the BIM-model must include a detailed overview of the layout and the use of the construction site and a way to manage the materials. Also, the material storage, the building crane and the scaffolding, for instance, should be incorporated in the model. In order to do so several frameworks have been developed for automated material logistics planning and management. An example of such is the framework of Cheng and Kumar (2015a), which extracts geometric and material information from a BIM-model and integrates this information with planning information in order to create a dynamic construction site layout model. This framework can be used to plan and monitor the material flows. Another example is the model of Chau et al. (2004), that focusses on managing on-site logistics, including site usage and material management. Their model is useful for both day-to-day logistics management and for predicting the occurrence of any potential site problems. These

are only two of the examples in which BIM is used for the management of the on-site logistics, showing that there are multiple possibilities for a main contractor to use BIM in the execution phase. Finally, a link between the BIM-model of the project and the production system of the subcontractors and suppliers would make the supply chain even more efficient. If they would produce from BIM, ordering and delivering materials would be much more simplified. An example of the final BIM-structure is shown in Figure 6.6.

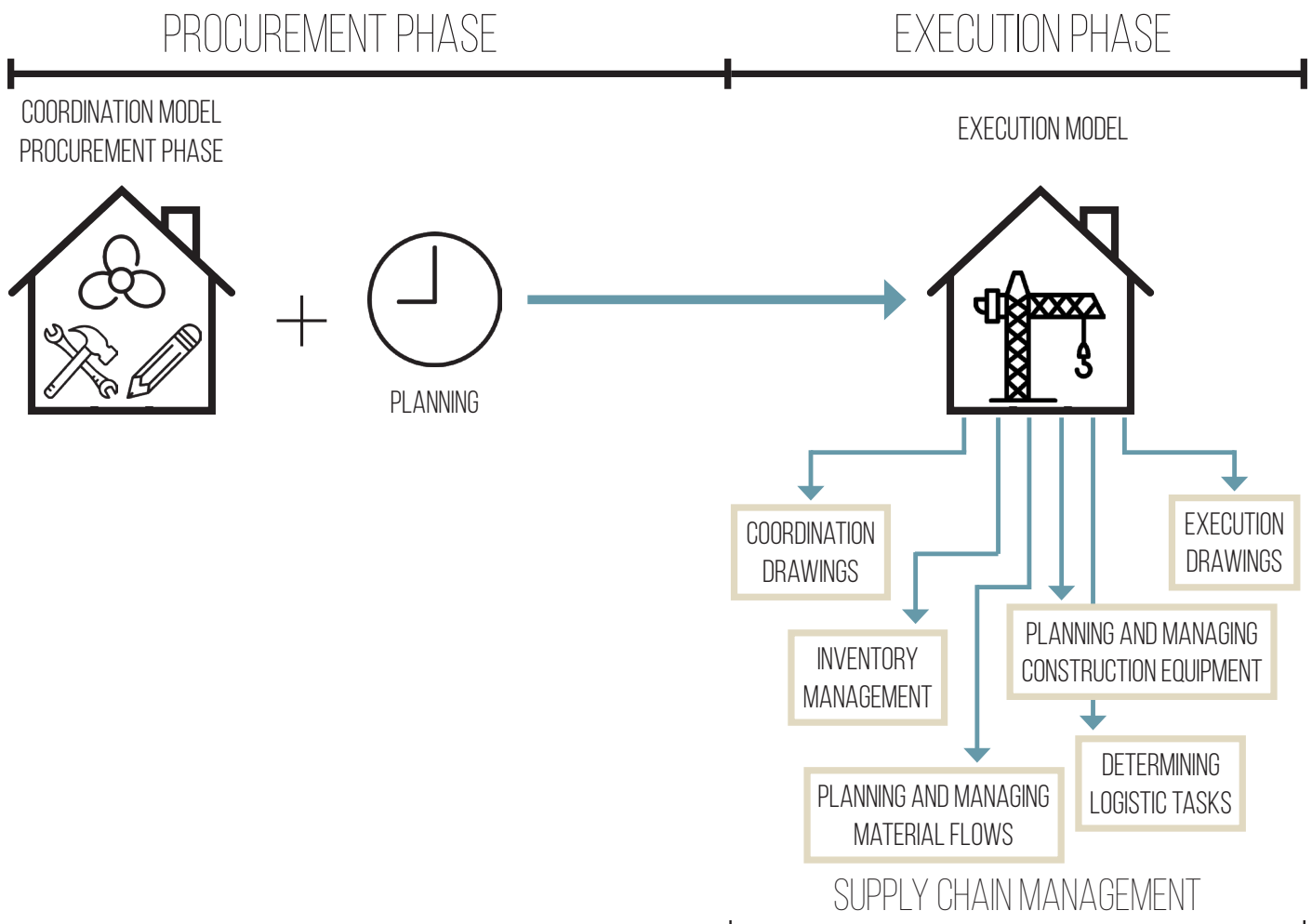


Figure 6.6 BIM - Phase three (own illustration (2017) based on Pioneering (2013))

Alex Sagius, the BIM-expert from HFB, confirms this. First, he says, contractors should make sure they are able to make good models and are able to combine these models with the models of their subcontractors and suppliers (A. Sagius, personal communication, March 13, 2017). For this the main contractors need to have detailed knowledge of BIM, experience with combining different models and very close communication with the third parties. All the right units and the right components need to be put in the model in the right way. Only when the models match perfectly they can go on to the next step, which is planning with the model. Pilots with, for instance, Vico and Synchro, planning software, have shown that it is possible to create a 4D-model that includes planning. It does, however, come with some difficulties. A model that can be used for planning is different from a model that is used for information take-off, therefore changes need to be made to the model (A. Sagius, personal communication, March 13, 2017). After that, the contractor must make sure they are able to plan with the model on a high level and the cooperation with the subcontractors and suppliers goes smoothly. Once they have achieved this, they could think about managing the logistics with BIM. This, however, comes with a lot of difficulties according to Alex Sagius (personal

communication, March 13, 2017). A first problem is that if a model needs to be used for supply chain management, the model must be designed for this from the start. This means that a lot of the decisions about the logistics need to be made in a much earlier state than they are made now, and often the contractors do not yet know what they want. Dennis Adegeest, Joost de Korte and Jorg van Schadewijk (personal communication, March 14, 2017) confirm this but state that they think it is possible to bring these decisions forward. The second problem Alex Sagius (personal communication, March 13, 2017) points out concerns the information in the model and the scale of that information. The finishing phase of the construction is relatively easy, because it mostly concerns furniture and other large components. But, all the materials needed to install the furniture are not incorporated in the model. These materials, such as fasteners, sand, screws, etc., are very important for the logistics and they need to be incorporated in the model, without making the model too large and therefore too difficult to read (A. Sagius, personal communication, March 13, 2017). The components as such can be put in the model relatively easy, it is the connection between components that is difficult. The shell construction phase is even more difficult to manage with BIM. A concrete floor, for instance, also needs formwork, which is not included in the model. Another example is that a hollow core slab floor might be modelled as one floor but consists of multiple floor slabs. The model does not correspond with reality anymore and is therefore not useful for logistics management.

So, although logistics management with BIM is possible, this mainly goes for large components in the finishing part of the construction phase. Fasteners and construction components from the shell construction phase are much more difficult to manage in BIM. However, BIM-experts such as Alex Sagius (personal communication, March 13, 2017) do see supply chain management with BIM becoming the standard in the future. This process goes step-by-step, from learning how to create a functional 4D-model to managing all the material flows of a construction site. Overall, it is important that all the information is linked to BIM and that the main contractor takes control in managing and coordinating this information. A schematic overview of the total information flow is shown in Figure 6.7.

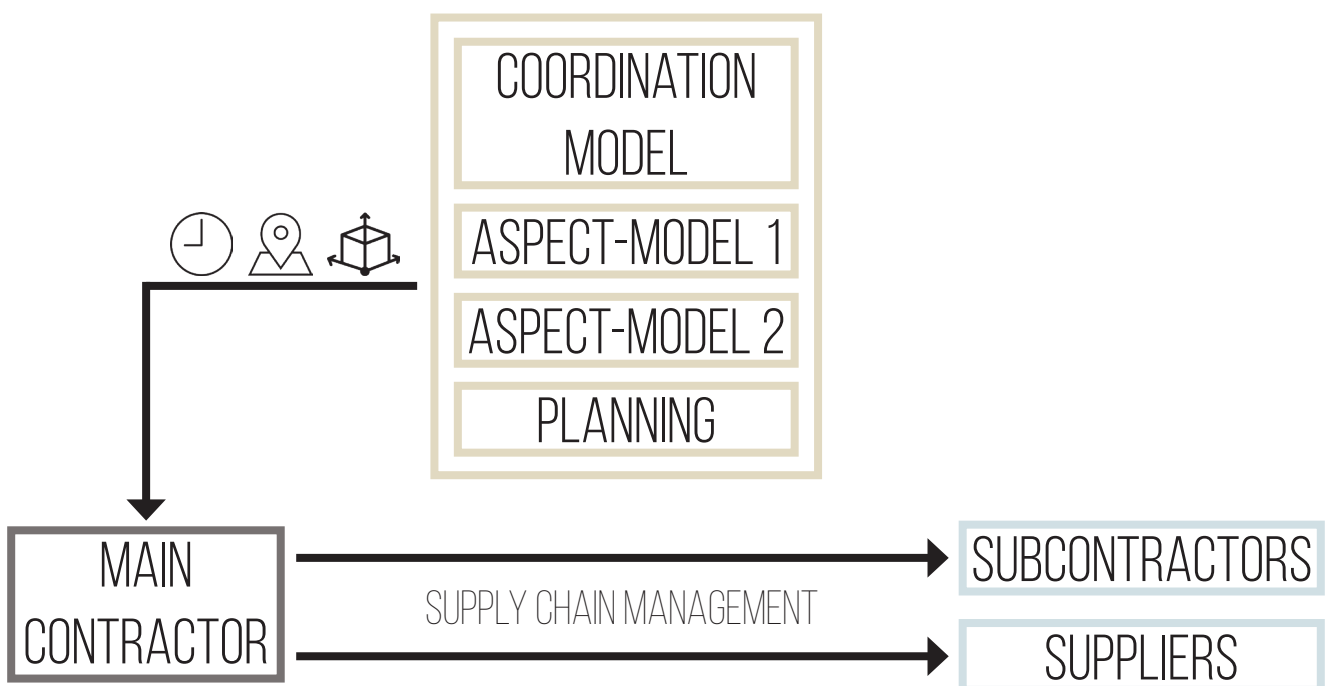


Figure 6.7 Phase three – current situation (own illustration, 2017)

07

THE FEASIBILITY

The fourth, and final, phase of the conceptual framework, Figure 2.5, consists of the finishing part of the construction phase. This is the phase in which all former phases come together. In this phase, the main contractor is still in charge of managing the construction and coordinating the third parties, but he should also be able to see the results of the changed supply chain management. This phase is also used for evaluation and feedback. The sub-questions related to this phase are:

How do third parties view supply chain management with BIM?

and

Is the implementation of BIM for supply chain management feasible for the main contractor?

The answers to the sub-questions will be elaborated in this chapter.

7.1 VIEW OF SUBCONTRACTORS AND SUPPLIERS

The case study research of project Bètatoren took place during the shell construction phase of the project. During this research, the project planners were still busy with the preparation of the finishing phase of the construction, which is planned to start around June 2017. This research took place during the very beginning of the shell construction phase, in which the main activities were laying the foundation and pouring the concrete of the first floors. None of the selected parties were involved in this phase and also the logistic plan was not yet implemented, since that focusses on the finishing phase. Therefore, it is not possible to measure the experiences of the third parties, simply because they do not have any experience yet. However, what can be stated is what their view is on supply chain management with BIM. Interviews have been conducted with representatives of all third parties in which they were asked about their opinion on supply chain management with BIM, together with the use of a material container.

The parties have quite different opinions on this. Calduran is the most positive out of the selected parties, they do see the benefits of supply chain management with BIM. They receive more and more requests from contractors who are planning with BIM and are asking Calduran to cooperate (A. Gils, personal communication, March 28, 2017). According to Albert Gils, supply chain management with BIM has many benefits for both the main contractor and the third parties. The construction site and the logistics can be modelled in 3D, which makes it easier for the main contractor to see potential bottlenecks (A. Gils, personal communication, March 28, 2017). Also, the communication with the third parties will be smoother because the information is streamlined in BIM. The material container is not relevant for Calduran as they are not involved in the finishing phase. Also, the amount of limestone they have to deliver per floor is too much for a container and it is better if they transport it themselves than have it done by runners.

The other parties are a bit more negative towards supply chain management with BIM. Both Breman and Tegel Idee fear that BIM will only make the situation more complicated. According to Johan Noteboom, modelling their main material (tiles) is not the problem, it is the fasteners that are the problem (J. Noteboom, personal communication, March 28, 2017). Glue and grout, for instance, are very difficult to model but have to be incorporated in the logistics since they have to be brought to the construction site. This causes differences between de model and reality, and for the main contractor it is difficult to know which extra products are necessary apart from the tiles. The main contractor simply lacks the detailed knowledge of the products that is necessary to manage the logistics. Next to that, Martin van Leeuwen from Breman also fears for communication issues. With all the information incorporated in one BIM-model, it could be difficult for the main contractor to handle the model (M. van Leeuwen, personal communication, March 31, 2017). Also, some subcontractors and suppliers, or their suppliers, are not able to work with BIM. This will result in communication errors between the connected parties (that work with BIM) and the unconnected parties (that do not work with BIM). Another argument of both Johan Noteboom and Martin van Leeuwen was that they think that using BIM will demand a lot of extra time and energy from both the main contractor and the subcontractor and suppliers. Johan Noteboom states that he thinks the main contractor might underestimate the extra work and that the end result might be less advantageous than they think (J. Noteboom, personal communication, April 18, 2017). Martin van Leeuwen mainly argues against the extra work they would have to put into it. According to him the benefits of supply chain management with BIM do not outweigh the extra work (M. van Leeuwen, personal communication, April 18, 2017). For Mark Lammertink it was difficult to form an image of this situation and the consequences it will have for Halfen. According to him BIM has some advantages, mainly because it makes it easier to retrieve information and the information is shown more clearly (M. Lammertink, personal communication, March 28, 2017). However, the advantages to him are not that big and he does not see how they could be in combination with supply chain management.

The parties were also asked about their opinion on a situation in which the main contractor is responsible for both the on-site and the off-site logistics. The main contractor would then arrange the transport for all the materials from supplier to construction site. None of the parties had a positive view on this. They all state that their logistics are already very efficient and the main contractor cannot make this more efficient. However, case study research shows that not all parties take measures to improve their logistics. So, although they all state that their logistics are efficient, research shows otherwise. In the end, some parties might benefit from overall supply chain management by the main contractor while others do not, because their logistics are already quite efficient. All interviewed parties, however, think they would not benefit. The main reason for this, however, is not the (in)efficiency of their logistics but the fact that they would lose the control over their logistics. All parties state that they now have complete control over their logistics and can arrange it how it is most beneficial for them, losing this control they fear it would have negative consequences for their activities because they would depend on someone else. Martin van Leeuwen (personal communication, March 31, 2017) emphasizes this by stating that there is a reason that contractors hire subcontractors. They want to transfer part of their tasks and responsibilities to others, not take on more.

Concluding, none of the interviewed subcontractors and suppliers were supportive of the idea of overall supply chain management by the main contractor. They fear that they will lose control of their own activities and that the main contractor takes on more than he can handle. Almost the same goes for supply chain management with BIM. Apart from Calduran, none of the parties had a positive view on the use of BIM to manage the logistics. They fear that it will cost them extra time and energy, which they are not willing to spend. They do see the benefits of BIM, but these do not outweigh the costs for them.

7.2 FEASIBILITY FOR THE MAIN CONTRACTOR

Next to the opinions of subcontractors and suppliers, there is one other important argument that determines if a main contractor will change their traditional supply chain to a supply chain that is managed with BIM: it must be feasible for them. The main contractor needs to take the initiative and, compared with the subcontractors and suppliers, must invest the most and takes the largest risk. Therefore, they need to make sure that the process of implementing BIM is feasible for them. This research assumes that the end result will also be feasible for the main contractor, but that is outside the scope of this research. This research focusses on whether it is feasible for the main contractor to change their traditional supply chain into a supply chain that is managed with BIM. It concerns the feasibility of the process, not of the end result. The feasibility will be based upon the opinions of the project team of Waal and literature. The feasibility is divided in three types: financial feasibility, organisational feasibility and social feasibility. For each type, the project team of Waal was asked whether they think this is feasible and why. These statements are then tested to the literature to form a conclusion.

The financial feasibility is selected because making a profit is the core business of a company. The project team of Waal differs in their opinion on whether the process is financially feasible. Joost de Korte and Jorg van Schadewijk both think it is financially feasible, while Dennis Adegeest is not sure. According to Jorg van Schadewijk (personal communication, April 13, 2017), the main contractor has to take the lead and must show the third parties what benefits can be obtained from implementing BIM. He is convinced that it is profitable to adopt BIM. Joost de Korte agrees with this although he states that not only the main contractor should contribute financially to the implementation of BIM, but also the subcontractors and suppliers (J. de Korte, personal communication, April 25, 2017). If all parties pay their part, the adoption of BIM is financially feasible for the whole chain. Dennis Adegeest finds it difficult to form an opinion because to him there is currently too little known about the financial implications of adopting BIM (D. Adegeest, personal communication, April 24, 2017). However, he agrees

that the main contractor should take the risk and try it, in order to see what the results are. Literature research shows that the adoption of BIM comes with several costs. The largest posts are for the investment in upgraded hardware, software licenses and the costs to train existing personnel and acquire new experienced personnel (Alinea Consulting, 2016; Sancandi, 2013). Even though the costs are substantial and should be seen as a serious investment, especially for smaller companies, this should not be a barrier. The price of the most used BIM-software packages is similar to that of common CAD-software, and if a company already uses 3D-BIM software it is a relatively minor upgrade to 4D or 5D BIM (Bryde et al., 2013). The costs of BIM are one of the main barriers of companies to adopt BIM, however research of Hong, Sepasgozar, Ahmadian, and Akbarnezhad (2016) shows that the costs are often perceived higher than they actually are. Companies that do not use BIM perceive the costs more negatively than companies that do use BIM, which indicates that it is possible that non-users overestimate the actual costs of BIM adoption, which makes them hesitant towards it (Hong et al., 2016). Overall, several studies on the costs and benefits of BIM conclude that in the end the benefits of BIM outweigh the costs. Examples of such studies are those of Bryde et al. (2013), Lu, Fung, Peng, Liang, and Rowlinson (2014), Hergunsel (2011) and Ghaffarianhoseini et al. (2017). The adoption of BIM requires a serious investment of a company, however this investment should be seen in perspective with the (long-term) benefits. Especially when BIM is adopted by all parties in the supply chain, these benefits will be substantial and outweigh the costs, making the adoption of BIM financially feasible.

The organisational feasibility focusses on whether it is feasible for the main contractor to coordinate the BIM-implementation process. The project team of Waal agrees that this is feasible. The main argument is that the contractor already is responsible for the overall outcome of the project and already has a coordinating role. Therefore, not much changes when BIM is implemented. Jorg van Schadewijk (personal communication, April 13, 2017) states that the role of coordinator and facilitator is exactly what fits the main contractor and therefore sees no problems with regards to the organizational feasibility. Dennis Adegeest (personal communication, April 24, 2017) does emphasize that it is important to adopt BIM step-by-step, to ensure a smooth implementation within the organization. This is confirmed by Hardin and McCool (2015), who state that the adoption of BIM requires a whole new organizational process. Companies cannot just adopt new software, they have to adopt the new processes and organizational structures too. This is also emphasized by Arayici, Khosrowshahi, Ponting, and Mihindu (2009), who state that together with BIM, companies must reinvent the workflow and reassign the responsibilities. Organizational support from the (top) management of the company is therefore very important for a smooth implementation. Both Hong et al. (2016) and Arayici et al. (2011) state that organizational support has a significant positive effect on the implementation of BIM. The management must create an implementation plan that shows all personnel what is expected from them with regards to BIM, which ensures they use BIM correctly within their projects (Eastman, Teicholz, Sacks, & Liston, 2011). BIM-adoption does require some effort and changes from an organization, however the main contractor is used to coordinate processes and if they are open to changes they can achieve a smooth implementation process and reap the benefits of BIM. Therefore, the adoption of BIM is organizationally feasible.

Finally, the social feasibility focuses on the interrelationships between supply chain partners and whether it is feasible for the main contractor to implement BIM with all the different parties. The project team of Waal also thinks that this is feasible, however they do see some difficulties. According to Joost de Korte (personal communication, April 25, 2017) BIM-adoption is socially feasible, however the third parties must be convinced of the benefits of BIM. If they do not see the benefits, it will be difficult to convince them to use BIM. This is emphasized by Dennis Adegeest (personal communication, April 24, 2017), who states that for a smooth implementation of BIM all supply chain partners must have a clear understanding

of the impact of BIM, together with the benefits and barriers. This means that mutual trust and being open and transparent is very important. It is a slow process, but still feasible according to them.

According to Hardin and McCool (2015) there are three key factors for a successful BIM-implementation: the right tools, processes and behaviour. The behaviour is related to the social feasibility: cooperative behaviour can speed up a process while unsupportive behaviour can slow it down. This is the most difficult component because behaviour is difficult to change. One of the ways to convince the third parties to cooperate is to show them the benefits of a BIM-process. According to Eastman et al. (2011) there are several benefits of BIM for subcontractors and suppliers, such as a reduction in design coordination errors, lower engineering and detailing costs and various improvements to quality control and supply chain management. Next to that it is important that more awareness about BIM is raised within the whole construction sector and that people improve their skills (Bryde et al., 2013). Construction companies must invest in the education and training of their staff, but contractors also need to help their supply chain partners with the use of BIM. Finally, it is important that the contractor focusses on integration and communication (Khalfan et al., 2015). The main contractor must communicate openly about the BIM-adaptation process and explain clearly what is expected of all involved parties. Although the focus should always be on good collaboration, the main contractor should not be afraid to use his position. The subcontractors and suppliers often do as told by the main contractor, so if necessary he can simply demand from the third parties that they use BIM, otherwise he will find other supply chain partners. This option might be a last resource, but it is a useful one. For a smooth implementation of BIM, it is important that all parties cooperate and the main contractor has several options to get them to. Even though it could be difficult, the adoption of BIM is therefore socially feasible.

Overall, Joost de Korte, Dennis Adegeest and Jorg van Schadewijk all think that the implementation of BIM for supply chain management is feasible for the main contractor. Joost de Korte (personal communication, April 25, 2017) does state that it depends on the size of the project and the contractor. For large projects or large contractors, it is much easier to take the risk of implementing BIM. Dennis Adegeest (personal communication, April 24, 2017) adds to this that the implementation process should be set up step-by-step, giving the organizations the chance to adapt to the new situation before something changes again. In general, they all state that the adoption of BIM is worth the effort.

