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“An approach to using BIM4D techniques to visualise infield status of building elements.”

T. van Breukelen - 18-8-2016
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T. van Breukelen
Version 6.0.2
August-18-2016
Markthal under construction in Rotterdam on October 1st, 2014
Image courtesy of Ronald Tilleman
Visualising the Status of Building Elements in Construction Projects.

“An Approach to using BIM4D Techniques to Visualise Infield Status of Building Elements.”

Master Thesis

a thesis submitted to the TU Delft
In partial fulfillment of the degree of Master of Science

by

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at the Delft University of Technology,
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Intelligence is the ability to adapt to change.

*Stephen W. Hawking*

The key to success is often the ability to adapt

*Anthony Brandt*
Dear reader,

The research laying in front of you is the final piece of my studies at the Technical University in Delft. For as long as I can remember I had the dream of building bridges. This is why I started Civil engineering back in 2008. After an unsuccessful year at the university I switched to the faculty of Technical Policy and Management. When my bachelor grade was achieved I again was posed with the question how I wanted to continue my studies. This is when I decided I would go back to construction projects and went to do my masters at Construction Management and Engineering. During the courses and my internship at Fluor I decided what would be my personal specialty. This would be the subject of my graduation thesis.

In the time at Fluor I was confronted with the possibilities of BIM lots of times. For me, it was quite unknown what would be possible using BIM but I liked the idea of it a lot. Eventually, the combination of BIM and Lean formed the basis of my research. JP van Eesteren gave me the opportunity to conduct my research at their projects. I would like to give a special thanks to Jeroen Koomen for the help and guidance he gave me during the research. His advices helped me forming my knowledge in BIM and laying the contacts needed for the execution of the research.

The graduation project is guided by a graduation committee. To properly execute my research I needed an expert in the field of managing complex projects, a BIM specialist, and a Lean specialist. These roles are fulfilled by Hans Bakker, Sander van Nederveen, and Ruben Vrijhoef. Hans has been and excellent support for any questions that arose during the research. Even though he struggled with health related problems in the past few months, his extensive feedback on the pieces handed in to him were a great help. Sander helped me a lot with the basic structure of the research, questions related to BIM issues, and general questions about the research approach. The meetings with Ruben enlightened me in the field of Lean. He pointed me to fields of research which helped me to fill in gaps in my knowledge of the Lean methodologies. Apart from that the entire committee helped me refine and tune the research questions and the report as a whole. Therefore I would like to thank the entire committee.

Hans, Jeroen, Sander, and Ruben thanks very much for the feedback and motivation that resulted in this graduation report.

Tom van Breukelen
August 2016
The construction industry is one of the most traditional industries around. The construction industry in the Netherlands awoke abruptly after the economic crisis of 2008. The efficiency of projects needed improvement to ensure the financial viability of projects. In addition, the demand of clients changed. Environmental, technical, spatial, and aesthetic demands, combined with tighter budgets and time frames made the construction projects even more complex. Current projects have to interweave the architecture, structure, and installations disciplines to cope with the changing