08

VALIDATION

In Chapter 4 to 7 the results of the case study research have been presented. To ensure these results are accurate and reliable, the results must be validated. Because this is a qualitative research, the validation can also be qualitative. Therefore, the validation consists of the opinions of experts. These experts are selected because they have experience in the construction industry, have knowledge about supply chain management and BIM and are involved in the NWO-project. The first expert is Arjen de Feijter, he is project manager supply chain management at Dura Vermeer. The second expert is Nathaniël Manubulu, BIM-manager at Boele & van Eesteren. The third expert is Thomas Heye, sustainability-coordinator at Boele & van Eesteren. The last expert is Léon van Berlo from TNO, who focuses on changing the industry from document-driven to data-driven with the help of BIM. The results derived from the data-analysis have been submitted to the experts, by means of semi-structured interviews. The interview guide can be found in Appendix R. Per phase their validation will be shortly discussed. The main focus will be on the overall outcome of the research: do the experts think supply chain management with BIM can give the main contractor more control of the logistics, and do they think it is feasible?

8.1 THE POSITION OF THE MAIN CONTRACTOR

The results of the first phase showed that currently the main contractor uses a unilateral approach when preparing the subcontractors and suppliers for the construction phase. They set up a logistic plan and send it to the third parties, together with a BIM-protocol. Based upon the case study research this approach should be bilateral, and the subcontractors and suppliers should be closely involved in the set-up of the logistic plan and the BIM-model. The experts slightly disagree on this. Although they emphasize the importance of cooperation, they do see the main contractor as the leader in the process, who decides how the logistics will be organised. Léon van Berlo has the strongest opinion. According to him the main contractor should set-up the plan and impose this on the third parties (L. van Berlo, personal communication, April 28, 2017). Making sure that everyone's interests are served is inferior in his opinion. He does, however, have a different background than the other experts, who are all contractors. Nathaniel Manubulu agrees with Léon but stresses that they do strive for a good cooperation. They start every project with a meeting in which all parties can share their ambitions and together they can define the opportunities and risks for the future (N. Manubulu, personal communication, May 4, 2017). All contractors try to find the perfect balance between implementing their own plans and ensuring that everyone's interests are served. However, sometimes this causes the contractor to lose sight of his own plans too much, as was the case with Waal in project Bètatoren. Contractors should always strive for innovation, even if it has a negative impact on the cooperation with the third parties. The negative consequences are only short-lived, on the long-term innovation will have a positive effect on their organisation.

8.2 THE POSITION OF THE SUBCONTRACTORS AND SUPPLIERS

The results of the second phase showed that a lot of logistic information was missing in the BIM-model and most logistic information was send in 2D. The information flows were very fragmented and uncoordinated. This should be solved by having the main contractor function as the coordinator and manager of the BIM-model and the information in it. This is confirmed by the experts. The subcontractors and suppliers have to complete their own information, but the main contractor is responsible for controlling and coordinating all the data (A. de Feijter, personal communication, April 18, 2017). The experts believe that they will be able to fulfil this role. However, they must take into account that taking on such a role will cost them a lot of extra time and effort, especially in the procurement phase. They must make sure to allocate sufficient amounts of time, people and financial resources to this process. If they do not invest enough, their yield will be insufficient.

8.3 MANAGING THE LOGISTICS WITH BIM

As for the third phase, the results showed that the logistic information and BIM were disconnected. In order for the main contractor to manage the logistics with BIM, first, all the logistic information needs to be available in BIM. Secondly, the planning must be linked to BIM. Thirdly, contractors should be able to extract the 4D-information and manage the logistics on site. The experts agree that this is the way to go, but underline that it is an extensive progress. According to Léon van Berlo (personal communication, April 28, 2017), the first step is to convince the main contractors to use the right planning software, and therefore to plan in a different way than they are used to. That is a big step, but once they are used to that the step to managing the logistics with BIM is relatively small. Arjen de Feijter (personal communication, April 18, 2017) agrees with this and states that technically it is all possible, it is the human nature that causes difficulties. People are resistant to change, not because of the change itself but because of the loss it represents (Kotter & Schlesinger, 2008). Loss triggers an emotional response, which is rooted in our nature (Bailey & Raelin, 2015). This reaction causes organizational difficulties because it is challenging for the management

to implement a new process when the employees are not cooperating. However, according to Thomas Heye (personal communication, May 4, 2017), contractors should not be afraid to take the risk. Most of the benefits and barriers of BIM are made clear, as was explained in Paragraph 2.2 and substantiated with research from, inter alia, Bryde et al. (2013), Yan and Damian (2008) and Mondrup et al. (2012). Contractors should not be affected by resistance from their employees or third parties. Change must be seen as an opportunity to strengthen the business by aligning operations with strategy, and the contractors must make sure their employees and the third parties also see it this way (Strebel, 1996). This can be achieved by educating them about the changes, communicating about the consequences it has for them, involving everyone in the implementation process and by being supportive (Kotter & Schlesinger, 2008). This will improve the implementation process and helps to make sure the adoption of BIM is supported broader within the supply chain.

8.4 FEASIBILITY FOR THE MAIN CONTRACTOR

In the final phase of the research, the feasibility of supply chain management with BIM was assessed on three levels: financial feasibility, organizational feasibility and social feasibility. The feasibility was assessed by the project team of Waal and validated with the use of literature. Within this chapter these results will also be validated by the experts.

All experts agree that the implementation of BIM is financially feasible for the main contractor, however there are some remarks. Léon van Berlo (personal communication, April 28, 2017) states that it does depend on the status of the contractor, if he already uses 3D-BIM it is relatively easy and inexpensive to upgrade to 4D or 5D BIM. If not, it is quite a large investment to start with 3D and expand to 4D or 5D. Thomas Heye (personal communication, May 4, 2017) emphasizes this but states that most contractors already use 3D-BIM. Research of de Boer, Kranenburg, Fokkelman, and Zeijlemaker (2015) indicates that in 2014 86% of the Dutch contractors had used BIM, and 58% even used BIM regularly. The step to upgrade BIM would therefore be relatively minor for a lot of construction companies. Thomas Heye (personal communication, May 4, 2017) also states that the information needed for the logistics is already needed for other disciplines, therefore there are no 'extra' costs for supply chain management with BIM. Arjen de Feijter agrees with this, although he states that the costs of adding extra logistic information to BIM might be substantial. Since there is a lack of data of logistic costs it is very difficult to make a cost/benefit analysis of implementing BIM for the management of logistics. But even though extra data is needed, Arjen de Feijter does state that there currently is enough information to manage the logistics and that this is financially feasible for them (A. de Feijter, personal communication, 01 May, 2017). Overall, the experts agree that the implementation of BIM requires a serious investment of a company, however these costs will be outweighed by the benefits, especially on the long term. This is in accordance with the results of the case study, which also concluded that the implementation of BIM for supply chain management is financially feasible for the main contractor.

The second subject is the organizational feasibility, on which all experts agree that this is feasible. The main contractor is already in charge of organizing the processes and therefore not much changes if BIM is implemented (A. de Feijter, personal communication, 01 May, 2017). However, the main contractor must make sure there is enough capacity within the organization to rearrange the processes and set up a new organizational structure. Rearranging the processes is a quite complex process and this should not be taken lightly by the main contractor. However, all experts think that this is possible. According to Léon van Berlo (personal communication, April 28, 2017), the main contractor could also use specific tools that automatically rearrange the BIM-model. He states that it is relatively easy to create a tool that imports all the necessary logistic information and links it to the BIM-model. This could make the implementation process a lot easier for the main contractor. However, the

information therefore needs to be available, which is currently not the case. The first challenge is to collect all the logistic information from the involved parties, which is the task of the main contractor according to the experts. Both Thomas Heye and Nathaniël Manubulu (personal communication, May 4, 2017) do not see any difficulties for the main contractor when it comes to the organizational feasibility. They agree with the other experts and the case study results that the main contractor already has a coordinating role and should already be responsible for managing the processes. Therefore, not much changes when BIM is implemented. The overall conclusion is therefore that the implementation of BIM for supply chain management is organizationally feasible for the main contractor.

The last part of the feasibility is the social feasibility, which is closely related to the organizational feasibility. All experts agree on this topic, although they are less convinced. According to Arjan de Feijter (personal communication, April 18, 2017) it depends on what the main contractor asks from the subcontractors and suppliers. If it is based on the current level of their BIM-models, the subcontractors and suppliers do not have to spend extra time and energy on it, making it therefore feasible to get them to join a BIM-project. However, if the third parties must retrieve a lot of extra logistic information and also need to learn how to work with BIM, this becomes a lot more difficult. Thomas Heye (personal communication, May 4, 2017) emphasizes this and states that they are currently discussing the mutual expectations with their subcontractors and suppliers. The processes need to be perfectly arranged in the procurement phase in order to be able to manage the logistics with BIM in the execution phase. To make sure all parties use the model in the correct way, a lot of communication is necessary beforehand (N. Manubulu, personal communication, May 4, 2017). Léon van Berlo (personal communication, April 28, 2017) has a more extreme view on this. According to him the subcontractors and suppliers are subordinate to the main contractor. The contractor may demand them to work with BIM and therefore make sure BIM is implemented in the whole process. It might not be the friendliest way, however all experts agree that the third parties should experience a project with BIM in order to be convinced of the benefits, and this might be the best way to get them to join the project. According to Arjen de Feijter (personal communication, April 18, 2017) the main contractor needs to take the risk by using BIM for supply chain management. Once the subcontractors and suppliers on that project see the benefits, they will be more cooperative towards a new project. The opinions of the experts are in line with the results from the case study research, therefore also the implementation of BIM for supply chain management is socially feasible for the main contractor.

Overall, all experts think that the implementation of BIM for supply chain management is feasible for the main contractor. Arjen de Feijter (personal communication, April 18, 2017) does state that the main contractor must have the right people and resources. Next to that, he must also be willing to allocate these people and resources to the BIM-implementation process. In general, all experts acknowledge the costs and effort necessary to implement BIM, but they are all convinced that the benefits far outweigh these costs. They also think that supply chain management with BIM will become mainstream in the future. The construction sector is already experimenting with 4D and 5D BIM, so it is only a matter of time before they start to manage their logistics with BIM. And once one contractor shows that it works, all the others will follow (L. van Berlo, personal communication, April 28, 2017). The experts are more certain on this subject than the project team of Waal, who are convinced of the benefits but still a bit hesitant towards the actual implementation of BIM. This is also related to the fact that Dura Vermeer and Boele & van Eesteren are both quite large contractors, and therefore are better able to carry the risks than a smaller contractor such as Waal. All experts also have more experience with BIM and have a clearer view of all the costs and benefits. Based on the knowledge and experience of the experts and the case study research, the final conclusion is that the implementation of BIM for supply chain management is feasible for the main contractor.

09

CONCLUSION

In Chapter 4 to 7 an extensive elaboration of all the sub-questions was presented. Each chapter described both the data collection and the data-analysis of a sub-question and the corresponding phase. Within this Chapter all the answers to the sub-questions will be combined to form a main conclusion, which is the answer to the main research question. The conclusion will be presented in the form of a framework, and provides the results of the case study research.

9.1 THE POSITION OF THE MAIN CONTRACTOR

The first phase of the conceptual framework, Figure 2.2, takes place during the procurement phase. This phase focuses on the position of the main contractor towards the third parties and the information the main contractor needs to provide to them. The hypothesis related to this phase is:

“Currently the link between BIM and supply chain management is missing in the set-up of the project, which leads to an incomplete BIM-model.”

Case study research showed that the information flow of the first phase currently consists of two main documents: the logistic agreement and the BIM-protocol. Both documents are created by Waal and form the main part of the information flow that shows the third parties what is expected from them and how these expectations will be fulfilled. The plans and documents are set-up by Waal and quite compelling. Although there is some coordination with the third parties, everything happens on the initiative of the main contractor. Waal takes the lead and is responsible for setting up the plans, providing the right information and informing parties about their tasks and responsibilities. However, even though both logistic information and BIM information is provided by Waal, these types of information are not linked. The BIM-protocol does not include anything on the logistics and the logistic plan does not include specifications about BIM. The information types are completely disconnected. A schematic representation of this is shown in Figure 9.1.



Figure 9.1 Phase one - current situation (own illustration, 2017)

Because the responsibilities and expectations with regards to both BIM and logistics are not well defined at the start, there will be problems with the BIM-model later on, because it is not clear who is responsible for which information. The hypothesis of the first phase is therefore true.

The sub-question of the first phase is:

How can a main contractor prepare the third parties for a new logistic system in order to get more control in the procurement phase?

The answer to this sub-question shows what the main contractor should do to get more control of the logistics by changing the information flow. These changes aim at making the information flow smoother, making it a more coherent process and focussing more on the final use of the BIM-model. The first change concerns the logistic plan. Instead of the unilateral approach that is currently used, the main contractor should involve the third parties in the set-up of the plan. This approach will increase the solidarity amongst the parties and the plan will be supported broader because everyone is able to give input. This will make it more likely that everyone signs the final agreement and sticks to it during the construction phase. The logistic plan should also include in what way BIM is used for the management. The second change concerns BIM. In order to use BIM to manage the logistics of a construction project, it is important that BIM is already implemented from the start of the project. After the logistic plan has been made, the main contractor has to define what the BIM-model needs in order to use it for the management of the logistics. The BIM-model should be adapted to this, after which it is provided to the third parties. The model will be send together with a BIM-protocol that states exactly how everyone should use the model, with a special focus on the logistics. The information flow is now complete and consists of a logistic plan and agreement, the BIM-model and a BIM-protocol. They all have a focus on the logistics and are set-up by Waal, in accordance with the subcontractors and suppliers. A schematic representation of this is shown in Figure 9.2.



Figure 9.2 Phase one – improved situation (own illustration, 2017)

9.2 THE POSITION OF THE SUBCONTRACTORS AND SUPPLIERS

The second phase of the conceptual framework, Figure 2.3, also takes place during the procurement phase. This phase focuses on the role of the subcontractors and suppliers and the information they need to provide for the BIM-model. The hypothesis related to this phase is:

“The fragmentation of the construction industry is the main reason for the inefficient supply chain organisation.”

Case study research showed that there is a mismatch between the production processes and the information processes. Some information is send in a traditional way, some information is send via BIM, but none of the information is connected to the production processes of the materials and the construction site. The main contractor provides the central model to all parties that are going to use BIM. They take this model as the basis but do not check the information in it and neither does the main contractor. Out of the total logistic information, more than half is missing in BIM. The missing information is either send in 2D (planning, drawings), or not send at all. Also, some of the information that is present in the BIM-model is send in 2D anyway. A schematic representation of this information flow is shown in Figure 9.3.

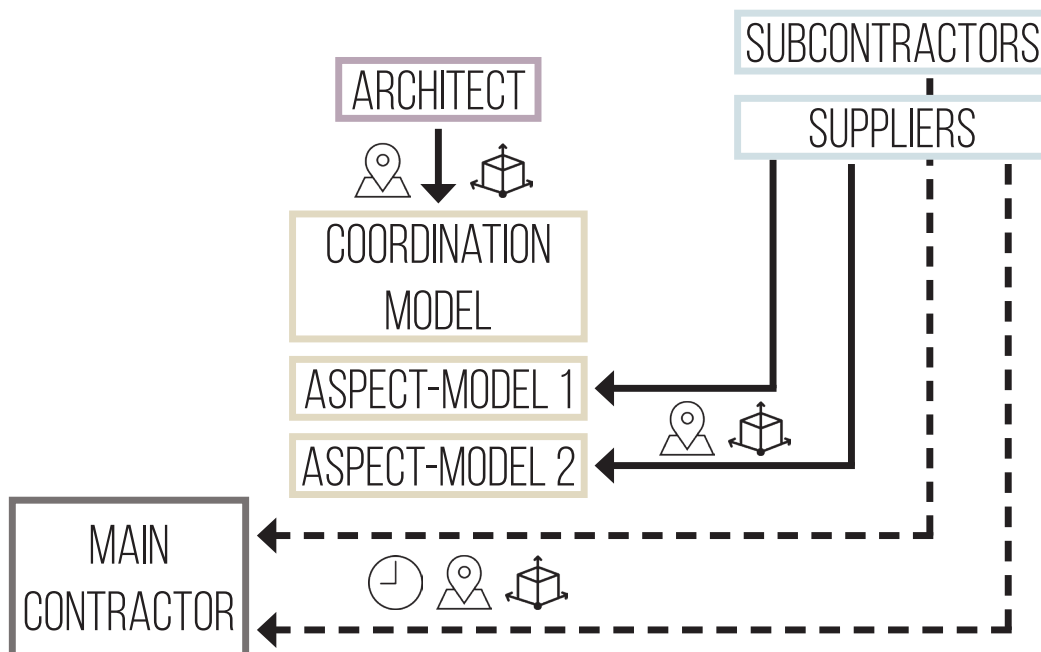


Figure 9.3 Phase two – current situation (own illustration, 2017)

One of the reasons for this is the fragmentation of the construction industry. The information and material flows are not bundled but spread across different parties within the supply chain. Instead of one complete model, there are several different models which are not linked. This fragmentation makes it very difficult for the main contractor to create a clear supply chain structure. Another important reason is that it is not clear who is responsible for the coordination

of the logistic information. Information about the dimensions, location and planning are, partly, included in the model, but it is not clear who is responsible for this information. The main contractor controls the process but does not coordinate the information, neither does anyone else. This leads to a fragmented and uncoordinated information flow. The hypothesis is proven to be partly true. The fragmentation is an important reason for the inefficient supply chain organisation, however there are other equally important reasons.

The sub-question of the second phase is:

What information of third parties is necessary in order to integrate logistic information in BIM software?

One of the problems is the fragmentation. This could be solved by linking the coordination model and the aspect-models and create one unified model. However, to be able to link the models it is important that the input is correct. The input should be based on the IFC-standards and the BIM basis ILS, to make sure all models are built the same and can be linked. The main contractor should encourage all parties to work with BIM and provide them with knowledge and assistance. All parties focus on creating their aspect-model and the main contractor is responsible for coordinating the aspect-models and linking them all together. The main contractor should also make sure to add the information from the disconnected parties to the BIM-model. A schematic representation of this can be found in Figure 9.4.

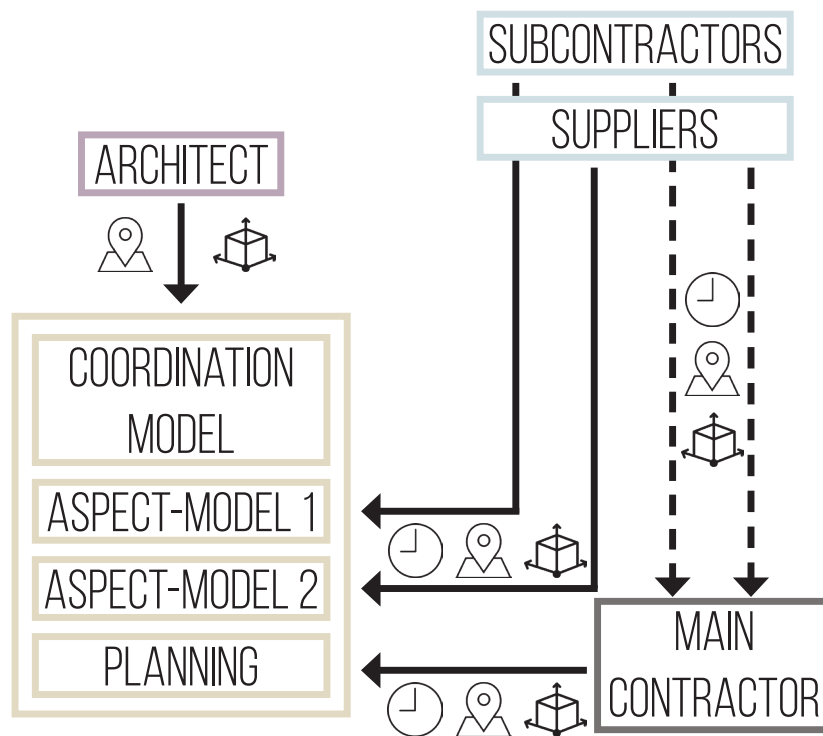


Figure 9.4 Phase two – improved situation (own illustration, 2017)

The main contractor is responsible for both the production processes on the construction site as the information processes. Therefore, the main contractor must make sure to coordinate both and ensure there is a match between them. This is done by coordinating the processes and guiding the subcontractors and suppliers in providing the right information in the right way. The subcontractors and suppliers are responsible for the information with regards to their own materials. They have to make sure their aspect-models include all the right information with regards to volumes (including packaging), weight, storage location and all other information

that is important for the logistics. The information about the location is the responsibility of both the architect and the main contractor. Finally, the information about the overall planning is the responsibility of the main contractor.

9.3 MANAGING THE LOGISTICS WITH BIM

The third phase of the conceptual framework, Figure 2.4, takes place during the construction phase. During this phase, the main contractor has to manage the construction of the building and has to coordinate the third parties. The hypothesis related to this phase is:

“To be able to manage the logistics with BIM, the model must include complete logistic information with regards to the dimensions, location and the planning.”

The results of the case study show that the logistic information and BIM are almost completely disconnected in this phase. The main contractor does perform a quality control on the aspect-models, but since they do not fully check the coordination model there could still be a mismatch. The logistic information in BIM is not complete, which makes it impossible to manage the logistics with BIM. The logistic information that is present, is extracted in 2D and then used to manage the actual logistics on the construction site, together with the 2D-information that was received directly from the subcontractors and suppliers. This creates an information flow that is completely disconnected from BIM. A schematic representation of this information flow is shown in Figure 9.5.

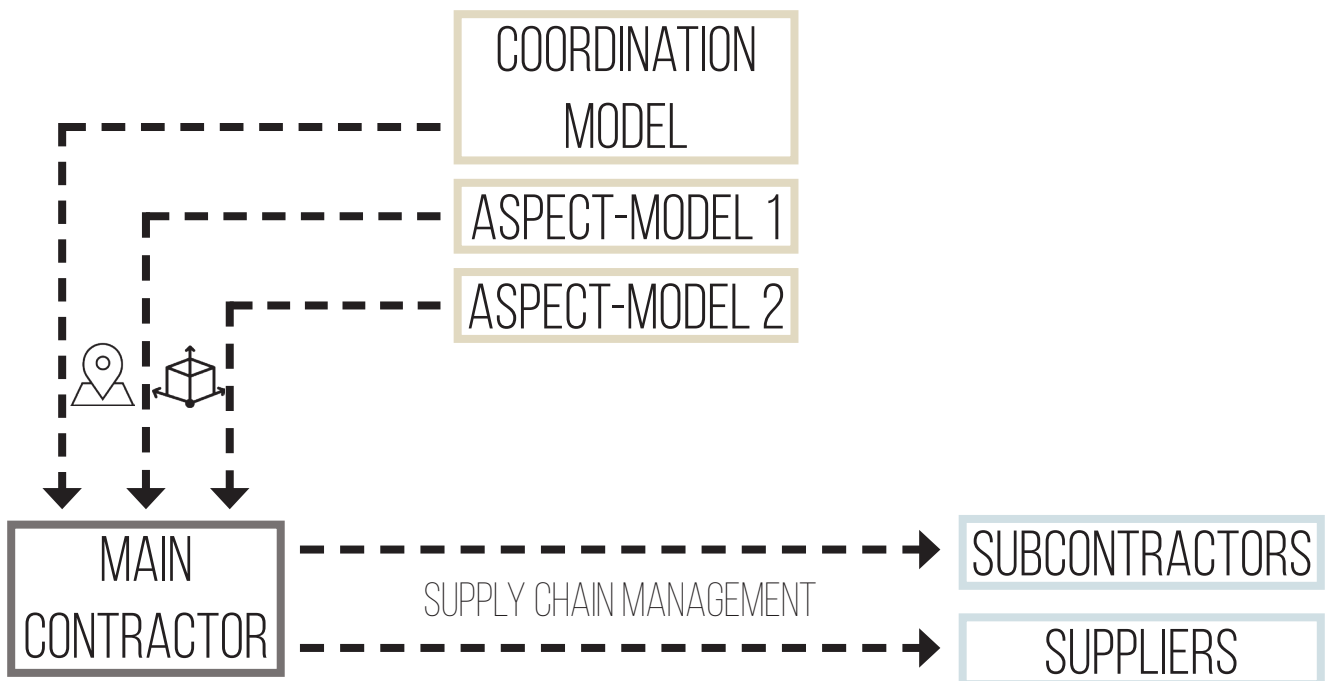


Figure 9.5 Phase three – current situation (own illustration, 2017)

The incomplete BIM-model makes it impossible to manage the logistics on site, which therefore has to be done in 2D. The hypothesis of the third phase is therefore true.

The sub-question of the third phase is:

How does the main contractor need to use the BIM-model in order to get control of the logistics in the execution phase?

To be able to manage the supply chain with BIM, the logistic information and BIM must be connected. First, the main contractor should check the coordination model of the procurement phase and compare it with the aspect-models received from the sub-contractors and suppliers. These must match with each other and comply with the standards. All the information with regards to location and dimensions needs to be complete. Secondly, the BIM-model needs to be linked to the planning. Thirdly, the BIM-model must include a way to manage the inventory on the construction site. There are several frameworks, such as the frameworks of Cheng and Kumar (2015b) or Chau et al. (2004) that can be used to manage the on-site logistics, including the site usage and the material flows. Once this is done, the BIM-model is ready. Managing the actual logistics with BIM, however, is still a bit difficult. Large components can be managed relatively easy with BIM, but it is the connecting materials that are difficult to manage, because we are not used to modelling them completely. If a BIM-model needs to be used for supply chain management, the model must be designed for this from the start. This means that a lot of the decisions about the logistics need to be made in a much earlier stage than they are made now. Also, good agreements need to be made between the main contractor and the third parties to make sure the logistics have been excogitated into the smallest details. If this is done, the information flow of the logistics will be completely connected to BIM. A schematic representation of this is shown in Figure 9.6.

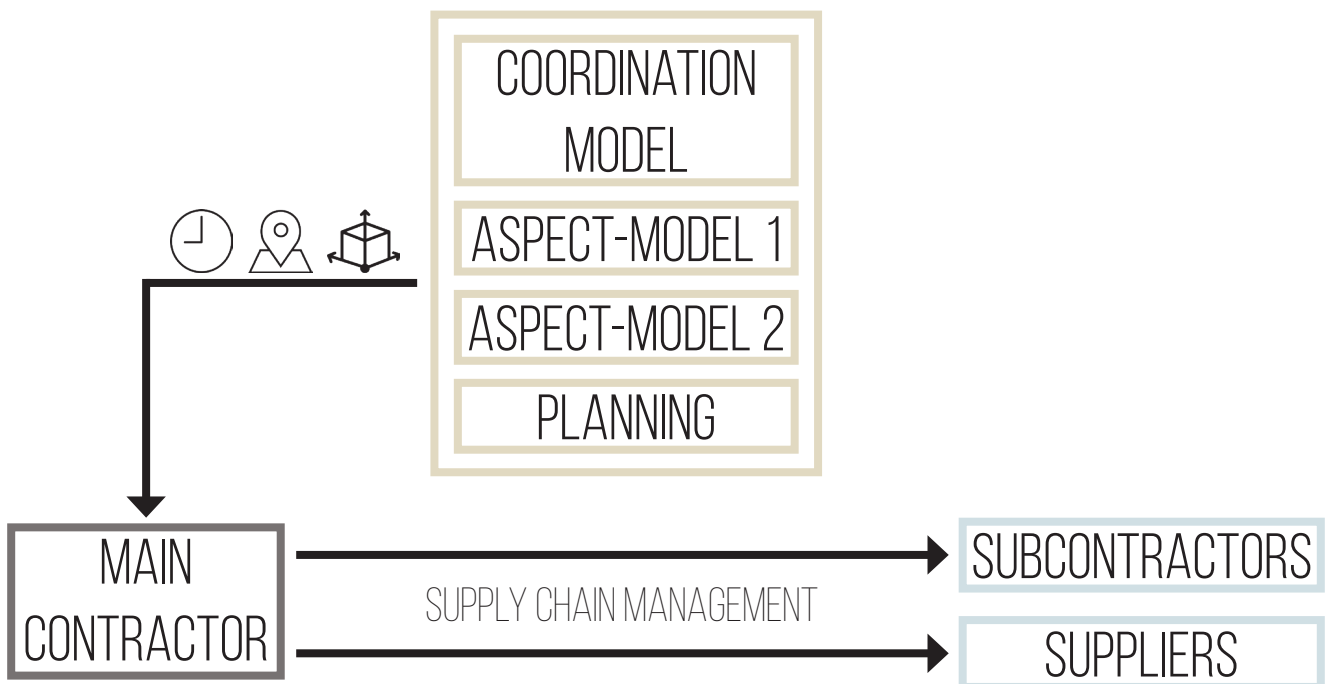


Figure 9.6 Phase three – current situation (own illustration, 2017)

9.4 VIEW OF SUBCONTRACTORS AND SUPPLIERS

The fourth, and final, phase of the conceptual framework consists of the finishing part of the construction phase, see Figure 2.5. This is the phase in which all former phases come together. In this phase, the main contractor is still in charge of managing the construction and coordinating the third parties, but he should also be able to see the results of the changed supply chain management. This phase is also used for evaluation and feedback. The first sub-question related to this phase is:

How do third parties view supply chain management with BIM?

The opinions of the parties differ on this subject. Calduran is the only one with a positive opinion and thinks supply chain management with BIM has many benefits for both the main

contractor and the third parties. They are also the only company out of the four who are actively improving their logistics. The other parties are a bit more negative. Their arguments are that BIM will only make things more complicated (Breman, Tegel Idee), it is very difficult to include fasteners in the model (Tegel Idee), the use of BIM could create communication issues (Breman) and, their main argument, using BIM will demand a lot of extra time and energy from both the main contractor as from the subcontractor and suppliers (Breman, Tegel Idee). For Mark Lammertink from Halfen it was difficult to give specific arguments but overall, he does not see the large benefits of BIM and therefore does not think they outweigh the costs. Concluding, almost none of the interviewed subcontractors and suppliers were supportive of the idea of supply chain management with BIM. They fear that they will lose control of their own activities and that the main contractor takes on more than he can handle. They also fear that it will cost them extra time and energy, which they are not willing to spend. They acknowledge that BIM has some benefits, but these do not outweigh the costs for them.

9.5 FEASIBILITY FOR THE MAIN CONTRACTOR

The second sub-question related to the fourth phase is:

Is the implementation of BIM for supply chain management feasible for the main contractor?

This research focusses on whether it is feasible for the main contractor to change their traditional supply chain into a supply chain that is managed with BIM. It concerns the feasibility of the process, not of the end result. The feasibility is based on the opinions of the project team of Waal, literature research and the validation of logistic and BIM-experts in the construction industry. The feasibility is divided in three aspects: the financial feasibility, the organisational feasibility and the social feasibility.

The adoption of BIM comes with several costs and should be seen as a serious investment; however, this should not be a barrier. Research has shown that the implementation costs are quite similar to that of common CAD-software and that the costs are often perceived higher than they actually are. Also, many cost/benefit-analyses show that the long-term benefits of BIM far outweigh the implementation costs. This is also agreed by the experts, who all state that the benefits of BIM are worth the adoption costs. They also emphasize that the costs are substantially lower if the main contractor already uses 3D-BIM. In that case, the step to 4D-BIM requires relatively little time and costs. Since most contractors already use BIM, a large part of the construction industry can easily be upgraded. Overall, the conclusion of this research is that the implementation of BIM for supply chain management is financially feasible for the main contractor.

The adoption of BIM requires a whole new organizational process, a company cannot simply buy new software and use the old processes. These are quite big adjustments, for which company-wide support is needed. However, even though BIM-adoption requires substantial changes from the organization, both the project team of Waal and the experts are convinced this is feasible. According to them the role of coordinator and facilitator is exactly what fits the main contractor and therefore they see no problems with regards to the organizational feasibility. BIM-adoption does require some effort and changes from an organization, however the main contractor is used to coordinate processes and if they are open to changes they can achieve a smooth implementation process and reap the benefits of BIM. Therefore, the overall conclusion of this research is that the implementation of BIM for supply chain management is organizationally feasible for the main contractor.

Finally, the social feasibility focusses on the interrelationships between supply chain partners. This is the most difficult aspect because the behaviour of people is difficult to change. For

a smooth implementation of BIM, all supply chain partners must have a clear understanding of the impact of BIM, together with the benefits and barriers. This means that mutual trust and being open and transparent is very important. If the subcontractors and suppliers are not convinced by showing them the benefits, the main contractor could use his position to convince them. The third parties are subordinate to the main contractor and the main contractor can simply demand them to work with BIM. All experts agree that convincing the subcontractors and suppliers is the most difficult part, however if the main contractor gives the right example they will follow. So, the conclusion of this research is that the implementation of BIM for supply chain management is socially feasible for the main contractor.

The hypothesis of this phase is:

“The implementation of BIM for the management of the on-site logistics is feasible for the main contractor.”

Overall, this research concludes that the implementation of BIM for supply chain management with BIM is feasible for the main contractor. Therefore, the hypothesis is true. However, there are a few remarks. For large projects or large contractors, it is much easier to take the risk of implementing BIM. For them the costs are much less substantial. Also, the main contractor must have the right people and resources. This means he must also be willing to allocate these people and resources to the BIM-implementation process. Finally, the implementation process should be step-by-step, giving the organizations the chance to adapt to the new situation.

9.6 GETTING CONTROL OF THE LOGISTICS

Based upon the data analysis of the case study there is one main conclusion with regards to the current status of supply chain management and BIM: the logistic information and BIM are disconnected. The logistic information is send from the subcontractors and suppliers to the main contractor and back, but this happens mainly in 2D. This is shown in all three phases, because most information (logistic agreement, drawings, planning) is send in 2D. Even information that is available in BIM is still send in 2D. This is partly due to the fact that there is a mismatch between the information processes and the production processes. As a result, information is missing in the BIM-model. No one takes responsibility and therefore the current information processes are fragmented and uncoordinated. The main contractor controls the process but does not coordinate the information, neither does anyone else. There are two main reasons for this. First, the contractors have little insight in their own information processes and have a conservative attitude. Even though BIM is implemented in the company, they tend to set-up the information processes in the same way as they did before BIM. 3D is different from 2D and therefore also needs a different process. Adopting BIM is not just about getting a new software licence, next to the product also a new process needs to be adopted. Currently this does not happen, which results in a disconnected information flow. Secondly, the contractors are afraid to take the risk of using BIM to manage their logistics. They have very little insight in the logistic costs of the subcontractors and suppliers, so the margin of profit is unclear. This makes them hesitant to take the risk. What makes it more difficult is that most subcontractors and suppliers also do not know their own logistic costs. Research will have to give more insight in this. Next to the logistic costs, the contractor also is a bit hesitant towards the extra responsibilities and the additional work involved. Although they are convinced that the overall benefits outweigh the costs, they are reluctant when they need to put it into practice. The disconnection resulting from this makes it not feasible to manage the logistics with BIM currently. An overview of the complete information flow is shown in Figure 9.7.

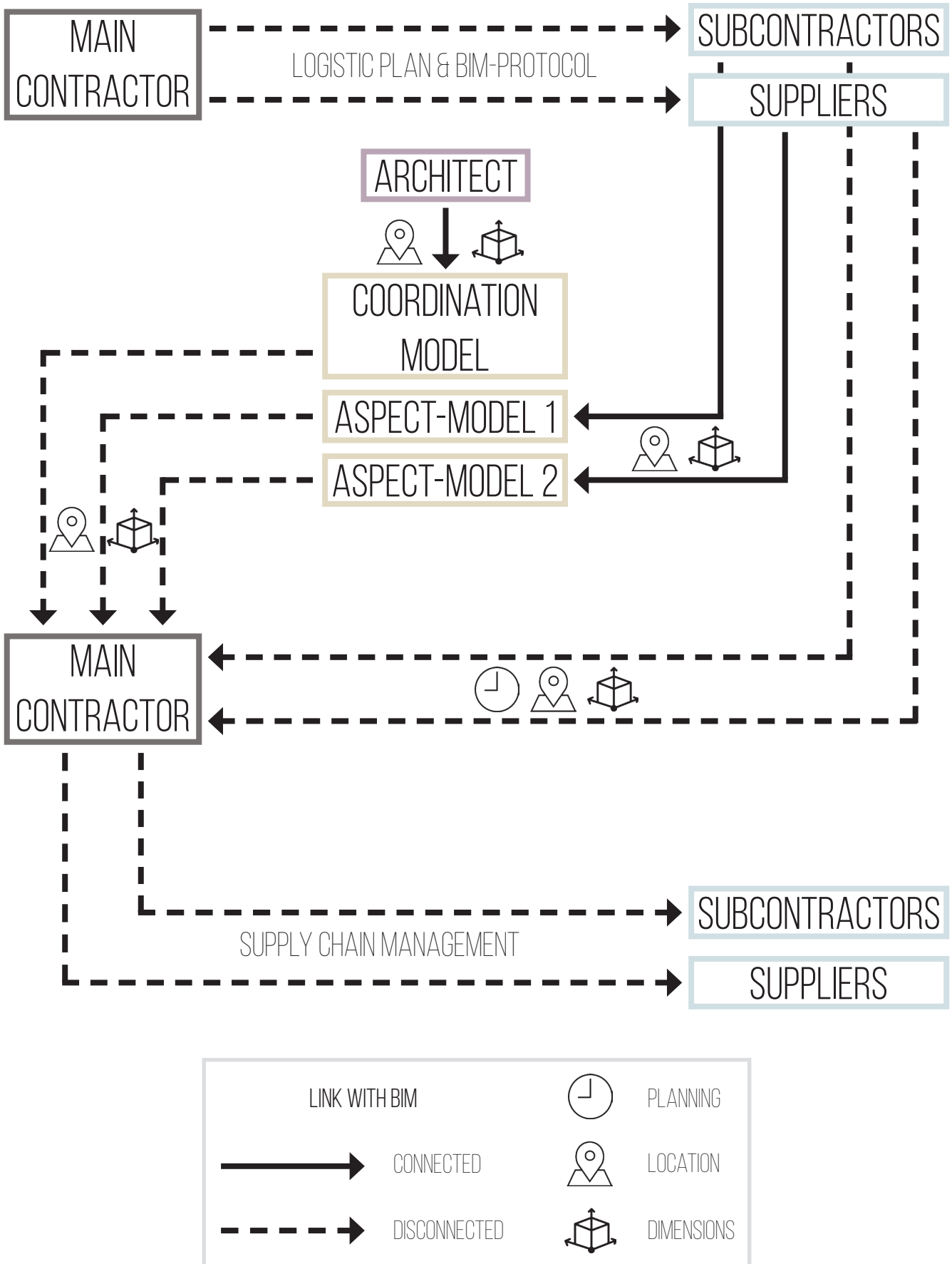


Figure 9.7 Information flows - current situation (own illustration, 2017)

The question is then, what changes should be made to the information processes to make the implementation of BIM for supply chain management feasible? The answer to this is the answer to the main question:

How does supply chain management with BIM help contractors to get control of the logistics of a building project?

First, the main contractor must take the responsibility and control the changes in the process. The main contractor must make sure he has extensive knowledge of BIM and also have experience with modelling. He must also make sure to get insight in his own information processes and be willing to change these. The theoretical framework confirms this. According to theory, the main contractor takes on the role as supply chain integrator. In that role, the main contractor must manage the supply chain, together with the information flows in it. He must actively lead the supply chain and demand collaborative behaviour from the subcontractors and suppliers. Overall, the main contractor must have an integrated approach that combines technical structures with social practices.

Secondly, the main contractor must make sure that the information processes and BIM are connected, and that the logistic information is incorporated in both. The BIM-model must already be made suitable for supply chain management from the beginning, and both the logistic agreement and the BIM-protocol should have a focus on supply chain management with BIM. All logistic information can easily be added to the families, however this should be done at the start of the model and not afterwards. Also, the BIM-model should be upgraded to at least 4D, by adding planning software. This is crucial for supply chain management. The main contractor should focus on all the aspects of BIM, from information take-off in the procurement phase to the management of the on-site logistics in the execution phase. The main contractor controls the BIM-model and manages the information flows. The subcontractors and suppliers are responsible for providing their logistic information, but the main contractor is responsible for coordinating and structuring this information. The main contractor is also responsible for the overall planning information and, together with the architect, for the information about the location of components. The main contractor needs to control the process and coordinate the information flows to make supply chain management with BIM feasible.

Thirdly, the case study research showed that the main contractor must make sure that the BIM-model aligns with the logistics on the construction site. For this, the main contractor can make use of several frameworks that support site management and material management with BIM. Currently, this is feasible for the larger components, but more difficult for fasteners and materials from the shell construction phase. Managing all the logistics is therefore currently not feasible, but a large step is made by managing the main components. From this supply chain management with BIM can be extended until the whole construction project is managed with BIM. The theoretical framework adds to this that the main contractor should not only focus on the logistics in the fourth phase, but also on measuring the performance of the third parties and provide them with feedback. In the end, he must evaluate the whole process with all third parties, so they can also give feedback to the main contractor. This will improve the supply chain management and the relationships between the involved actors.

Based on the results of the literature study and the case study research, the final framework for supply chain management with BIM has been defined, see Figure 9.8.

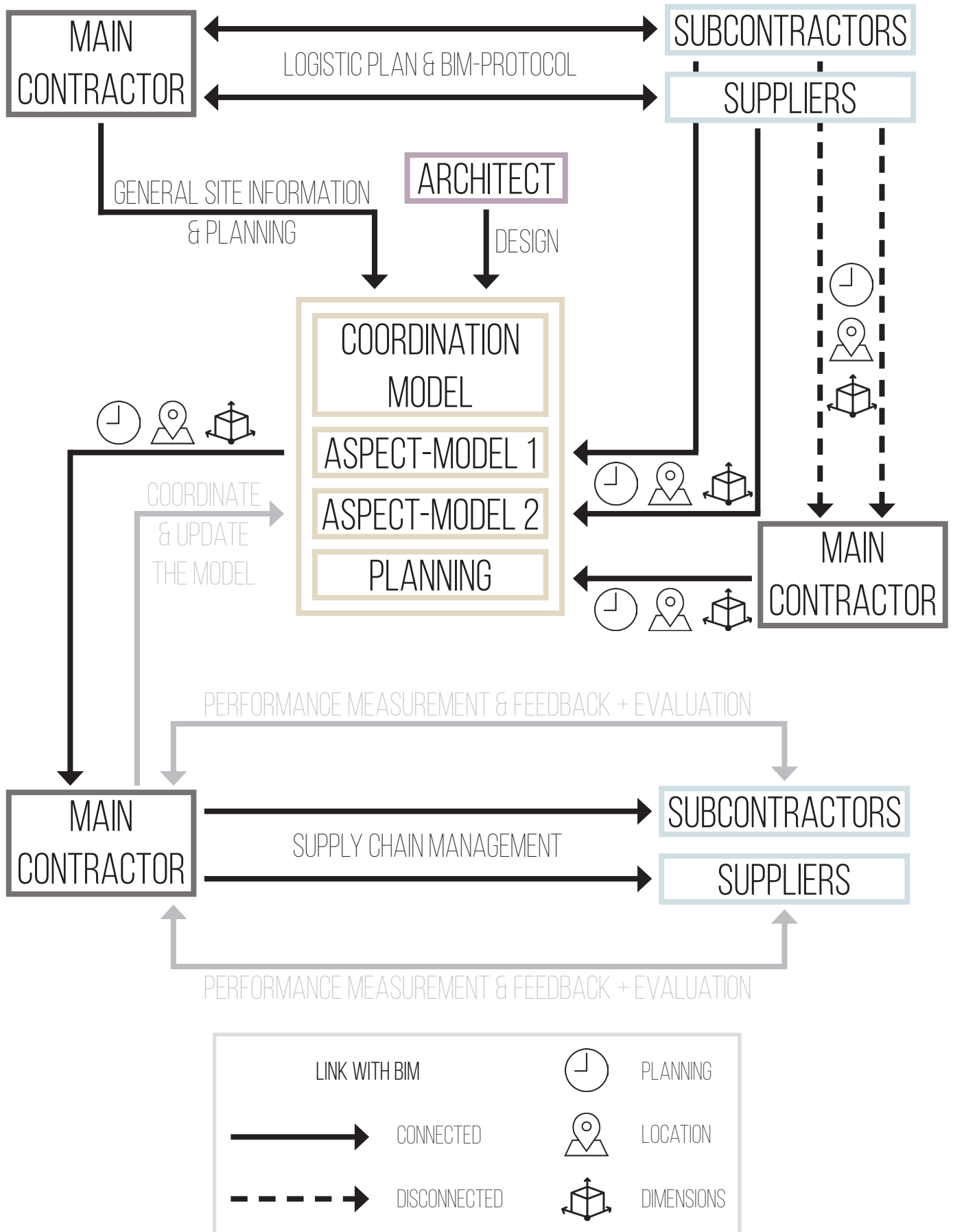


Figure 9.8 Total information flow (own illustration, 2017)

Next to the information flows, this research also focused on providing more clarity on the processes in BIM. Figure 9.9 summarizes the structure of BIM from the design phase to the execution phase, with the goal to manage the logistics on site with BIM.

The information flows and the BIM-structure should be connected to make supply chain management with BIM feasible. Overall, both the case study research and the theoretical framework state that if the main contractor takes control, actively coordinates and structures the information flow and focusses on connecting the logistic information and BIM, he can get control of the logistics. According to the case study research and the validation of experts, the process of changing a traditional supply chain to a supply chain management with BIM is both financially, organisationally and socially feasible for the main contractor.

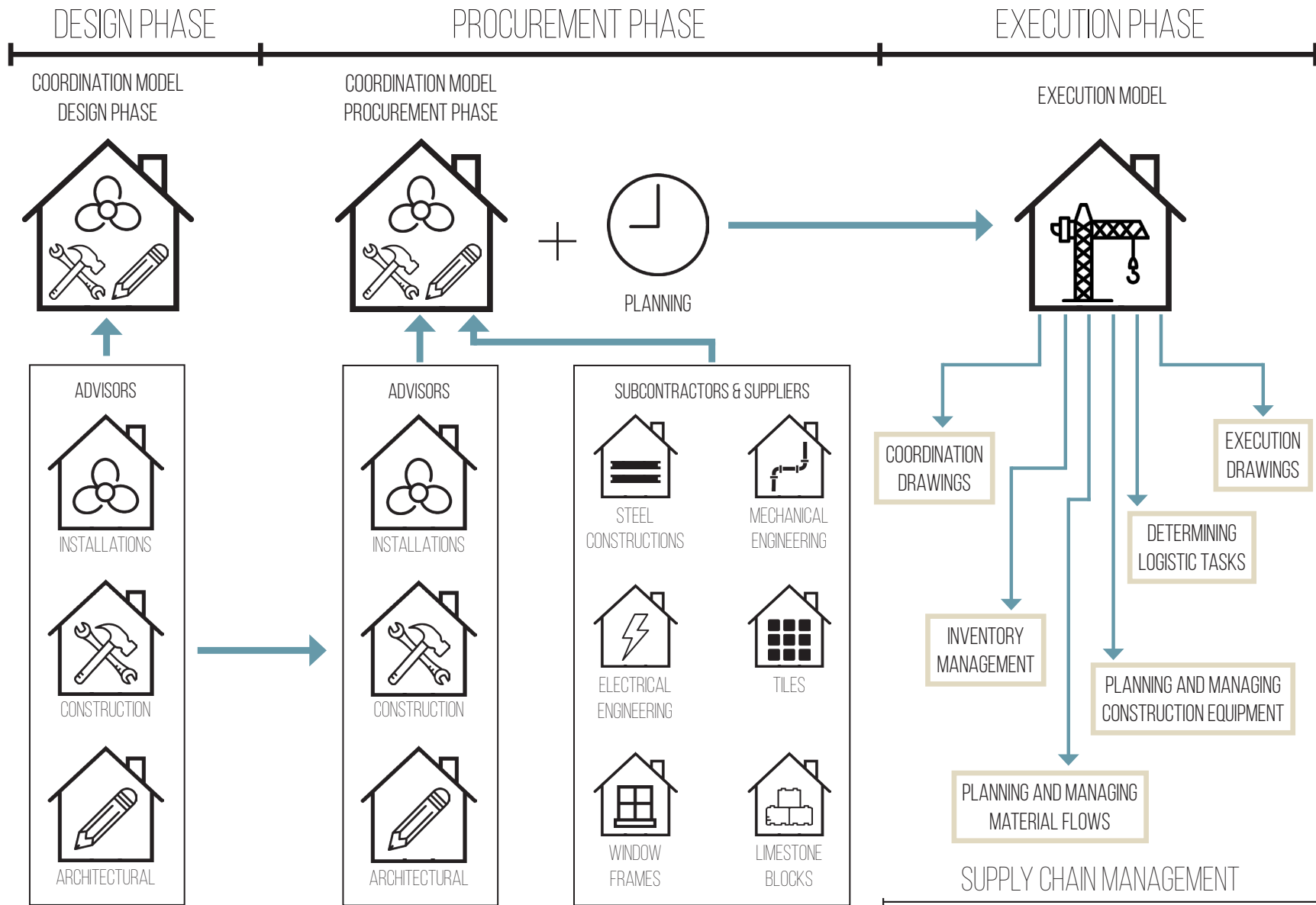
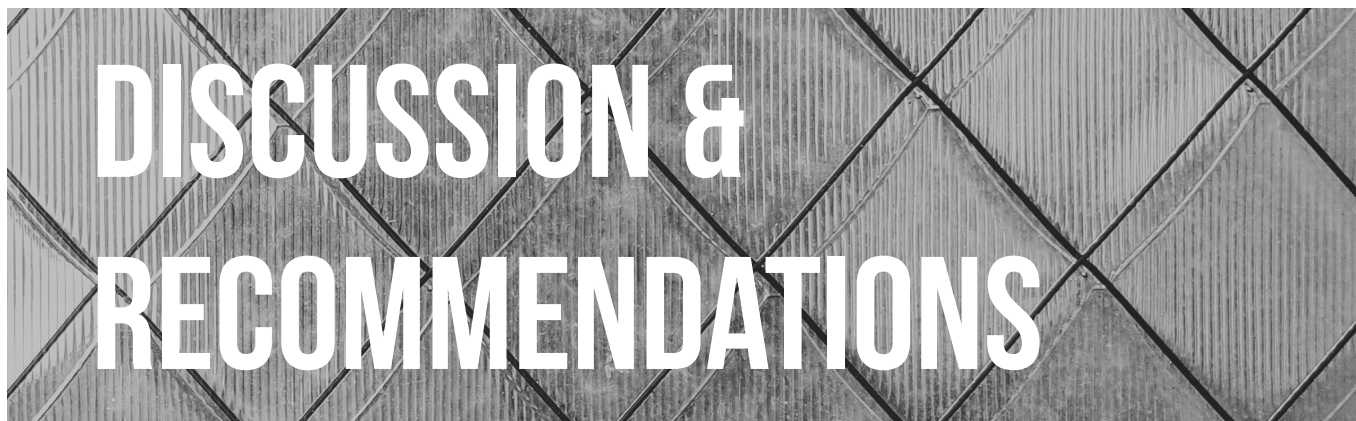


Figure 9.9 Structure BIM-models (own illustration, 2017)

10



DISCUSSION & RECOMMENDATIONS

This research has shown what the current status is of supply chain management with BIM in the construction industry, what contractors can do to change their traditional supply chain in a supply chain that is management with BIM and whether this is feasible or not. Based upon these results a few recommendations can be made both for further research and for practice. First, the results presented in the previous chapter will be discussed. Secondly, recommendations will be made for contractors that want to manage their logistics with BIM. This research is conducted within Waal, but the recommendations are suitable for any main contractor that wants to adopt BIM. Finally, recommendations will be made for further research on this subject

10.1 DISCUSSION

In the previous chapter the results of the case study have been presented. The research has been conducted within a case, however multiple parties from inside and outside the case were involved in the research. Next to that the research is based on both case study research and a literature study, in order to establish external validity. Finally, the case study research was set-up by using a case study protocol, ensuring that if another researcher would conduct

the exact same case study in the future, the results and conclusions would be the same. The results show that currently the logistic information and BIM are completely disconnected and that these should be connected in order for the main contractor to have control of the logistics. This is in accordance with the expectation that currently main contractors are not actively taking control. They are slowly adopting the software but are not adopting the associated processes. A possible explanation for this is that contractors have little insight in their own information processes and have a conservative attitude. They are very reluctant towards any kind of change. Another possible explanation is that contractors are afraid to take the risk of using BIM to manage their logistics. They have very little insight in the logistic costs of the subcontractors and suppliers, so the margin of profit is unclear. This makes them reluctant to take the risk.

This research is an addition to existing literature on supply chain management and BIM, because previous studies were lacking data on the organisational structure of the whole supply chain that is needed for the management of the logistics with BIM. Based on this research contractors can change their traditional supply chain into a supply chain that focusses on logistics management with BIM.

What is important to take into account is that a few assumptions were made at the start of this research. First of all, it is assumed that one of the reasons for the inefficient construction logistics is that main contractors do not have full control of their logistics and that full control would make their logistics more efficient. Secondly, this research assumes that BIM can help main contractors to take control of the logistics. It is important to note that this research does not claim that BIM is the only option that could make construction logistics more efficient. There are other alternatives, however since previous research has shown the positive effects of BIM and additional research on the link between BIM and logistics is needed, this is the tool selected for this research.

What also needs to be taken into account is that the case study of this research focusses on a medium-sized contractor. For medium-sized contractors the risks of implementing BIM are different than for large contractors, for instance because they have less financial resources. Conducting this case study with a large contractor could give different results. What should also be taken into account is that only four sub-contractors and suppliers were selected for this research. This sample is not representative for the whole construction industry.

10.2 RECOMMENDATIONS FOR MAIN CONTRACTORS

Based on this research a few recommendations can be made for contractors that want to adopt BIM for the management of their on-site logistics.

10.2.1 TAKE CONTROL

This research has presented a framework that contractors can use to implement BIM for supply chain management. However, this research has also shown that often contractors are hesitant towards the actual adoption of BIM. They see the benefits of BIM and are willing to adopt BIM, but are still afraid to take the risk. Often subcontractors and suppliers are not convinced of using BIM, which also does not contribute to the BIM-implementation. Nevertheless, the main contractor should take the risk of adopting BIM, despite the fact that not all of the effects are known. This research has shown that it is feasible for the main contractor to adopt BIM for supply chain management. Next to that there are many studies showing the benefits of BIM, and the fact that they far outweigh the costs. This should prove enough that BIM-adoption is the best option to get control of the logistics. Main contractors should do what is in their core business: take control and be in charge. They should take the risks and convince their subcontractors and suppliers to do so too. The outcome can only be known if one takes

the risk, therefore it is important that contractors stop thinking and start doing. Research has shown it is feasible, now it is up to them to put it into practice.

10.2.2 CREATE A BIM-PROTOCOL THAT FOCUSES ON LOGISTICS

The research showed that for a smooth process the logistics should be incorporated in BIM from the beginning. At the start of the project, agreements must be made between the main contractor and the third parties on how the BIM-model will be used for supply chain management. One of the things that can help with this is the BIM-protocol. The research showed that the BIM-protocol is an important document that is used at the start of the project and describes, inter alia, the BIM-related project goals, modelling stages, deliverables and agreements for meetings. If the BIM-model is used to manage the logistics, the procedures for this should also be stated in the BIM-protocol. The recommendation is therefore that contractors add a chapter on logistics to their current BIM-protocol. This forces them to incorporate BIM from the start of the project and think well about the implementation. Based on the findings of this research an example of such a chapter has been created. This chapter consists of a step-by-step plan that contractors are advised to follow in order to get more control of their logistics.

STEP 1: CREATING A 4D-BIM MODEL

The first step in implementing BIM for supply chain management is to link the planning to the 3D BIM-model. This will create a 4D-model that gives much more insight in the BIM-model. A 4D-model makes it possible to show which tasks need to be carried out at a certain moment, which equipment is needed, which materials are needed and when they need to be brought to the site. To link the planning to the BIM-model, specific software is necessary. The two best options are currently Synchro and Vico, both tools that can create a 4D and even a 5D BIM-model. This software can be used in the whole process, from the project planners to the construction supervisor, who uses it on site. Linking the planning to the 3D-model is crucial for logistics management. Therefore, the first step is that the contractor purchases the right software, creates a 4D BIM-model and gets familiar with it.

STEP 2: CHECK THE LOGISTIC INFORMATION OF THE MATERIALS

Once the 4D-BIM model is created the model is ready for the next step. The second step is to check the properties of the materials. All subcontractors and suppliers create their own aspect-model, based upon the IFC-standards and the BIM basis ILS. Next to that, agreements must be made at the start about which logistic information needs to be included in the families of the materials. This includes information about the volume, the delivery date and delivery instructions. These rules must be set at the beginning of the procurement phase, so all parties can include them in their aspect model. Once they send their model to the main contractor, he must check whether the models comply with the rules. A checklist that includes the most important rules can be found in Appendix S. If all logistic information is modelled properly, the model can be linked to the procurement model. Once all aspect models are checked and linked, the procurement model can be transformed into the execution model.

STEP 3: ADD FRAMEWORKS FOR SITE AND MATERIAL PLANNING

Once the BIM-model has been checked and includes both the planning and the logistic information, it is time for the final step. One of the most important parts of the on-site logistics is the management of the site. Site management is about finding the best arrangement of the site layout so that the transportation distances of the equipment, materials and on-site personnel are minimized. Several tools have been developed that can be linked to BIM and create the most optimal site layout planning. Examples of these are the frameworks of Cheng and Kumar (2015a) and Getuli, Mastrolembo Ventura, Capone, and Ciribini (2016) which both focus on modelling the real site conditions. The main contractor should add one of these

frameworks, or another one, and make sure the site layout of the project is fully displayed in the BIM-model. This includes the location of all storage spaces, the site equipment and all transportation options. Next to that a framework can be added that focusses specifically on material planning. The core business of logistics management is to get all the materials on the right place, on the right time. A material framework can help to establish this. An example is the framework of Cheng and Kumar (2015b), which focusses on creating a material logistics planning. The main contractor should include such a framework in the BIM-model. The framework ensures the optimization of the planning and monitoring of the material flows. These frameworks, together with the planning and logistic information, create a complete model that can be used for the management of on-site construction logistics. Contractors are advised to follow all of these steps, in order to get more control of their logistics in the execution phase.

10.3 RECOMMENDATIONS FOR FURTHER RESEARCH

Based on this research several recommendations can be made for further research. These recommendations could be combined in a large research, but could also be used as the basis of a single research.

10.3.1 TESTING THE ORGANIZATIONAL STRUCTURE IN PRACTICE

This research creates a framework for the organisational structure of the information flows when the supply chain of a construction project is managed with BIM. The framework is based on a case study, literature research and the validation of experts, however has not been tested in practice. For further research, it would be useful to test the final framework in practice, in a similar case as project Bètatoren. This can indicate whether the framework is correct or whether adjustments need to be made to the framework. Testing the framework in practice could deliver the final prove for this research.

10.3.2 RESEARCHING THE EFFECTS OF SUPPLY CHAIN MANAGEMENT WITH BIM

Within this research a large part is based on assumptions because there is not enough data available on the subject. One of these subjects that lack data are the effects of supply chain management with BIM. There are several researches that conduct a cost/benefit analysis of BIM, however they focus on the overall effects and not specifically on the logistics. In order to convince the construction industry of adopting BIM for logistics management it is important to have accurate data on this subject. A research that compares a traditional project to a project that uses BIM to manage the logistics would therefore be very useful. This research would contribute to the lack of data that was established in this research. The results of this research can prove whether supply chain management with BIM actually is more efficient than a traditional supply chain.

10.3.3 RETRIEVING DATA ON LOGISTIC COSTS

One of the things that emerged from this research was the fact that there is a lack in data on the logistic costs made by subcontractors and suppliers. Contractors agree on a fixed price that includes the logistics and they have no idea what the exact costs for the logistics are. Next to that, the subcontractors also do not know. They never had to break down their quotation and often also pay a fixed price to their suppliers. This results in the fact that no one knows the exact logistic costs. Further research of for instance NWO strives towards a situation in which the main contractor gets full control of the logistics. In order to do so the main contractor must know the costs that are linked to this. If the exact costs are not known, the main contractor will not take the risk of taking over the logistics from the subcontractor or supplier. Therefore, it is important that additional data is retrieved on this subject. A comparing study should give insight in the logistic percentages of quotations of different types of subcontractors and

suppliers, creating an overview of the whole construction industry.

10.3.4 RESEARCHING THE LINK BETWEEN BIM AND LABOUR PRODUCTIVITY

A lot of research has been conducted on the costs and benefits of BIM in general, however not specifically on the benefits that are related to the logistics. An important part of the logistics is the labour productivity. Currently contractors pay a fixed price for their subcontractors and suppliers, which includes both the labour and the materials. As explained in the previous paragraph, it is important to retrieve more data on logistic costs. Part of this is data on the labour productivity. Currently, it is assumed that the average labour productivity is quite low and that logistic measures can increase the labour productivity. However, not much research has been conducted on this subject, especially not with a focus on BIM. The labour costs are more than half of the total costs of a construction project, so contractors would be largely benefited by an increase of the labour productivity. Future research could focus on the link between BIM, supply chain management and the labour productivity to see whether BIM has an effect on the labour productivity and what kind of effect that is.

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APPENDICES

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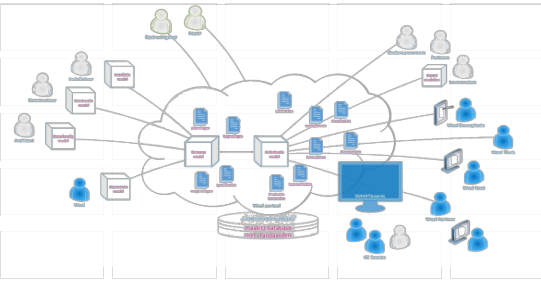
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2017		ACTIES & ONTWIKKELINGEN															
		ICT	Modelleren (3D)	Tekenen	Coördineren	Werkplannen	Uittrekken	Afrijzen (5D)	Simuleren (5D)	Plannen (4D)	Samenwerken	Bouwplaats	Producteren	Analyseren	Beheren	Innovaties	
ACTIES & ONTWIKKELINGEN																	
					Procesplanning BIM Incl. informatie behoefte & overdrachten												
		Referentiemodel: Richtlijnen ontwerp Uitgangspunten Ley's		Bijhouden/bijwerken/ opstellen Solibri werkmethode.					Solibri controle calculate modellen.								
		Opleiden WVB en PL over werking modellen		Clashregels Solibri uitvoeren richting leveranciers.					Bibliothek app Basisproject Rapporten								Koppeling 4PS
	Uitrollen nieuwe tools	Onderzoeken Revit server.	Updaten/vullen BIM protocol	Maatwerk workflow standaardiseren en afstemmen.				Implementatie Team D Keingebieden Werkmethode			Evaluaties projecten Kennisdelen					Dynamo Hoofden	
	Tool updates	Basis coördinate bibliothek Revit (Packages/Template).	Issue management verder uitvechten (BIM/BIM collab) Opleiden/extern	Standaardiseren packages voor werkplannen (bijv. bouwplaats)				Ontwikkelen Team C Keingebieden Rapportages Werkpakketten	3D film tbv aanbesteding en werkpian aannulning			CE sessies begeleiden BIM protocol begeleiden	Gebruik Solibri Viewer op bouwplaats (ITC's)	BIM inkoopstrategie partners.			12Build
	Software updates	Inkoopchecklist architect/constructeur/ adviseurs.	Welke tekeningen in welke fase. Hoe zien deze er uit.	Vergroten betrokkenheid projectteam bij BIM.	Basis Revit training ontwikkelen en geven aan WVB.	ITC's in Solibri inregelen.	Modellieren om te calculeren. Incl. juiste bibliothek.	Werkmethode logistieke ringen.	Uitzoeken gebruik VIDO planning.		BIM op elk project Openen in A3 plannen.	BIM modellen naar de bouw tbv dagstarts	Inkoopchecklist BIM O.A. en Ley's.				Daqri Bouwhelm
DOELEN	ICT	Modelleren (3D)	Tekenen	Coördineren	Werkplannen	Uittrekken	Afrijzen (5D)	Simuleren (5D)	Plannen (4D)	Samenwerken	Bouwplaats	Producteren	Analyseren	Beheren	Innovaties		
		Nieuwe manieren van samenwerken vragen meer van de ICT ondersteuning. Performance van de omgeving en up to date programma's zijn van cruciaal belang. De software voor het modelleren en modellen bekijken moet up to date zijn. Minimaal 1 oudere versie moet blijven staan. Tevens moeten werkmethoden binnen pakketten worden geüpdate	Modelleren Het bouwen van een digitaal prototype van het gebouw/project. Modellen worden breed ingezet (intern en extern). Er dienen goede afspraken gemaakt te zijn wat er minimaal moet worden gemodelleerd en templates moeten worden afgestemd. Ook manieren van modelleren moeten worden vastgesteld i.v.m. IFC exports. Modelleur/moder IFC experts zijn.	Tekenen De vertaling van het digitale prototype naar algemene overzichtstekeningen. Hoe minder hoe beter 'Waar zet het maken van overzichtstekeningen als een noodzakelijke fase? Waar we kunnen voorkomen dat er geen tekentek moet worden gezeten en daar op in. Het maken van tekeningen en details voor algemeen belang (overzichtstekeningen) vergt veel tijd en zal naar de toekomst gaan verwijzen.	Coördineren Het coördineren van de partijen in het ontwerp- en engineeringproces. Een heel groot onderdeel van de werkzaamheden van Waal is het organiseren van alle informatie rondom een bouwproject. Het 3D model kan een deel van dat werk overnemen of ondersteunen waardoor de kans op fouten kleiner wordt en communicatie transparanter.	Werkplannen Hiermee maken we het verschil! Maatwerk informatie afgestemd op de gebruiker ervan. Dit voorkomt fouten. Door het maken van goede werkplannen kunnen we de mensen waarmee we werken beter aansluiten. Het maken van een werkplan moet een eenvoudige en snelle handeling zijn waarbij de juiste informatie in duid en tijd kan worden geïntegreerd.	Uittrekken We gebruiken de hoeveelheden uit het model om te rekenen en plannen. Het 3D model kan heel veel hoeveelheden genereren. Door de gebruiker er zelf mee te laten werken komt vanzelf de vraag terug bij de modelleur naar meer of andere hoeveelheden.	Afrijzen (5D) Prisvorming Op basis van de hoeveelheden parametrische recepten maken. Na het gebruiken van hoeveelheden kan er ook 'automatisch' mee gerekend worden. Hiermee kan de calculator meer worden ingezet als commerciële middel om klanten te vertedien.	Simuleren Het model gebruiken om logistiek en bouwmethode te optimaliseren. Zowel intern om te optimaliseren als extern als commerciële middel om klanten te vertedien.	Plannen Vanuit het 3D model een planning maken en interactief optimaliseren. Waar bij het simuleren een planning aan het model wordt gekoppeld zal bij deze stap de planning uit het model gegenereerd worden en kan door middel van het spelen met ploegen en volgorde het proces geoptimaliseerd worden.	Samenwerken Interactief samenwerken, intern en extern en gezamenlijk op afstand. Gezamenlijk werken op een SMARTboard en daarmee te aanbevelingen en gedachten meten digitaliseren is zijn een grote winst. Slag twee ook het werken op afstand. SharePoint zorgt voor het deel en bewikbaar maken van de project informatie.	Bouwplaats Het model wordt gebruikt om de bouw aan te sturen. De uitvoerder heeft de beschikking over het model en kan hiernaast zijn bouw aansturen. Tevens zijn partijen die produceren op de bouw aangesloten op het model. Bijvoorbeeld maatschappij.	Producteren Leveranciers produceren direct vanuit het model. Het 3D model dient als communicatiemiddel om leveranciers aan te sluiten. Afstemming met omringende onderdelen gaat hiermee beter en het model dient als communicatiemiddel.	Analyseren Modellen beoordelen op passing, regelgeving en bouwbaarheid. 3D modellen automatisch kunnen controleren op technische aspecten. Doel is dat ontwerp fouten daarmee aan het licht komen en de 2D controlewerk van de werkvoorbereider voorkomt.	Beheren	Ontdekken	
ROLLEN	Calculator	Planontwikkelaar	Modelleur	Werkvoorbereider	Projectleider/Inkoop	Uitvoerder											
	Calculator	Planontwikkelaar	Modelleur	Werkvoorbereider	Projectleider/Inkoop	Uitvoerder											
ACTIEHOUDERS	Dennis Adegeste	Boudewijn Goossens	Jeroen van Leeuwen	Auke Verbraken	Michel Keizer	George van Scheijndel	ALLEN										



Per actie wordt een planneig gelijgewordt en gedeelt in deze groep. Dennis Adegeste, bewaakt de overall voortgang en George van Scheijndel is vertegenwoordiger vanuit MTJ.

DOCSDB-# 306531
Datum: 8-3-2017

Figure A1 Bim-vision of Waal (Waal, 2017a)

BIM-MATURITY MODEL

Strategy	0 Not present	1 Initially	2 Managed	3 Defined	4 Quantitatively managed	5 Optimalised
BIM vision and goals	No BIM vision and/or goals are formulated.	There is a basic BIM vision.	BIM goals are defined in general terms.	The BIM vision fits within the overall mission and strategy.	BIM goals are defined SMART.	The BIM vision and goals are regularly reviewed and adjusted if necessary.
Management support for BIM implementation	No support by the management.	Limited, unstructured support.	Sufficient support, but with limited resources.	Full support with sufficient resources.	Sufficient resources are provided for further BIM development.	Full support for continuous redevelopment of BIM now and in the future.
BIM expert / meetings / department	No BIM expert, work group or department.	BIM expert with limited time for initiatives, small BIM meetings.	BIM expert with sufficient time for BIM support and initiatives, BIM meetings.	BIM expert cooperates closely with the whole organisation, large BIM meetings.	BIM expert is part of the management, the whole organisation is represented in BIM meetings.	BIM decisions by the BIM expert are part of the overall strategy of the organisation.
Organisational structure	0 Not present	1 Initially	2 Managed	3 Defined	4 Quantitatively managed	5 Optimalised
Tasks and responsibilities	Tasks and responsibilities have not been determined.	BIM tasks and responsibilities are determined to a limited extent.	Basic tasks are determined, are integrated to a limited extent.	Responsibility for BIM lies with the project teams, tasks are determined and integrated.	BIM tasks and responsibilities are defined and fully integrated, they receive full support.	Tasks and responsibilities are reviewed regularly and adjusted if necessary.
People and culture	0 Not present	1 Initially	2 Managed	3 Defined	4 Quantitatively managed	5 Optimalised
Personal motivation and willingness to change	Organisational culture is demotivating for BIM implementation.	Organisational culture does not support BIM implementation, this is based on personal motives.	Personal motivation for BIM implementation is insufficiently supported by the organisational culture, there is willingness to change.	Joint motivation for BIM implementation creates unity within the organisation.	The organisational culture stimulates BIM implementation, traditional structures are adjusted.	Full BIM support by the whole organisation and full commitment to change.

Stimulating actor (internal)	There is no stimulating actor	There is a stimulating actor but he/she has limited time available.	BIM actor is present with sufficient time.	There are multiple BIM actors within the organisation.	There are multiple BIM actors of which one is part of the management.	There is a BIM actor within the board who cooperates with other external BIM experts.
Education, training and support	There is no education or training available.	Education and training are unstructured.	Education and training is available for employees working with BIM.	General information about BIM for the whole organisation. Education and training for people working with BIM.	Education and training program is tailored to the personal needs of the employees, focus on support in the practice.	Education and training program are continuously improved and available for the whole organisation.
Cooperation	Organisation is internally orientated, BIM processes are internal.	Cooperation between partners is ad hoc and proactive.	The importance of cooperation is recognized, cooperation via BIM on a low level.	Mutual activities with partners to adjust the tasks and processes to each other.	External cooperation is part of the organisational strategy, mutual trust between partners.	Close cooperation, both internal and external. Continuous review of the cooperation.
Processes and procedures	0 Not present	1 Initially	2 Managed	3 Defined	4 Quantitatively managed	5 Optimalised
Procedures and work instructions	No BIM procedures or work instructions are determined.	BIM processes are determined to a limited extent. Instructions are used inconsistently.	Instructions and procedures are determined for important BIM processes.	Detailed instructions are defined for important BIM processes. There is attention for external processes.	Detailed process documents and procedures are available for BIM processes.	The detailed process documents are often reviewed and adjusted if necessary.
ICT	0 Not present	1 Initially	2 Managed	3 Defined	4 Quantitatively managed	5 Optimalised
Hardware and network	There is no hardware available that supports BIM.	Hardware is partly able to support BIM, only for internal use.	Employees that work with BIM have access to suitable hardware. Models can be exchanged.	Advanced hardware systems are partly available within the organisation, based on the need to use BIM.	All hardware is able to support BIM. The network supports the concomitant use of a BIM model.	A program has been set-up to keep the BIM hardware systems up-to-date.
Software	There is no BIM software.	There is software available that can read BIM data.	There is basic BIM software available.	The software supports advanced BIM applications.	Exchanging information is facilitated by the software.	A program has been set-up to keep the BIM software systems up-to-date.
BIM facilities	There is no BIM workplace available.	There are a few BIM workplaces available to read data.	There is workspace available large enough to work together with a few people.	There is workspace available to work together with extra facilities.	There are special BIM workplaces amongst the regular workplaces.	There is a policy defined to manage the need for BIM workplaces.

Data	0 Not present	1 Initially	2 Managed	3 Defined	4 Quantitatively managed	5 Optimised
Information management	There is no system for the storage or management of data.	There is a document management system but it is unstructured.	The use of the document management system is described in procedures. The system is not linked to the model.	For important BIM applications can the system be linked to the BIM model.	The system is fully linked to the BIM model and all data is synchronized.	All project data is managed from a comprehensive system. There is a datamanager responsible for the system.
Data exchange	There is no exchange of data.	Exchange of data via the BIM model is limited and ad hoc.	Exchange of data is mainly focused on internal use. External exchange is difficult.	Data exchange between partners is defined in contracts and often used.	Data-exchange is fully used both internal and external. The organisation is transparent.	Both BIM data and performance data is exchanged in order to improve the processes.

Table A1 BIM-maturity model (own illustration (2017) based on Siebelink et. al. (2015))

INTERVIEW I

This interview will be conducted with Joost de Korte, Dennis Adegeest and Jorg van Schadewijk from Waal and is about phase 1.

Introduction

1. What is your role in project Bètatoren?

Logistic measures

2. What kind of experience do you have with logistic measures?
3. Which measures do you prefer?
4. Which measures do you dislike?
5. Which measures do you want to take at project Bètatoren?
 - a. Why these measures?

BIM Input

6. What is your previous experience in working with BIM?
7. What is your view on supply chain management with BIM?
8. How do you prepare yourself for a project in which the supply chain is managed with BIM?
Or, in case there is no experience, how would you prepare yourself?
9. What information do you send to your sub-contractors and suppliers beforehand concerning the supply chain management with BIM?
 - a. Do you have experience with a BIM protocol?

BIM Output

10. How would you manage the supply chain without using BIM?
11. What do you think changes when you use BIM?
12. What activities would you set-up in order manage the supply chain with BIM?
 - a. Do you provide knowledge and assistance to the third parties about BIM? Why or why not?
 - b. Do you organise BIM-sessions? Why or why not?
 - i. Do you organise these BIM sessions individually or with all third parties together?

INTERVIEW II

This interview will be conducted with two suppliers (Calduran and Halfen) and two subcontractors (Breman and Tegel Idee) from project Bètatoren and is about phase 1 and 2.

Introduction

1. What is your role in project Bètatoren?
2. During which phases of the project will you be active?
 - a. When will these phases take place?

Logistic measures

3. What kind of experience do you have with logistic measures?
4. Which measures do you prefer?
5. Which measures do you dislike?

BIM

6. What is your previous experience in working with BIM?
 - a. How will you use BIM in project Bètatoren?
7. What is your view on supply chain management with BIM?
8. How do you prepare yourself for a project in which the supply chain is managed with BIM?
Or, in case there is no experience, how would you prepare yourself?
9. What information would you need from the main contractor in order to be prepared?
 - a. Would a BIM protocol be necessary?
 - b. Would you expect the main contractor to provide knowledge and assistance? Why or why not?
 - c. Would you expect the main contractor to organise BIM sessions? Why or why not?
 - i. Would you prefer these BIM sessions individually or with all third parties together?
10. How should a main contractor communicate in your opinion in order to make the logistics function perfectly?
11. Are you going to model for project Bètatoren?
 - a. If yes, when will this model be ready?

Supply chain management

12. What kind of materials do you deliver to project Bètatoren?
 - a. Where do you get these materials from?
13. How much material do you deliver to project project Bètatoren (in m3)?
 - a. How much deliveries are this?
 - b. How will these materials be delivered?
14. What is the planning schedule for the deliveries of these materials?
15. How do you manage the logistics of these orders?

INTERVIEW III

This interview is conducted with Alexander Sagius from HFB in Rotterdam.

Introduction

1. What exactly does HFB do as a company?
2. What is your role within HFB and what does your job entail?

BIM and supply chain management

3. What is your experience with the combination supply chain management and BIM?
4. Is there specific software or a certain framework designed to manage the logistics of a construction project with BIM?
5. What do you think are the costs for a main contractor for the use of BIM?
6. What information do you think is necessary as an input for BIM in order to manage the supply chain?
 - a. Who do you think is responsible for the input?
7. How can the information in BIM be extracted and used to manage the supply chain?
 - a. Who do you think is responsible for the output?
8. Do you think that the main contractor should provide extra help for the third parties? (such as a BIM-specialist, BIM-meetings, etc.)
9. Do you have any do's and don'ts for contractors who want to use BIM for supply chain management?

INTERVIEW IV

This interview is conducted with Joost de Korte, Jorg van Schadewijk and Dennis Adegeest from Waal and is about phase 2.

1. What is the start of the BIM-model? How do you decide when to model yourself and when to outsource it to an architect?
 - a. Why did you choose for an architect in case of project Betatoren?
2. Wat kind of information did you hand to the architect when they needed to make the model?
 - a. How did you receive for instance detailed information about the dimensions of furniture?
3. Are the sub-contractors and suppliers in any way part of the set-up of the BIM model?
 - a. If yes, what kind of information did they send and when did they do so?
 - b. If no, why not?
4. How do you make sure that the information shown in the BIM model is the right information?
 - a. Do you perform a quality control and if yes, who does this?
5. If you would want to use BIM for the logistics, what kind of information do you think needs to be part of the BIM model? (dimensions, planning, location, etc.)
6. Who is responsible for providing this information?
7. When should this information be provided? Before the start so the architect can incorporate it or should Waal/third parties add it themselves later?
8. How should this information be added (separate models, etc.)?
9. How can you make sure other parties deliver what you need? And how can you make sure this matches with your BIM?
10. What do you think is reasonable to ask from other parties with regards to BIM? Would you like them to model themselves or is it okay if they outsource it?
11. How do you decide to ask a party to model or not? What is the trade-off that you make and how do you make an estimation of the benefits?
12. If the logistics are managed with BIM and there are parties that do not use BIM (such as Tegel Idee) how do you think these parties should hand in their information?
 - a. Who is responsible for managing this information in BIM? For translating the traditional information into BIM information.

INTERVIEW V

This interview is conducted with two suppliers (Calduran and Halfen) and two sub-contractors (Bremann and Tegel Idee) from project Bètatoren and is about phase 2.

1. What kind of information have you received from Waal at the start of the project? (PvE, etc.)
2. What kind of information have you send to Waal? (planning, amounts, costs)
 - a. When have you send this information?
3. Have you seen the BIM model of project Betatoren?
 - a. If yes, did you perform a quality control? Why or why not?
 - b. If not, why not? Would you like to?
4. In case you are not going to model for project Betatoren, why not?
 - a. Would you think it would benefit the project if you would have made a BIM model? Why or why not?
 - b. Do you or would you have made a separate model or would you have fitted it in the existing model? Why?
5. What kind of information do you need from the main contractor to make a BIM model regarding the logistics of the project?
6. If the main contractor would use BIM throughout the whole process, from the design to the execution and asks the third parties use BIM too. Would you do so? Why or why not?
 - a. Do you see the benefits of using BIM?
 - b. When would you start to implement BIM in your company? Or when do you think it could be useful?
7. Where do you think are the difficulties of using BIM? In which phase? And at which party?
8. With your product, do you have a push or a pull strategy? Why?
 - a. Which one do you prefer?



INTERVIEW VI

This interview is conducted with Joost de Korte, Jorg van Schadewijk and Dennis Adegeest from Waal and is about phase 3.

1. Who controls the information that is submitted by the third parties?
 - a. Is there a quality check and who does this? If not, who should do this?
2. How can you make sure there is no mismatch between the data?
 - a. Should this be solved only when a mismatch is identified or should measures be taken way before that? What kind of measures would this be?
3. What kind of information regarding the logistics is received from the third parties (planning, delivery schedules, etc.) and how is this information used?
 - a. What do you (planner) do with this information?
 - b. What does the construction supervisor do with this information?
4. How can BIM be used to relieve the executor of his tasks?
5. Do you think the link between the werkvoorbereiding and the uitvoering is strong enough to use BIM for the logistics during the whole project? Why or why not?
 - a. How could this be done better?
6. Do you think that currently there is a push or a pull strategy at Waal?
 - a. What do you think is better and why?
 - b. How can you reach that?
7. Where do you think are the difficulties in the transfer of the information? At Waal or at the third party? And where exactly in the organisation?
8. How could this be solved?

INTERVIEW VII

This interview is conducted with two suppliers (Calduran and Halfen) and two sub-contractors (Bremann and Tegel Idee) from project Bètatoren and is about phase 3.

1. What is your opinion on the use of a material container? Do you think it will make construction logistics more efficient?
2. What do you think are the pro's and con's of a material container for you?
3. What do you think are the pro's and con's of a material container for a main contractor?
4. Do you think it is feasible?
5. Is it something you are willing to use on a project?

In order to use a material container in the execution phase, you need to do a lot of preparatory work in the procurement phase.

6. All the preparation for a material container is useful (you need to know if it will fit), but it also costs a lot of time. Do you think that such an extensive preparation is necessary?
7. Who do you think is responsible for the preparation? Is this a task for the subcontractor or supplier, the main contractor or do they have to do it together?

In order to manage the logistics three types of information are important: information regarding the dimensions, the location and the planning. Research of the BIM-model of Bètatoren shows that a lot of this information is missing. This information needs to be completed in order to manage the logistics with BIM.

8. Who do you think is responsible for completing the information in BIM? The subcontractor or supplier, or the main contractor?
9. Do you think it is difficult to complete the information? And which information is the most difficult?
10. Do you think implementing supply chain management with BIM is feasible for the main contractor? Why or why not?
11. Do you think implementing supply chain management with BIM is feasible for the subcontractors and suppliers? Why or why not?

INTERVIEW VIII

This interview is conducted with two suppliers (Calduran and Halfen) and two sub-contractors (Breman and Tegel Idee) from project Bètatoren and is about phase 4.

Overall supply chain management

1. What is your opinion on a situation in which the main contractor is responsible for all the logistics, including the logistics to the construction site?
2. What is the percentage of logistic costs in your quotations?
 - a. Which components does this consist of?
3. Do you think the logistics will become more efficient if the main contractor is responsible for it?
4. Do you think it will positively or negatively affect you if the main contractors takes on the management of all the logistics? Why?
5. Do you think it will positively or negatively affect the main contractor? Why?

Traditional project

6. On average, how many of the deliveries are on time?
7. How long does a truck need to wait before it can unload?
8. How long do construction workers need to wait before they can unload a truck?
9. How far in advance does a main contractor need to place an order for you to deliver it on time?

Supply chain management with BIM

10. Does your organizational structure need to change if you would want to manage your supply chain with BIM?
11. Do you think supply chain management with BIM is feasible for the main contractor? Why or why not?
12. Do you think supply chain management with BIM is feasible for the subcontractors and suppliers? Why or why not?

INTERVIEW IX

This interview is conducted with Joost de Korte, Dennis Adegeest and Jorg van Schadewijk from Waal and is about phase 4.

Overall supply chain management

1. What is your opinion on a situation in which the main contractor is responsible for all the logistics, including the logistics to the construction site?
2. Do you think the logistics will become more efficient if the main contractor is responsible for it?
3. What do you think are the pro's and con's for the main contractor of such a structure?
4. What do you think are the pro's and con's for the subcontractors and suppliers of such a structure?
5. Do you think subcontractors and suppliers will agree to cooperate with this?

Traditional project

6. On average, how many of the deliveries are on time?
7. How long does a truck need to wait before it can unload?
8. How long do construction workers need to wait before they can unload a truck?

Supply chain management with BIM

9. Can you explain how you are going to use the material container in the execution phase?
10. What are the benefits you think you will achieve?
11. Are there also disadvantages of using a material container?
12. Do you think it will make the logistics more efficient? Please estimate per KPI what you think is the current percentage and what you think the percentage will be once the supply chain is managed with BIM.
 - a. Labour productivity
 - b. Deliveries in accordance with requirements
13. Do you think you are able to get part of your investment back from the subcontractors and suppliers?
14. Do you think using a material container is feasible? Why or why not?

In order to use a material container in the execution phase, you need to do a lot of preparatory work in the procurement phase.

15. All the preparation for a material container is useful (you need to know if it will fit), but it also costs a lot of time. Do you think that such an extensive preparation is necessary?
16. Who do you think is responsible for the preparation? Is this a task for the subcontractor or supplier, the main contractor or do they have to do it together?

In order to manage the logistics three types of information are important: information regarding the dimensions, the location and the planning. Research of the BIM-model of Bètatoren shows that a lot of this information is missing. This information needs to be completed in order to manage the logistics with BIM.

17. Who do you think is responsible for completing the information in BIM? The subcontractor or supplier, or the main contractor?
18. Do you think it is difficult to complete the information? And which information is the most difficult?
19. Why is the information incomplete? And if you do not get your information from BIM, where do you get it from?

20. What do you think are the benefits of supply chain management with BIM for the main contractor?
21. What do you think are the disadvantages of supply chain management with BIM for the main contractor?
22. What do you think are the benefits of supply chain management with BIM for the subcontractors and suppliers?
23. What do you think are the disadvantages of supply chain management with BIM for the subcontractors and suppliers?
24. Do you think implementing supply chain management with BIM is feasible for the main contractor? Why or why not? Please focus on:
 - a. Financial feasibility
 - b. Organizational feasibility
 - c. Social feasibility
 - d. Overall feasibility
25. Do you think implementing supply chain management with BIM is feasible for the subcontractors and suppliers? Why or why not?

CALCULATIONS - TEGEL IDEE

Logistics	
Area Revit	840.4 m ²
Calculation	689.73 m ²
Delivery	9 pallets

Calculation

$$688.52 + 1.21 = 689.73 \text{ m}^2$$

Delivery

$$840.4 / 0.09 = 9,337.78 \text{ tiles}$$

$$9,337.78 * 1.1 = 10,271.56 \text{ tiles}$$

tile = 30 x 30 cm = 0.09 m²

pallet = 90 (w) x 120 (l) x 100 (h)

tiles per pallet = 3 (w) x 4 (l) x 100 (h) = 1,200 tiles

$$10,272 / 1,200 = 8.56 \text{ pallets}$$

*possibly 123.06 m² of 40 x 40 cm tiles for the entrance

$$123.06 / 0.16 = 769.13 \text{ tiles}$$

$$769.13 * 1.1 = 846.04 \text{ tiles}$$

tiles per pallet = 2 (w) x 3 (l) x 100 (h) = 600 tiles

$$847 / 600 = 1.41 \text{ pallets}$$

Logistics	
Area Revit	3,654.7 m ²
Calculation	3,513.25 m ²
Delivery	38 pallets

Calculation

$$3507.62 + 5.625 = 3,513.25 \text{ m}^2$$

Delivery

$$3,654.7 / 0.045 = 81,215.56 \text{ tiles}$$

$$81,215.56 * 1.1 = 89,337.11 \text{ tiles}$$

tile = 15 x 30 cm = 0.045 m²

pallet = 90 (w) x 120 (l) x 100 (h)

tiles per pallet = 6 (w) x 4 (l) x 100 (h) = 2,400 tiles

$$89,338 / 2,400 = 37.22 \text{ pallets}$$

CALCULATIONS - CALDURAN

Logistics	
Volume Revit	411.77 m3
Calculation	429.52 m3
Delivery	398 pallets

Calculation

$$\begin{aligned}
 14,099.98 &+ 34,864.98 &= &48,964.96 && \text{blocks} \\
 48,964.96 &/ 11.4 &= &4,295.17 && \text{m2} \\
 4,295.17 &* 0.1 &= &429.52 && \text{m3}
 \end{aligned}$$

1 pallet = 1,000 blocks
 1,000 blocks = 11,4 m2

Delivery

$$\begin{aligned}
 411.77 &/ 0.1 &= &4,117.7 && \text{m2} \\
 4,117.7 &/ 11.4 &= &361.20 && \text{pallets} \\
 361.20 &* 1.1 &= &397.32 && \text{pallets}
 \end{aligned}$$

Logistics	
Volume Revit	33.66 m3
Calculation	17.73 m3
Delivery	33 pallets

Calculation

$$\begin{aligned}
 2,021.17 &/ 11.4 &= &177.30 && \text{m2} \\
 177.30 &* 0.1 &= &17.73 && \text{m3}
 \end{aligned}$$

1 pallet = 1,000 blocks
 1,000 blocks = 11,4 m2

Delivery

$$\begin{aligned}
 33.66 &/ 0.1 &= &336.6 && \text{m2} \\
 336.6 &/ 11.4 &= &29.53 && \text{pallets} \\
 29.53 &* 1.1 &= &32.48 && \text{pallets}
 \end{aligned}$$

LOGISTIC INFORMATION - BIM-MODEL BÈTATOREN

				Designation		Dimensions					Location			Time				
				Family	Type	Length	Width	Height	Weight	Area	Volume	Level	Appartment	Room	Phase	Delivery date	Construction date	
Subcontractors	Breman	Bathroom	Sink	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	✓	✓	✗	✗	
			Shower	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗
			Bathtub	✓	✓	✓	✗	✓	✗	✗	✗	✗	✓	✓	✓	✓	✗	✗
			Radiator	✓	✓	✓	✓	✗	✗	✗	✗	✗	✓	✓	✓	✓	✗	✗
	Toilet	Toilet	✓	✓	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✗	✗	
		Sink	✓	✓	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✗	✗	
Tegel Idee	Bathroom / Toilet	Floor tiles	✓	✓	✓	✓	✓	✗	✓	✓	✓	✗	✗	✓	✗	✗		
		Wall tiles	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓	✗	✗	✓	✗	✗	
Suppliers	Calduran	Corridor	Limestone	✓	✓	✓	✓	✓	✗	✓	✓	✓	-	-	✓	✗	✗	
		Bicycle Storage	Limestone inside wall	✓	✓	✓	✓	✓	✗	✓	✓	✓	-	-	✓	✗	✗	
			Limestone outside wall	✓	✓	✓	✓	✓	✗	✓	✓	✓	-	-	✓	✗	✗	
	Halfen	Facade	Facade structure	✓	✓	✓	✓	✓	✓	✗	✗	✗	-	-	✓	✗	✗	
			Miscellaneous	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	-	-	✓	✗	✗

Table A2 Logistic information retrieved from the BIM-model of project Bètatoren (own illustration, 2017)

FLOOR PLAN 7TH FLOOR - BËTATOREN

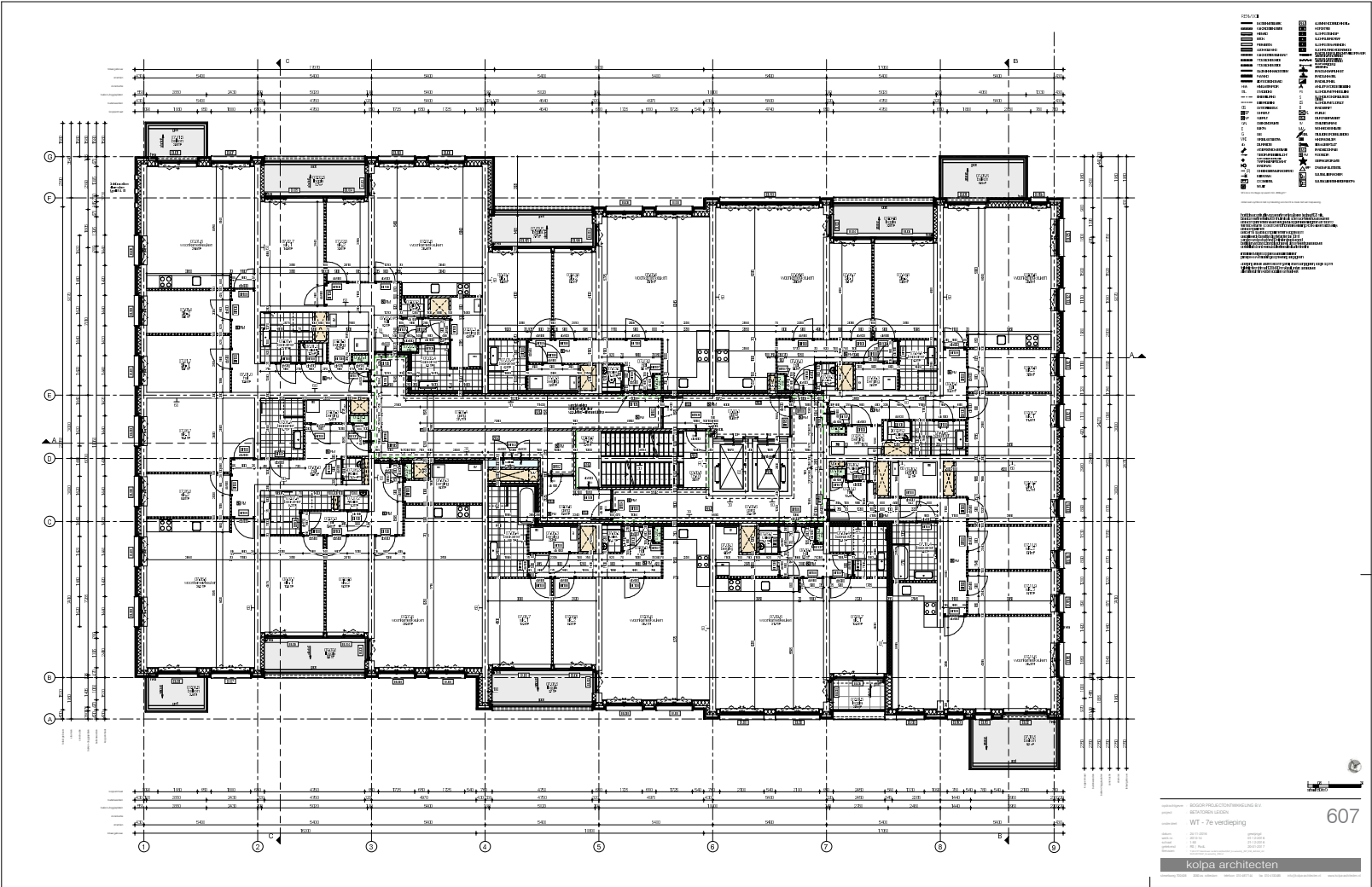


Figure A2 Floor plan of the 7th floor of project Bëtatoren (Kolpa Architekten, 2016)

FLOOR PLAN 11TH FLOOR - BÈTATOREN

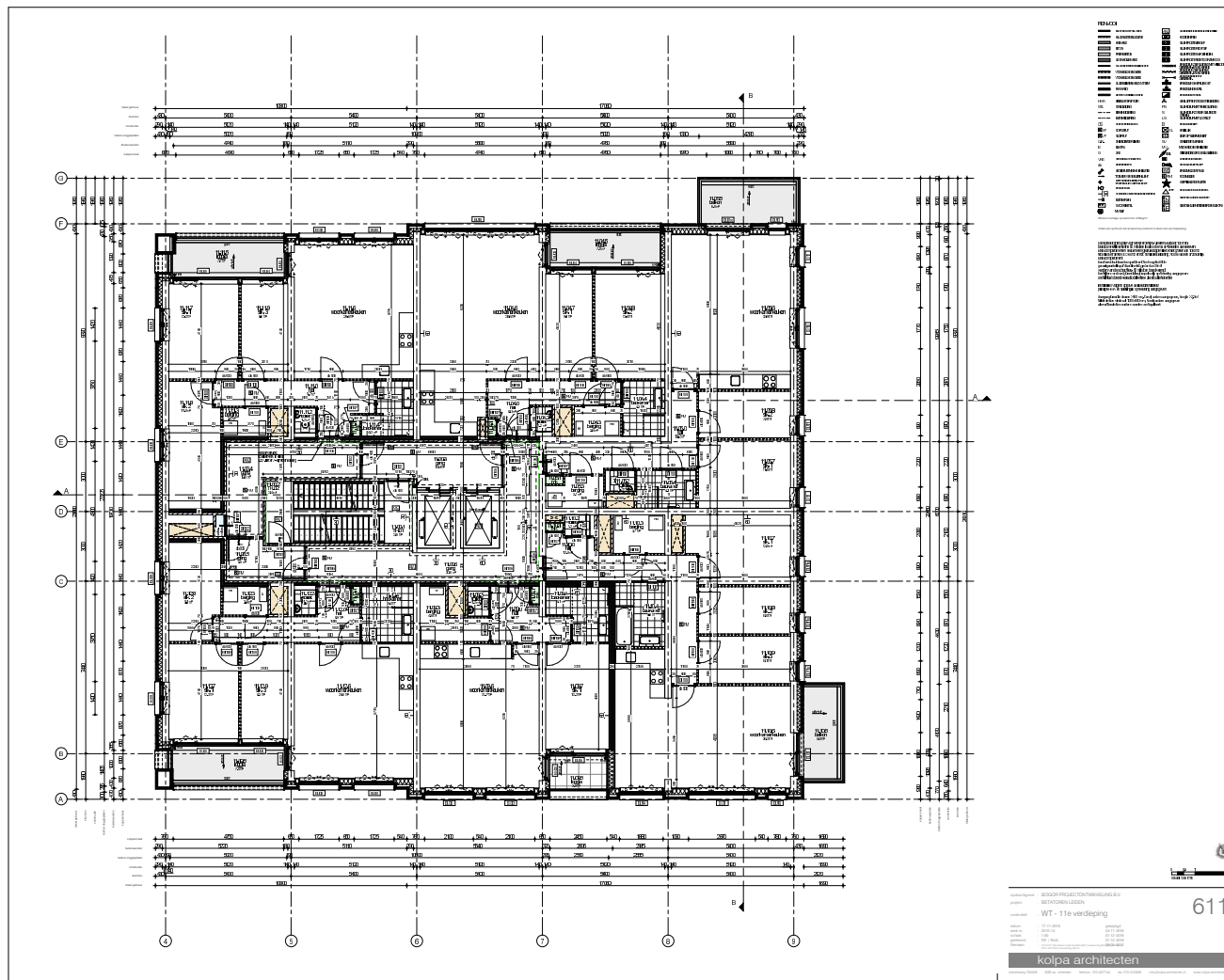


Figure A3 Floor plan of the 11th floor of project Bètatoren (Kolpa Architecten, 2016)

CALCULATIONS - BREMAN

Ground Floor

Total 1.65

Second Floor

Apartment 1 0.55
 Apartment 2 0.55
 Apartment 3 0.55
 Apartment 4 0.55
 Apartment 5 0.55
 Apartment 6 0.55
 Apartment 7 0.55
 Apartment 8 1.36
 Apartment 9 0.55
 Apartment 10 1.36
Total 7.12

Third Floor

Apartment 1 0.55
 Apartment 2 0.55
 Apartment 3 0.55
 Apartment 4 0.55
 Apartment 5 0.55
 Apartment 6 0.55
 Apartment 7 0.55
 Apartment 8 1.36
 Apartment 9 0.55
 Apartment 10 1.36
Total 7.12

Fourth Floor

Apartment 1 0.55
 Apartment 2 0.55
 Apartment 3 0.55
 Apartment 4 0.55
 Apartment 5 0.55
 Apartment 6 0.55
 Apartment 7 0.55
 Apartment 8 1.36
 Apartment 9 0.55
 Apartment 10 1.36
Total 7.12

Fifth Floor

Apartment 1 0.55
 Apartment 2 0.55
 Apartment 3 0.55
 Apartment 4 0.55
 Apartment 5 0.55
 Apartment 6 0.55
 Apartment 7 0.55
 Apartment 8 1.36
 Apartment 9 0.55
 Apartment 10 1.36
Total 7.12

Sixth Floor

Apartment 1 0.55
 Apartment 2 0.55
 Apartment 3 0.55
 Apartment 4 0.55
 Apartment 5 0.55
 Apartment 6 0.55
 Apartment 7 0.55
 Apartment 8 1.36
 Apartment 9 0.55
 Apartment 10 1.36
Total 7.12

Seventh Floor

Apartment 1 0.55
 Apartment 2 0.55
 Apartment 3 0.55
 Apartment 4 0.55
 Apartment 5 0.55
 Apartment 6 0.55
 Apartment 7 0.55
 Apartment 8 1.36
 Apartment 9 0.55
 Apartment 10 1.36
Total 7.12

Eighth Floor

Apartment 1 0.55
 Apartment 2 0.55
 Apartment 3 0.55
 Apartment 4 0.55
 Apartment 5 0.55
 Apartment 6 0.55
 Apartment 7 0.55
 Apartment 8 1.36
 Apartment 9 0.55
 Apartment 10 1.36
Total 7.12

Ninth Floor

Apartment 1 0.55
 Apartment 2 0.55
 Apartment 3 0.55
 Apartment 4 0.55
 Apartment 5 0.55
 Apartment 6 0.55
 Apartment 7 0.55
 Apartment 8 1.36
 Apartment 9 0.55
 Apartment 10 1.36
Total 7.12

Tenth Floor

Apartment 4 0.55
 Apartment 5 0.55
 Apartment 9 1.36
 Apartment 10 0.55
 Apartment 11 0.55
 Apartment 12 0.55
Total 4.11

Eleventh Floor

Apartment 4 0.55
 Apartment 5 0.55
 Apartment 9 1.36
 Apartment 10 0.55
 Apartment 11 0.55
 Apartment 12 0.55
Total 4.11

Twelfth Floor

Apartment 4 0.55
 Apartment 5 0.55
 Apartment 9 1.36
 Apartment 10 0.55
 Apartment 11 0.55
 Apartment 12 0.55
Total 4.11

Thirteenth Floor

Apartment 4 0.55
 Apartment 5 0.55
 Apartment 9 1.36
 Apartment 10 0.55
 Apartment 11 0.55
 Apartment 12 0.55
Total 4.11

Fourteenth Floor

Apartment 4 0.55
 Apartment 5 0.55
 Apartment 9 1.36
 Apartment 10 0.55
 Apartment 11 0.55
 Apartment 12 0.55
Total 4.11

Fifteenth Floor

Apartment 4 0.55
 Apartment 5 0.55
 Apartment 9 1.36
 Apartment 10 0.55
 Apartment 11 0.55
 Apartment 12 0.55
Total 4.11

Sixteenth Floor

Apartment 4 0.55
 Apartment 5 0.55
 Apartment 9 1.36
 Apartment 10 0.55
 Apartment 11 0.55
 Apartment 12 0.55
Total 4.11

Seventeenth Floor

Apartment 4 0.55
 Apartment 5 0.55
 Apartment 9 1.36
 Apartment 10 0.55
 Apartment 11 0.55
 Apartment 12 0.55
Total 4.11

Eighteenth Floor

Apartment 4 0.55
 Apartment 5 0.55
 Apartment 9 1.36
 Apartment 10 0.55
 Apartment 11 0.55
 Apartment 12 0.55
Total 4.11

TOTAL 93.91

INTERVIEW X

This interview is conducted with Arjen de Feijter from Dura Vermeer, Nathaniel Manubulu and Thomas Heye from Boele & van Eesteren and Léon van Berlo from TNO.

Introduction

1. What is your role within your company?
2. What is your previous experience with both supply chain management and BIM?
3. How would you judge your logistic processes?
4. What are you currently doing to improve the logistics?
5. Do you use BIM?
 - a. If so, how do you use BIM?
 - b. Do you also use BIM to manage the logistics?
6. Do you have a BIM-protocol?
7. How do you prepare the subcontractors and suppliers for the use of BIM and supply chain management in general?

Overall supply chain management

8. What is your opinion on a situation in which the main contractor is responsible for all the logistics, including the logistics to the construction site?
9. Do you think the logistics will become more efficient if the main contractor is responsible for it?
10. What do you think are the pro's and con's for the main contractor of such a structure?
11. What do you think are the pro's and con's for the subcontractors and suppliers of such a structure?
12. Do you think subcontractors and suppliers will agree to cooperate with this?

Material container

13. What is your opinion on the use of a material container? Do you think it will make construction logistics more efficient?
14. What are the benefits you think you will achieve?
15. Are there also disadvantages of using a material container?
16. Do you think you are able to get part of your investment back from the subcontractors and suppliers?
17. Do you think using a material container is feasible? Why or why not?
18. Would it be something that you would use on a project?

In order to use a material container in the execution phase, you need to do a lot of preparatory work in the procurement phase.

19. All the preparation for a material container is useful (you need to know if it will fit), but it also costs a lot of time. Do you think that such an extensive preparation is necessary?
20. Who do you think is responsible for the preparation? Is this a task for the subcontractor or supplier, the main contractor or do they have to do it together?

In order to manage the logistics three types of information are important: information regarding the dimensions, the location and the planning. Research of the BIM-model of Bêtatoren shows that a lot of this information is missing. This information needs to be completed in order to manage the logistics with BIM.

21. Who do you think is responsible for completing the information in BIM? The subcontractor or supplier, or the main contractor?

22. Do you think it is difficult to complete the information? And which information is the most difficult?
23. If you do not get your information from BIM, where do you get it from?

For project Betatoren we defined two KPIs: 1) the labour productivity, and 2) the percentage of deliveries in accordance with the requirements.

24. Please estimate per KPI what you think is the current percentage and what you think the percentage will be once the supply chain is managed with BIM.
 - a. Labour productivity
 - b. Deliveries in accordance with requirements

Supply chain management with BIM

25. What do you think are the benefits of supply chain management with BIM for the main contractor?
26. What do you think are the disadvantages of supply chain management with BIM for the main contractor?
27. What do you think are the benefits of supply chain management with BIM for the subcontractors and suppliers?
28. What do you think are the disadvantages of supply chain management with BIM for the subcontractors and suppliers?
29. Do you think implementing supply chain management with BIM is feasible for the main contractor? Why or why not? Please focus on:
 - a. Financial feasibility
 - b. Organizational feasibility
 - c. Social feasibility
 - d. Overall feasibility
30. Do you think implementing supply chain management with BIM is feasible for the subcontractors and suppliers? Why or why not?

LOGISTICS CHECKLIST - BIM-PROTOCOL

Although there are several options to manage the logistics with BIM, the most logic option is to manage the logistics with the execution model. This model is derived from the coordination model of the planning phase and focusses on the execution phase. To make sure this model is also suitable for supply chain management several aspects have to be incorporated in the model. These aspects are listed in this appendix so contractors can check if their model is ready for supply chain management. This checklist is not a standalone document, but always part of a BIM-protocol that describes the general agreements with regards to BIM.

CHECKLIST BIM

The families of the materials must include:

- The type of material
 - *Example: Sink_Sphinx365*
- The supplier of the material
 - *Example: Technische Unie*
- The dimensions of the materials (length, width, height, weight, area and volume)
 - *Example: length - 900 mm, width – 480 mm, height – 55 mm, weight – 10 kg, volume – 0,02 m3*
- The dimensions of the materials including the packaging (length, width, height, weight, area and volume)
 - *Example: length – 1000 mm, width – 580 mm, height 155 mm, weight – 10,5 kg, volume – 0,90 m3*
- The location of the material in the building (level, apartment, room)
 - *Example: level – 7, apartment – 5, room – 3*
- The delivery date and timeslot on the construction site
 - *Example: 18 May 2017, 07:00 – 09:00*
- The construction date in the building
 - *Example: 24 May 2017*
- The end date
 - *Example: 01 June 2017*

And optional (if needed) the families must include:

- The location of storage on site
 - *Example: Storage A1*
- The intermediate location in the building
 - *Example: level – 7, central hallway*
- Equipment needed to transport the materials
 - *Example: twinlift*
- Delivery instructions
 - *Example: 'very fragile'*

SUMMARY - DUTCH

I. INTRODUCTIE

Logistiek kan worden gedefinieerd als 'het georganiseerd verplaatsen van materialen of mensen' en is een belangrijk onderdeel binnen verschillende sectoren. De logistiek in de bouwsector verschilt van andere sectoren vanwege de verdeling die wordt gemaakt tussen logistiek op de bouwplaats en de logistiek daarbuiten. Dit onderzoek focust op de logistiek op de bouwplaats. Dit omvat alle diensten op de bouwplaats die de hoofdactiviteit ondersteunen: het feitelijke bouwen (Lundesjö, 2015). Momenteel is de logistiek op bouwplaatsen vaak niet goed georganiseerd, met name in binnenstedelijke gebieden. Dit ineffektieve bouwmanagement leidt tot verschillende problemen, waaronder tijd- en kostenoverschrijdingen. Er wordt aangenomen dat een van de oorzaken van deze ineffektiviteit is dat de hoofdaannemer geen volledige controle heeft over de logistiek. Er is daarom aanvullend onderzoek nodig om te bepalen hoe de hoofdaannemer deze controle kan krijgen.

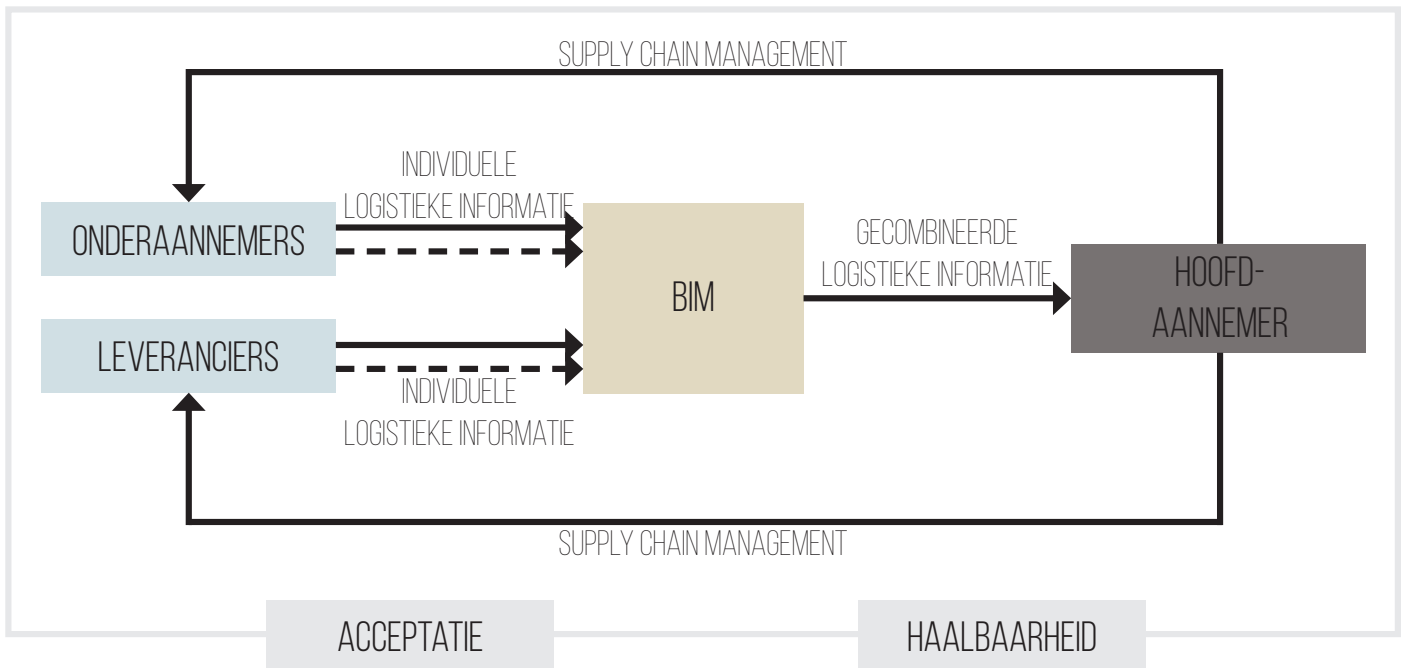
Sinds een aantal jaar voert TNO onderzoek uit naar bouwlogistiek. Het huidige onderzoek wordt geleid door NWO en bestaat uit een consortium van onderzoeksinstituten, onderwijsinstellingen en aannemers. Het project onderzoekt verschillende logistieke oplossingen die zijn uitgevoerd in proefprojecten, met als doel om de logistiek in de bouw efficiënter te maken. Een van deze oplossingen is Building Information Modelling. BIM-software kan logistieke informatie combineren met computermodellen en ondersteunt bedrijven in het managen van hun logistieke keten. Er zijn echter nog een aantal technische en organisatorische knelpunten die opgelost moeten worden voordat BIM gebruikt kan worden voor supply chain management. Dit onderzoek streeft naar het oplossen van deze knelpunten en onderzoekt hoe een hoofdaannemer de logistiek op een bouwplaats moet managen met BIM. Dit onderzoek is onderdeel van het NWO-project en draagt bij aan het overkoepelende onderzoek naar bouwlogistiek.

II. DE ESSENTIE VAN HET ONDERZOEK

Het doel van dit onderzoek is aannemers inzicht geven in hoe zij meer controle kunnen krijgen over hun bouwlogistiek met behulp van BIM. De hoofdvraag van dit onderzoek is:

Hoe kan supply chain management met BIM aannemers helpen om meer grip te krijgen op de logistiek van een bouwproject?

De hoofdvraag bestaat uit twee delen: het eerste deel focust op de manier waarop de hoofdaannemer de supply chain processen moet opzetten met BIM en het tweede deel focust op de acceptatie door derde partijen en de haalbaarheid voor de hoofdaannemer. Het onderzoek wordt uitgevoerd vanuit een organisatorisch perspectief. The focus ligt op de manier waarop de aannemer de supply chain van een bouwproject moet inrichten met BIM, op zodanige wijze dat de aannemer meer controle heeft over de logistiek. Het conceptueel model wordt weergegeven in figuur A4.



Figuur A4 Conceptueel framework (eigen afbeelding, 2017)

Het model toont de informatiestromen die nodig zijn voor supply chain management met BIM. Het onderzoek focust op alle individuele informatiestromen om uit te zoeken hoe ze georganiseerd moeten worden voor het managen van de bouwlogistiek met BIM. De deelvragen die hieronder worden weergegeven horen bij de verschillende delen van het onderzoek.

1. Hoe kan de hoofdaannemer de derde partijen voorbereiden op een nieuw logistiek systeem om ervoor te zorgen dat hij meer grip krijgt op de logistiek in de werkvoorbereidingsfase?
2. Wat voor informatie van de derde partijen is nodig voor het integreren van logistieke informatie in BIM-software?
3. Hoe moet de hoofdaannemer het BIM-model gebruiken om ervoor te zorgen dat hij meer grip krijgt op de logistiek in de uitvoeringsfase?
4. Hoe kijken onderaannemers en leveranciers aan tegen supply chain management met BIM?
5. Is de implementatie van BIM voor supply chain management haalbaar voor de hoofdaannemer?

III. THEORETISCH FRAMEWORK

Als basis voor het empirisch onderzoek is een literatuurstudie uitgevoerd. De literatuurstudie is uitgevoerd aan de hand van de fases van het conceptueel framework dat is weergegeven in figuur A4. Voor elke fase is een literatuurstudie uitgevoerd die samen een theoretisch antwoord vormen op de hoofdvraag.

BIM is geselecteerd voor dit onderzoek omdat het een zeer uitgebreid instrument is dat gebruikt kan worden om de informatiestromen te stroomlijnen. Bovendien is het relatief makkelijk te implementeren vanwege de lage impact op de betrokken partijen en de lage

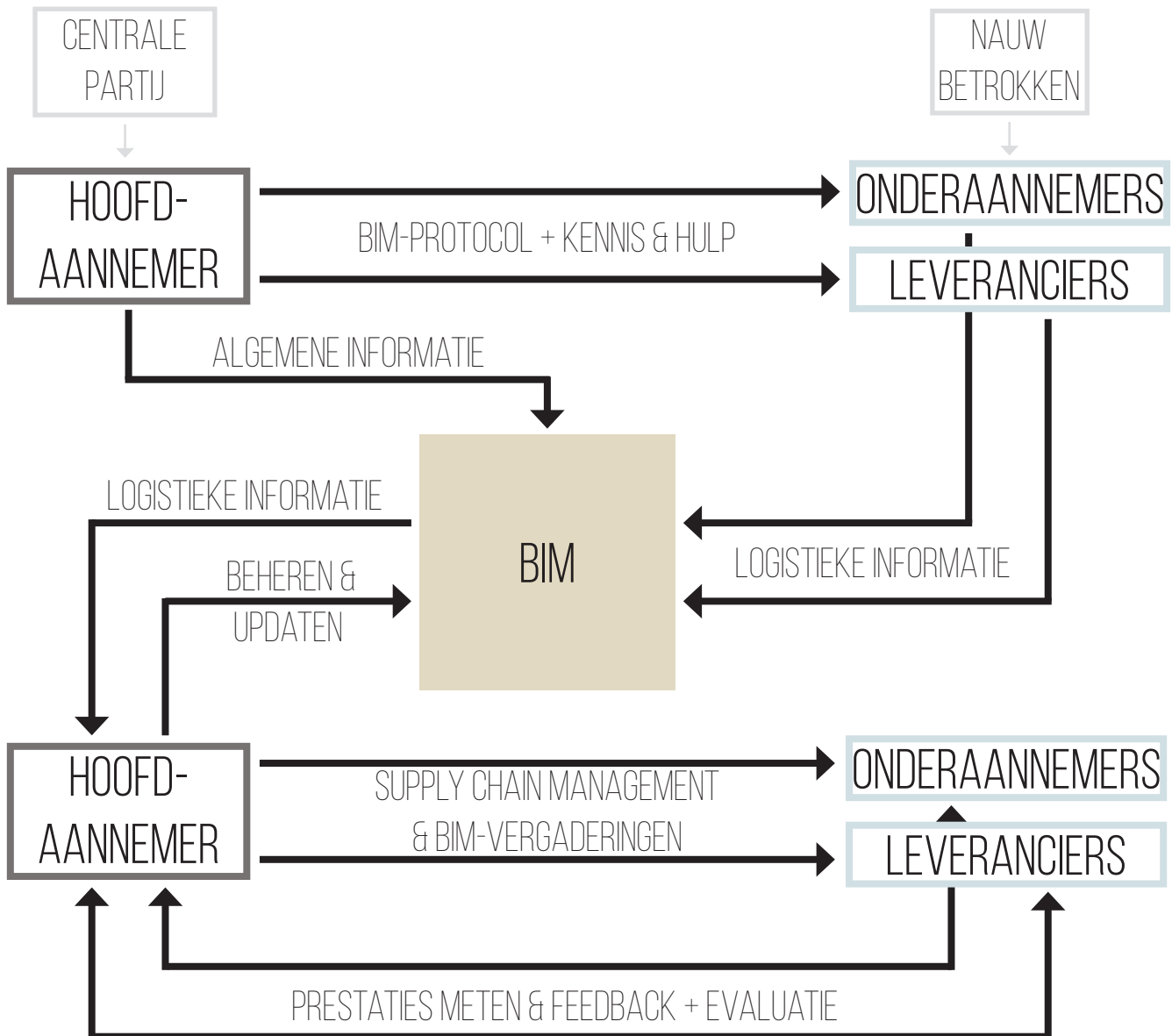
implementatiekosten. Onderzoek heeft aangetoond dat BIM verscheidene voordelen heeft maar dat er ook een aantal uitdagingen zijn. Voordelen van BIM zijn een vermindering in tijd en kosten en verbeterde communicatie, coördinatie en kwaliteit (Bryde et al., 2013). De grootste uitdaging vormen de zogenaamde 'menselijke problemen', hetgeen te maken heeft met het feit dat men de nieuwe software moet accepteren, moet samenwerken met elkaar en data moet delen. Voor supply chain management is de link tussen BIM en planning software erg belangrijk. Onderzoek naar het gebruik van 4D BIM voor het plannen en managen van de bouwlogistiek heeft veelbelovende resultaten opgeleverd, zoals gereduceerde voorraden en meer grip op de materiaalstromen. Deze studie onderzoekt hoe de processen en informatiestromen per fase georganiseerd moeten worden om deze resultaten te kunnen bereiken.

In de eerste fase is de hoofdaannemer verantwoordelijk voor het organiseren van de logistieke keten en het voorbereiden van de derde partijen. In deze fase staan de positie van de hoofdaannemer en de relatie tot de derde partijen centraal. De hoofdaannemer is de centrale partij en daardoor verantwoordelijk voor de ketenintegratie. De hoofdaannemer moet actief de supply chain leiden en ervoor zorgen dat de onderaannemers en leveranciers samenwerken. Daarnaast moet de hoofdaannemer de derde partijen voorbereiden op de combinatie van bouwlogistiek en BIM. Hij moet een BIM-protocol verstrekken aan het begin van het project en zorgen voor voldoende kennis en assistentie tijdens het proces. Communicatie is erg belangrijk, dus de hoofdaannemer moet zorgen voor een integrale aanpak die het technische met het sociale combineert. De hypothese voor deze fase is dat op dit moment de link ontbreekt tussen BIM en supply chain management in de opzet van het project, hetgeen leidt tot een incompleet BIM-model.

In de tweede fase wordt de rol van de onderaannemers en de leveranciers gedefinieerd. Afhankelijk van hun rol en taken moeten zij bepaalde informatie verstrekken die dient als de input van het BIM-model. Voor het opzetten van een efficiënte supply chain structuur kan er veel geleerd worden van andere sectoren, zoals de vliegtuig- en scheepsbouwindustrie. In deze industrieën zijn de koper en de leverancier sterk afhankelijk van elkaar. Onderaannemers en leveranciers zijn betrokken vanaf het eerste begin en hebben een grote verantwoordelijkheid. Ze zijn alleen verantwoordelijk voor hun eigen product en de centrale partij is verantwoordelijk voor de logistiek en het assembleren van het eindproduct. Er wordt ook op hoog niveau informatie uitgewisseld: de onderaannemers en leveranciers zijn dicht betrokken bij het bouwproces en wisselen gedetailleerde informatie uit met de centrale partij. Alle partijen communiceren intensief met de hoofdaannemer, maar ze communiceren niet met elkaar. Dit zorgt ervoor dat de hoofdaannemer de controle houdt. De hypothese voor deze fase is dat de fragmentatie in de bouwsector de hoofdreden is voor de inefficiënte organisatie van de supply chain.

In de derde fase is de hoofdaannemer verantwoordelijk voor de uitvoering van het bouwproject en het managen van de derde partijen. Dit kan hij doen door gebruik te maken van de logistieke informatie uit BIM. Eerst moet de hoofdaannemer ervoor zorgen dat er algemene informatie toegevoegd wordt aan het BIM-model. Deze informatie bestaat onder andere uit de inrichting van de bouwplaats. Daarnaast is hij verantwoordelijk voor het coördineren en updaten van het BIM-model, het samenvoegen van aspectmodellen en het organiseren van BIM-meetings om alle partijen up-to-date te houden (Papadonikolaki et al., 2015). Tijdens dit proces moet de hoofdaannemer er ook voor zorgen dat hij de prestaties van de derde partijen meet en hen feedback geeft hierop. Aan het eind van het bouwproject moet hij het gehele proces evalueren met de derde partijen, waarop zij ook feedback kunnen geven aan de hoofdaannemer. Dit draagt bij aan de relatie tussen de betrokken actoren en verbetert het supply chain management. De hypothese van deze fase is dat het BIM-model complete informatie moet bevatten met betrekking tot afmetingen, locatie en planning om het geschikt te maken voor het managen van de logistiek.

Tijdens de literatuurstudie is per fase gedefinieerd wat de hoofdaannemer en de derde partijen moeten doen om een organisatiestructuur op te zetten die het mogelijk maakt op de bouwlogistiek te managen met BIM. Een overzicht van deze informatiestromen is weergegeven in figuur A5.



Figuur A5 Informatiestromen - theoretisch framework (eigen afbeelding, 2017)

In de vierde fase komen alle voorgaande fases samen en zijn de resultaten van de nieuwe supply chain structuur zichtbaar. Gebaseerd op de resultaten van de literatuurstudie wordt aangenomen dat als BIM op de juiste manier geïmplementeerd wordt in de juiste organisatorische structuur, het de hoofdaannemer meer grip kan geven op de logistiek. Dit kan leiden tot verscheidene voordelen voor alle betrokken partijen. De hypothese voor deze fase is daarom dat de implementatie van BIM voor het managen van de logistiek op de bouw haalbaar is voor de hoofdaannemer.

De hypothesen zullen getest worden door het empirisch onderzoek. De opzet van dit onderzoek wordt beschreven in het volgende hoofdstuk.

IV. ONDERZOEKSKADER

Het empirisch onderzoek wordt uitgevoerd als een case study. De case die geselecteerd is voor dit onderzoek is project Bètatoren. Dit is een middelgroot bouwproject dat bestaat uit 134 appartementen en een deel commerciële ruimte in het binnenstedelijke gebied van Leiden. De ruwbouw is gestart in januari 2017, de afbouw staat gepland voor juni 2017 en het gebouw wordt opgeleverd in juli 2018. De hoofdaannemer van het project is Waal. Waal is een middelgrote aannemer uit Vlaardingen. Ze hebben ervaring met BIM maar gebruiken het voornamelijk in de werkvoorbereidingsfase. Wel zien ze de voordelen van BIM en zijn bereid te onderzoeken hoe ze BIM kunnen inzetten voor supply chain management.

Naast Waal zijn er nog vier partijen van project Bètatoren betrokken bij dit onderzoek. Dit zijn twee onderaannemers en twee leveranciers, om zo te onderzoeken of er verschillen zijn tussen deze typen partijen. De twee onderaannemers zijn Breman en Tegel Idee. Breman is de werktuigbouwkundig installateur en is nauw betrokken tijdens de gehele uitvoeringsfase. Tegel Idee is verantwoordelijk voor al het tegelwerk en is alleen betrokken tijdens de afbouwfase. De twee leveranciers zijn Calduran en Halfen. Calduran is de leverancier van het kalkzandsteen en Halfen levert de gevelbevestiging en de stalen lateien. Beiden zijn alleen betrokken in de ruwbouwfase.

Naast de geselecteerde onderaannemers en leveranciers zijn er ook een aantal BIM- en supply chain experts betrokken bij dit onderzoek voor de validatie van de resultaten.

V. CASE STUDY

Dit hoofdstuk beschrijft de resultaten van het empirisch onderzoek. Het onderzoek is uitgevoerd per fase en elke paragraaf behandelt zowel de dataverzameling als de data-analyse van een fase.

FASE 1 – DE POSITIE VAN DE HOOFDAANNEMER

De eerste fase van het conceptuele framework vindt plaats tijdens de werkvoorbereidingsfase. Deze fase focust op de positie van de hoofdaannemer in relatie tot de derde partijen en op de informatie die de hoofdaannemer aan hen moet verstrekken.

Het onderzoek toont aan dat de informatiestroom van de eerste fase op dit moment bestaat uit twee documenten: een logistieke overeenkomst en een BIM-protocol. De logistieke overeenkomst is ontworpen door Waal en beschrijft welke logistieke maatregelen genomen zullen worden tijdens het project, hoe deze maatregelen uitgevoerd worden en wat er verwacht wordt van de onderaannemers en leveranciers. Het BIM-protocol is ook gemaakt door Waal en beschrijft de verantwoordelijkheden en verwachtingen van alle partijen met betrekking tot BIM. Het BIM-protocol wordt alleen verstrekt aan partijen die daadwerkelijk een eigen BIM-model gaan maken. Deze partijen ontvangen ook het centrale BIM-model van project Bètatoren, dat gemaakt is door de architect. Het BIM-protocol en de logistieke overeenkomst vormen het hoofddeel van de informatiestroom die aangeeft wat er van de derde partijen verwacht wordt en hoe ze dit moeten uitvoeren. De plannen en documenten zijn opgezet door Waal en vrij dwingend. Hoewel er enig overleg is met de derde partijen aan het begin wordt alles uitgevoerd op initiatief van de hoofdaannemer. Waal neemt de leiding en is verantwoordelijk voor het opzetten van de planning, het verstrekken van de juiste informatie en het informeren van de derde partijen over hun taken en verantwoordelijkheden. Alhoewel Waal zowel informatie over de logistiek als informatie over BIM verstrekt, zijn deze documenten niet gelinkt. Dit toont aan dat BIM en de logistiek niet gekoppeld zijn in deze fase.

Om ervoor te zorgen dat de hoofdaannemer meer grip krijgt op de logistiek moeten er aanpassingen gemaakt worden aan de informatiestroom in het begin van de werkvoorbereidingsfase. Deze aanpassingen dienen ervoor te zorgen dat de informatiestroom

efficiënter wordt, een meer samenhangend proces is en meer gericht is op het uiteindelijke gebruik van het BIM-model. De eerste aanpassing heeft betrekking op het logistieke plan. In plaats van de huidige eenzijdige aanpak moet de hoofdaannemer de derde partijen meer betrekken bij het opzetten van het plan. Deze aanpak zal de solidariteit bij de partijen verhogen en ervoor zorgen dat het plan breder gedragen wordt omdat iedereen input kan geven. Dit maakt het waarschijnlijker dat de uiteindelijke overeenkomst door iedereen getekend wordt en dat iedereen zich eraan houdt tijdens de uitvoering. De tweede aanpassing heeft betrekking op BIM. Om BIM te kunnen gebruiken voor de bouwlogistiek is het belangrijk dat BIM vanaf het begin van het project is geïmplementeerd. Nadat het logistieke plan is gemaakt moet de aannemer definiëren wat het BIM-model nodig heeft om het te kunnen gebruiken voor het managen van de logistiek. Het BIM-model moet hierop aangepast worden waarna het verstrekt wordt aan de derde partijen. Het model wordt verstrekt samen met het BIM-protocol dat exact aangeeft hoe iedereen het model moet gebruiken, met een speciale focus op de logistiek. De informatiestroom is nu compleet en bestaat uit een logistiek plan en overeenkomst, het BIM-model en het BIM-protocol. Alle documenten zijn gericht op de logistiek en zijn opgezet door Waal in samenwerking met de onderaannemers en leveranciers.

FASE 2 – DE POSITIE VAN DE ONDERAANNEMERS EN LEVERANCIERS

De tweede fase van het conceptueel framework vindt ook plaats tijdens de werkvoorbereidingsfase. Deze fase richt zich op de rol van de onderaannemers en de leveranciers en de informatie die zij moeten verstrekken voor het BIM-model.

Het onderzoek toont aan dat er een discrepantie is tussen de productieprocessen en de informatieprocessen. Een deel van de informatie wordt op de traditionele manier gestuurd (in 2D), sommige informatie wordt gestuurd via BIM, maar geen enkel deel van de informatie is gelinkt aan de productieprocessen van de materialen en de bouwplaats. De hoofdaannemer verstrekt het centrale model aan alle partijen die gaan modelleren. Zij nemen dit model als basis maar controleren niet de informatie die erin zit, ook de hoofdaannemer doet dit niet. Van de totale hoeveelheid aan logistieke informatie is minder dan de helft aanwezig in het BIM-model. De ontbrekende informatie wordt ofwel in 2D gestuurd (planning, tekeningen) of helemaal niet gestuurd omdat de hoofdaannemer het niet gebruikt. Ook wordt sommige informatie die wel aanwezig is in het BIM-model alsnog in 2D gestuurd. De hoofdaannemer is verantwoordelijk voor het proces maar coördineert niet de informatie, dit wordt ook niet gedaan door iemand anders. Dit zorgt voor een gefragmenteerde en ongecoördineerde informatiestroom.

Een van de grootste problemen is de fragmentatie. Dit kan opgelost worden door het centrale model te linken met de aspectmodellen. Echter, om de modellen te kunnen linken is het belangrijk dat de input klopt en overeenkomt. De modellen moeten gebaseerd zijn op de IFC-standaarden en de BIM basis ILS, wat ervoor zorgt dat alle modellen op dezelfde manier gebouwd zijn. De hoofdaannemer moet alle partijen aanmoedigen om met BIM te werken en kennis en assistentie verlenen tijdens het proces. Alle partijen focussen op het maken van hun aspectmodel en de hoofdaannemer is verantwoordelijk voor het coördineren van de aspectmodellen en het samenvoegen hiervan. De derde partijen zijn verantwoordelijk voor het verstrekken van alle informatie omtrent de afmetingen en overige logistieke zaken. De hoofdaannemer is verantwoordelijk voor alle informatie over de locatie en de planning. Ook draagt hij zorg voor zowel de productieprocessen op de bouwplaats als de informatieprocessen. De hoofdaannemer moet zorgen dat hij beide coördineert en dat ze aan elkaar gelinkt zijn. Dit kan gedaan worden door de processen te managen en de onderaannemers en leveranciers te ondersteunen in het verstrekken van de juiste informatie.

FASE 3 – SUPPLY CHAIN MANAGEMENT MET BIM

De derde fase van het conceptueel framework vindt plaats tijdens de uitvoeringsfase. Tijdens

deze fase is de hoofdaannemer verantwoordelijk voor de uitvoering en het managen van de derde partijen.

De resultaten van het onderzoek tonen aan dat de logistieke informatie en BIM bijna geheel zijn losgekoppeld in deze fase. De hoofdaannemer voert een kwaliteitscontrole uit op de aspectmodellen, maar aangezien ze het centrale model niet volledig kunnen checken er nog steeds fouten in zitten. De ontbrekende logistieke informatie in BIM zorgt ervoor dat het model incompleet is, hetgeen het onmogelijk maakt om de logistiek met BIM aan te sturen. De logistieke informatie die wel aanwezig is wordt in 2D uit het model gehaald en daarna gebruikt om de logistiek op de bouwplaats aan te sturen, samen met de 2D-informatie die rechtstreeks naar de hoofdaannemer is gestuurd. Dit zorgt voor een informatiestroom die volledig is losgekoppeld van BIM.

Om ervoor te zorgen dat de logistiek met BIM aangestuurd kan worden moeten de logistieke informatie en BIM gelinkt zijn. Om dit te bereiken moet de hoofdaannemer eerst het coördinatiemodel van de werkvoorbereidingsfase controleren en het vergelijken met de aspectmodellen van de onderaannemers en leveranciers. Ten tweede moet het BIM-model gelinkt worden aan de planning. Het toevoegen van de tijdsfactor aan BIM is cruciaal voor het managen van de logistiek. Tot slot moet de hoofdaannemer een manier vinden om de voorraden te beheren. Het BIM-model moet een gedetailleerd overzicht bevatten van de bouwplaats en een strategie voor het beheren van de materialen. Er zijn verscheidene frameworks ontworpen, zoals die van Cheng and Kumar (2015b) en Chau et al. (2004), die hiervoor gebruikt kunnen worden. Het gebruik van een dergelijk framework geeft de hoofdaannemer meer grip op de materiaalstromen op de bouwplaats. Als bovenstaande stappen goed uitgevoerd worden geeft dat de hoofdaannemer de mogelijkheid om de bouwlogistiek te managen met BIM. Echter, dit onderzoek richt zich voornamelijk op het managen van grote componenten. Bevestigingsmaterialen en materialen uit de ruwbouwfase zijn veel lastiger te managen met BIM omdat we niet gewend zijn deze volledig en naar werkelijkheid te modelleren. Dit zal uiteindelijk wel mogelijk worden in de toekomst wanneer aannemers gewend raken aan 4D-modelleren en het managen van de bouwlogistiek. Het belangrijkste aspect is dat alle logistieke informatie gelinkt is aan BIM en dat de hoofdaannemer de leiding neemt in het managen en coördineren van deze informatie.

FASE 4 – HET PERSPECTIEF VAN DE ONDERAANNEMERS EN LEVERANCIERS

In de vierde, en laatste, fase komen alle voorgaande fases samen. In deze fase zijn de resultaten van de nieuwe structuur zichtbaar. Omdat de hoofdaannemer de logistiek niet kan aanpassen zonder de medewerking van de ketenpartners is het belangrijk om hun kijk op bouwlogistiek en BIM ook mee te nemen in dit onderzoek. Geen enkele van de onderzochte partijen stond positief tegenover het idee waarbij de hoofdaannemer verantwoordelijk is voor de gehele logistiek. De voornaamste redenen hiervoor was dat ze bang waren controle te verliezen over hun eigen activiteiten en dat de hoofdaannemer te veel werk op zich neemt. Hetzelfde geldt voor bouwlogistiek en BIM. Afgezien van Calduran had geen enkele partij een positieve kijk op het managen van de bouwlogistiek met BIM. Hun voornaamste argument was dat het hun meer tijd en energie gaat kosten, hetgeen ze er niet voor over hebben. Ze zien de voordelen van BIM, maar voor hen wegen die niet op tegen kosten.

FASE 4 – HAALBAARHEID VOOR DE HOOFDAANNEMER

Naast het perspectief van de onderaannemers en leveranciers is het ook belangrijk om te weten wat de impact is voor de hoofdaannemer. Als de verandering van traditioneel proces naar bouwlogistiek met BIM niet haalbaar is voor hen wordt het niet geïmplementeerd. Dit onderzoek richt zich op de haalbaarheid van het implementatieproces. De haalbaarheid is verdeeld in drie typen: de financiële haalbaarheid, organisatorische haalbaarheid en de sociale haalbaarheid. For elk type is een kleine studie uitgevoerd gebaseerd op de case

study, de ervaringen van het projectteam van Waal en literatuur.

Het invoeren van BIM is gebonden aan verschillende kosten. Hoewel de kosten aanzienlijk zijn en gezien moeten worden als een serieuze investering, zeker voor kleine bedrijven, zou dit geen belemmering moeten vormen. De prijs van de meest gebruikte BIM softwarepakketten is even hoog als die van traditionele CAD-software, en als een bedrijf al gebruik maakt van 3D-BIM software is het een relatief kleine upgrade naar 4D of 5D BIM (Bryde et al., 2013). De investering moet gezien worden in perspectief met de voordelen, ook die op lange termijn. Deze voordelen zijn aanzienlijk en overstijgen de kosten, zeker wanneer BIM gebruikt wordt door alle partijen in de keten. Hierdoor wordt de implementatie van BIM financieel haalbaar. De organisatorische haalbaarheid kijkt of het haalbaar is voor de hoofdaannemer om het BIM-implementatieproces te coördineren. De invoering van BIM vraagt om een geheel nieuw organisatorisch proces. Bedrijven moeten niet alleen maar nieuwe software invoeren, ze moeten ook de bijbehorende nieuwe processen en organisatorische structuren adopteren (Hardin & McCool, 2015). De invoering van BIM vergt enige inspanning en veranderingen van een organisatie. De hoofdaannemer is echter gewend aan het coördineren van processen en als ze bereid zijn om te veranderen kunnen ze een soepel implementatieproces bewerkstelligen en de voordelen van BIM plukken. Hierdoor is de implementatie van BIM organisatorisch haalbaar.

Tot slot focust de sociale haalbaarheid zich op de onderlinge verhoudingen tussen de ketenpartners en op de haalbaarheid voor de hoofdaannemer om de implementatie van BIM te bewerkstelligen bij alle partijen. Een van de manieren om de derde partijen over te halen om mee te werken is om ze de voordelen van BIM te laten zien. Daarnaast is het belangrijk dat er meer bewustzijn over BIM wordt gecreëerd binnen de gehele bouwsector en dat de vaardigheden van mensen verbeteren (Bryde et al., 2013). Tot slot is het belangrijk dat de aannemer focust op integratie en communicatie (Khalfan et al., 2015). Voor een soepel implementatieproces is het belangrijk dat alle partijen samenwerken en de hoofdaannemer heeft meerdere opties om ze daartoe te krijgen. Ook al is het een lastig proces, de invoering van BIM is sociaal gezien haalbaar.

Over het geheel genomen is het projectteam van Waal het met elkaar eens dat de implementatie van BIM voor het managen van de bouwlogistiek haalbaar is voor de hoofdaannemer. Joost de Korte (persoonlijke communicatie, 25 April, 2017) geeft wel aan dat het afhangt van de grootte van het project en de aannemer. Voor grote aannemers of projecten is het makkelijker om de risico's van het implementeren van BIM te nemen. Dennis Adegeest (persoonlijke communicatie, 24 April, 2017) voegt hieraan toe dat het implementatieproces stap voor stap opgezet moet worden, om de organisatie zo de kans te geven langzaam aan de nieuwe situatie te wennen. Uiteindelijk zijn zij het allen eens dat de implementatie van BIM de moeite waard is.

VI. VALIDATIE

De validatie is gebaseerd op de ervaringen van verschillende BIM- en supply chain experts van Dura Vermeer, Boele & van Eesteren en TNO.

In de eerste fase lieten de resultaten van het onderzoek zien dat de onderaannemers en leveranciers betrokken moeten worden bij de opzet van het logistieke plan en het BIM-model. De experts zijn het hier lichtelijk mee oneens. Hoewel zij het belang van samenwerken benadrukken, zien zij de hoofdaannemer als de leider van het proces en als degene die bepaalt hoe de logistiek georganiseerd wordt. Aannemers moeten altijd streven naar innovatie, ook als dit de samenwerking met de derde partijen negatief beïnvloedt. De negatieve consequenties zijn van korte duur, op de lange termijn zal de innovatie een positief effect hebben op de organisatie.

De resultaten van de tweede fase tonen aan dat de informatiestromen gefragmenteerd en ongecoördineerd zijn. Volgens de experts is de hoofdaannemer verantwoordelijk voor het beheren en coördineren van alle data. Zij geloven dat de aannemer geschikt is om deze rol te vervullen. Echter moeten ze hierbij rekening houden met het feit dat deze nieuwe rol hen extra tijd en moeite zal kosten, zeker in de werkvoorbereidingsfase. Aannemers moeten zorgen dat zij voldoende tijd, mankracht en financiële middelen ter beschikking stellen voor dit proces. Als ze niet genoeg investeren kunnen ze er ook niet genoeg uit halen.

De resultaten van de derde fase lieten zien dat het linken van het BIM-model aan de planning de voornaamste prioriteit is. De experts zijn het hiermee eens, maar benadrukken dat het een uitgebreid proces is. Ook benadrukken zij de zogenoemde 'menselijke problemen'. Echter moeten aannemers zich niet laten beïnvloeden door weerstand van hun werknemers of ketenpartners. Verandering moet gezien worden als een mogelijkheid om het bedrijf te versterken door de bedrijfsactiviteiten te koppelen aan de strategie, en aannemers moeten ervoor zorgen dat hun werknemers en ketenpartners dit ook zo zien (Strebel, 1996). Dit kan bereikt worden door, onder andere, men inzicht te geven in de veranderingen en te communiceren over de gevolgen die het voor ze heeft (Kotter & Schlesinger, 2008). Dit zal het implementatieproces verbeteren en ervoor zorgen dat de invoering van BIM breder gedragen wordt binnen de keten.

De experts werden ook gevraagd naar hun mening over de financiële, organisatorische en sociale haalbaarheid van het implementatieproces van BIM. De experts waren het er allemaal over eens dat het implementatieproces financieel gezien haalbaar is voor de hoofdaannemer, echter met een paar kanttekeningen. De haalbaarheid hangt namelijk ook af van het huidige niveau van BIM binnen de organisatie, de hoeveelheid logistieke data die ontbreekt en de logistieke kosten van de derde partijen. Al met al zijn de experts het erover eens dat de implementatie van BIM een serieuze investering is voor een bedrijf, echter is de investering de opbrengsten waard, zeker op de lange termijn.

De experts zijn het ook eens over de organisatorische haalbaarheid. De hoofdaannemer heeft al een coördinerende functie en is al verantwoordelijk voor het managen van de processen. Daarom verandert er niet veel wanneer BIM wordt ingevoerd. De conclusie is daarom dat de implementatie van BIM voor het managen van de bouwlogistiek organisatorisch gezien haalbaar is voor de hoofdaannemer.

Wat betreft de sociale haalbaarheid zijn de experts het ook eens met de resultaten van het onderzoek, echter iets minder overtuigend. De sociale haalbaarheid hangt sterk af van de ervaring van de derde partijen en van wat er van hen gevraagd wordt door de hoofdaannemer. De experts geven aan dat de aannemer moet focussen op het aantonen van de voordelen. Op het moment dat ze deze zien zullen de ketenpartners coöperatiever worden.

Over het geheel genomen zijn alle experts het erover eens dat het implementatieproces van BIM voor de bouwlogistiek haalbaar is voor de hoofdaannemer. Ze benadrukken hierbij dat de aannemer moet beschikken over de juiste mensen en middelen. Ook geven ze aan dat het managen van de bouwlogistiek met BIM gemeengoed wordt in de toekomst. De bouwsector is al aan het experimenteren met 4D en 5D BIM, dus het is slechts een kwestie van tijd voordat alle logistiek met BIM aangestuurd wordt.

VII. CONCLUSIE

Dit hoofdstuk presenteert de antwoorden op de deelvragen en de hoofdvraag. De conclusie van het onderzoek zal gepresenteerd worden in de vorm van een framework.

De hypothese van de eerste fase is: *“Op dit moment ontbreekt de link tussen BIM en de bouwlogistiek tijdens de start van het project, hetgeen leidt tot een incompleet BIM-model.”* Het onderzoek toont aan dat BIM en de logistiek niet zijn verbonden in de eerste fase.

Omdat de verantwoordelijkheden en verwachtingen met betrekking tot BIM niet goed zijn gedefinieerd aan begin, zijn er problemen met het BIM-model in latere fases omdat het niet duidelijk is wie verantwoordelijk is voor welke informatie. De hypothese is dus waar. De deelvraag van de eerste fase is: *“Hoe kan de hoofdaannemer de derde partijen voorbereiden op een nieuw logistiek systeem om ervoor te zorgen dat hij meer grip krijgt op de logistiek in de werkvoorbereidingsfase?”* Het onderzoek toont aan dat de hoofdaannemer de derde partijen moet betrekken bij het opzetten van het logistiek plan en daarbij ook moet bepalen op wat voor manier BIM gebruikt wordt voor de logistiek. Daarnaast moet het BIM-model aangepast worden voor het managen van de logistiek en worden verstrekt aan de derde partijen samen met het BIM-protocol. Alle documenten moeten betrekking hebben op zowel BIM als logistiek en moeten worden opgezet in samenwerking met de onderaannemers en de leveranciers.

De hypothese van de tweede fase is: *“De fragmentatie in de bouwsector is de voornaamste reden voor de inefficiënte supply chain organisatie.”* Uit het onderzoek blijkt dat er een mismatch is tussen de productieprocessen en de informatieprocessen. Een van de redenen hiervoor is de fragmentatie van de bouwsector. De informatiestromen en materiaalstromen zijn niet gebundeld maar verspreid over verschillende ketenpartners. De hypothese is dus deels waar. De deelvraag van deze fase is: *“Wat voor informatie van de derde partijen is nodig voor het integreren van logistieke informatie in BIM-software?”* Volgens het onderzoek zijn de onderaannemers en leveranciers verantwoordelijk voor alle informatie over hun eigen materialen. Zij maken eigen aspectmodellen waarin alle informatie wordt opgenomen met betrekking tot afmetingen (inclusief verpakking), gewicht, opslag en andere informatie die belangrijk is voor de logistiek. De informatie over de locatie in het algemeen en de planning zijn de verantwoordelijkheid van de hoofdaannemer. Daarnaast moeten alle partijen ook zorgen dat niet alleen de inhoud correct is, maar dat de informatie ook is gebaseerd op de IFC-standaarden.

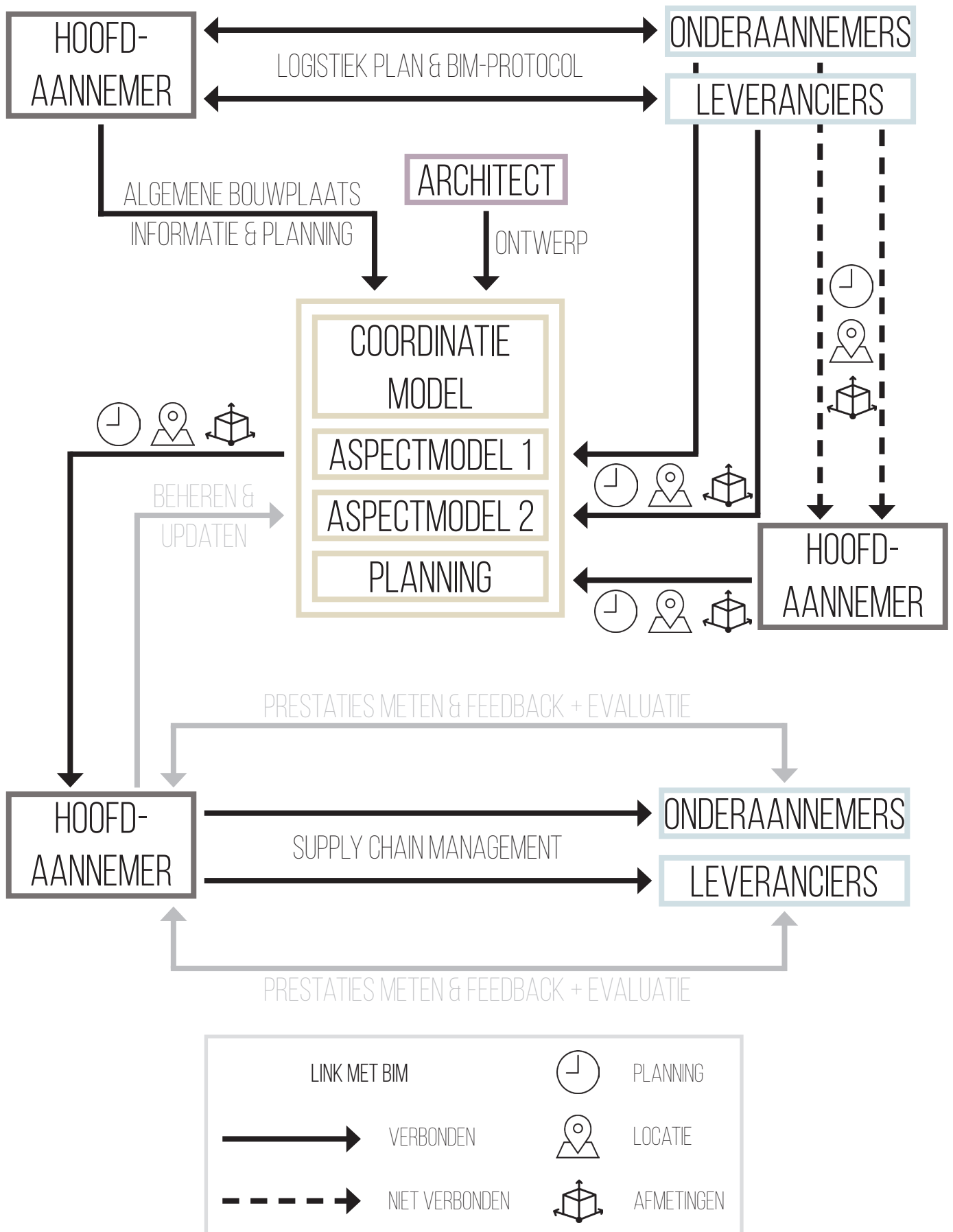
De hypothese van de derde fase is: *“Om de logistiek aan te kunnen sturen met BIM moet het model complete logistieke informatie bevatten met betrekking tot de afmetingen, locatie en de planning.”* Het onderzoek toont aan dat de logistieke informatie en BIM compleet zijn losgekoppeld in deze fase. De logistieke informatie in BIM is niet compleet, hetgeen het onmogelijk maakt om de logistiek op de bouwplaats aan te kunnen sturen met BIM. Dit gebeurt daarom met 2D informatie. De hypothese is dus waar. De deelvraag van deze fase is: *“Hoe moet de hoofdaannemer het BIM-model gebruiken om ervoor te zorgen dat hij meer grip krijgt op de logistiek in de uitvoeringsfase?”* Ten eerste moet de hoofdaannemer het werkvoorbereidingsmodel controleren en vergelijken met de aspectmodellen van de onderaannemers en leveranciers. Deze moeten met elkaar overeenkomen en overeenkomen met de standaarden. Ten tweede moet het BIM-model gelinkt worden aan de planning. Als derde moet de aannemer met het BIM-model de voorraden op de bouwplaats kunnen beheren. Er zijn verschillende frameworks beschikbaar die geschikt zijn voor het managen van bouwlogistiek met BIM, waaronder modellen voor bouwplaatsbeheer en materiaalbeheer. Wanneer bovenstaande stappen uitgevoerd zijn kan het BIM-model gebruikt worden voor het managen van de logistiek. Een belangrijke kanttekening is dat voor soepel logistiek management met BIM het model hier vanaf de start voor is ontworpen. Ook moeten er goede afspraken gemaakt worden tussen de hoofdaannemer en de derde partijen om ervoor te zorgen dat de logistiek tot in de kleinste details is uitgedacht. Als dit gedaan is zullen de informatiestromen van de logistiek volledig gelinkt zijn aan BIM.

De vierde fase is verdeeld in twee delen: het perspectief van de derde partijen en de haalbaarheid voor de hoofdaannemer. De eerste deelvraag van deze fase is: *“Hoe kijken onderaannemers en leveranciers aan tegen supply chain management met BIM?”* Bijna geen enkele partij stond positief tegenover het idee om de bouwlogistiek aan te sturen met BIM. De voornaamste argumenten zijn dat ze vrezen de controle over hun eigen activiteiten te

verliezen en dat de hoofdaannemer meer werk op zich neemt dan hij aan kan. Ze vrezen ook dat het hen extra tijd en energie kost, hetgeen ze er niet voor over hebben. De partijen erkennen enige voordelen van BIM maar deze wegen voor hen niet op tegen de kosten.

De tweede deelvraag is: *“Is de implementatie van BIM voor supply chain management haalbaar voor de hoofdaannemer?”* Onderzoek gebaseerd op de case study, de meningen van experts en literatuur wijst uit dat de invoering van BIM voor het managen van de bouwlogistiek zowel financieel als organisatorisch en sociaal haalbaar is. De hypothese voor deze fase is: *“De implementatie van BIM voor het managen van de bouwlogistiek is haalbaar voor de hoofdaannemer.”* De hypothese is dus waar. Er zijn echter een paar kanttekeningen. Voor grote aannemers is het makkelijker om het risico te nemen van het invoeren van BIM, hetzelfde geldt voor grote projecten. Ook moet de aannemer beschikken over de juiste mensen en middelen. Ten slotte moet het implementatieproces stap voor stap ingezet worden om organisaties langzaam te laten wennen aan de nieuwe situatie.

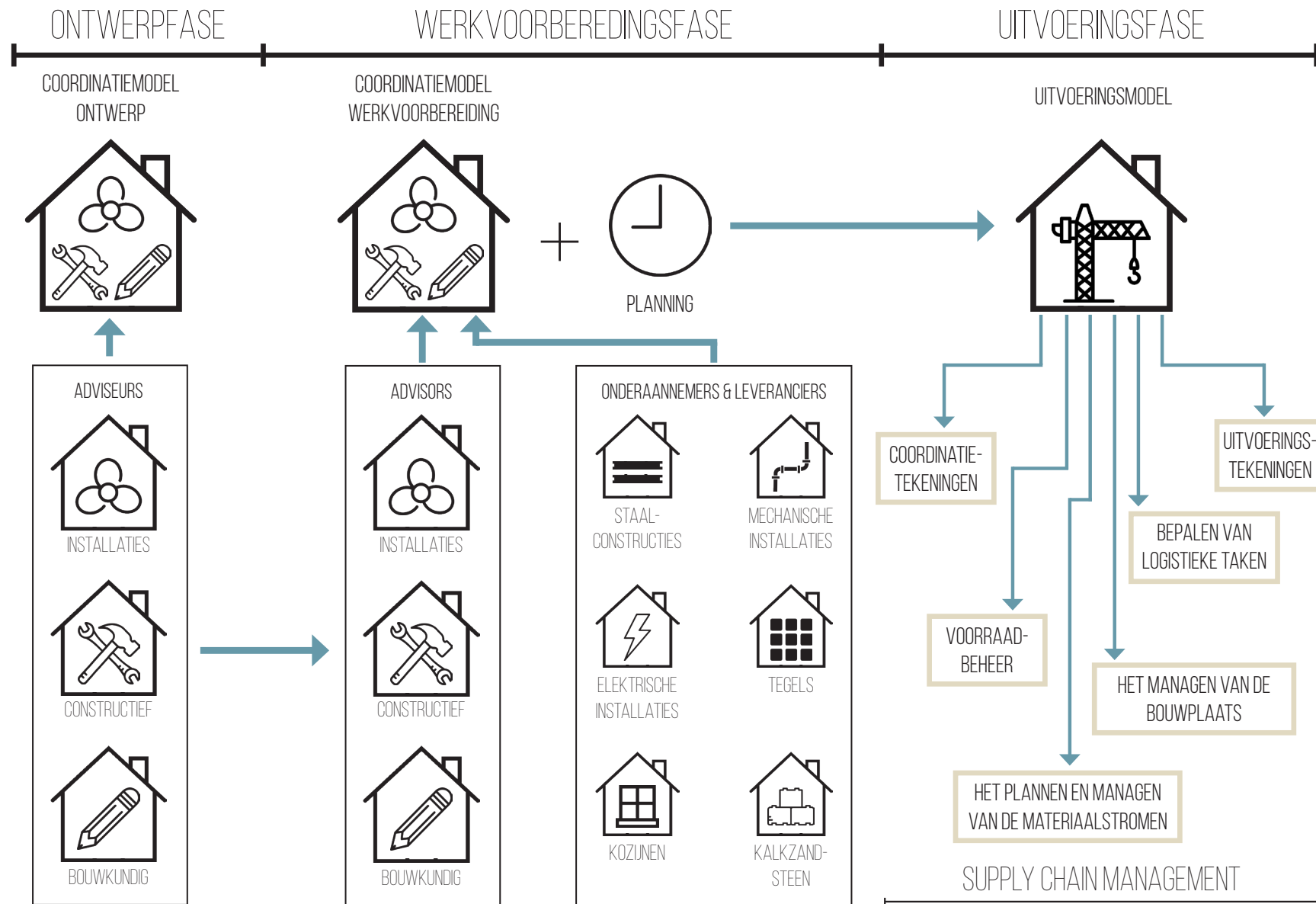
Uit het onderzoek komt een conclusie naar voren met betrekking tot bouwlogistiek en BIM: de logistieke informatie en BIM zijn volledig losgekoppeld. Niemand neemt verantwoordelijkheid waardoor de huidige informatieprocessen gefragmenteerd en ongecoördineerd zijn. Hiervoor zijn twee hoofdredenen. Ten eerste hebben aannemers weinig inzicht in hun eigen informatieprocessen en zijn ze vaak conservatief van aard. Hoewel ze vaak al BIM gebruiken voor een deel van hun werkzaamheden hebben ze de neiging om dezelfde informatieprocessen te hanteren als ze deden voor BIM. Ten tweede zijn aannemers bang om het risico te nemen om BIM te gebruiken voor het managen van de bouwlogistiek. Ze hebben erg weinig inzicht in de logistieke kosten van de onderaannemers en leveranciers dus de winstmarge is onduidelijk. Dit maakt ze terughoudend in het nemen van het risico. Hoewel ze er van overtuigd zijn dat de uiteindelijke voordelen van bouwlogistiek en BIM opwegen tegen de kosten, zijn ze terughoudend om dit in de praktijk te brengen. Dit resulteert in een gefragmenteerde en ongecoördineerde informatiestroom. De ontkoppeling die hieruit voort komt maakt het momenteel niet haalbaar om de bouwlogistiek aan te sturen met BIM. De vraag is dan ook welke aanpassingen er gemaakt moeten worden aan de informatiestromen om dit wel haalbaar te maken. Het antwoord hierop is het antwoord op de hoofdvraag: *“Hoe kan supply chain management met BIM aannemers helpen om meer grip te krijgen op de logistiek van een bouwproject?”* Ten eerste moet de hoofdaannemer zijn verantwoordelijkheid nemen en de veranderingen in het proces begeleiden. De hoofdaannemer moet zorgen voor uitgebreide kennis van BIM en ervaring met modelleren. Ook moet hij ervoor zorgen dat hij inzicht krijgt in zijn eigen informatieprocessen en bereid zijn om deze aan te passen. Ten tweede moet de hoofdaannemer ervoor zorgen dat de informatiestromen gekoppeld zijn aan BIM en dat de logistieke informatie is opgenomen in beide. Ook moet het BIM-model op zijn minst 4D zijn door het te linken aan planning software. Ten derde toont het onderzoek aan dat de hoofdaannemer het BIM-model moet koppelen aan de logistiek op de bouwplaats. Tot slot is het de taak van de hoofdaannemer om de prestaties van de derde partijen te meten tijdens het proces en ze feedback te verstrekken. Op basis van de resultaten van de literatuurstudie en het empirisch onderzoek is een framework samengesteld voor het managen van bouwlogistiek met BIM, hetgeen is weergegeven in figuur A6.



Figuur A6 Totale informatiestroom (eigen afbeelding, 2017)

Dit onderzoek focust niet alleen op het verduidelijken van de informatiestromen, maar ook op het verduidelijken van de processen in BIM. Figuur A7 vat de BIM-structuur samen van de ontwerpfase tot de uitvoeringsfase, waarbij het doel is om de logistiek op de bouwplaats aan te sturen met BIM.

De informatiestromen en de BIM-structuur moeten gekoppeld zijn om het aansturen van de bouwlogistiek met BIM haalbaar te maken. Zowel het empirisch onderzoek als de literatuurstudie wijzen uit dat als de hoofdaannemer de leiding neemt, actief zorgt voor de coördinatie en structuur van de informatiestromen en focust op het koppelen van de logistieke informatie en BIM, hij meer grip krijgt op de logistiek.



Figuur A7 Structuur BIM-modellen (eigen afbeelding, 2017)

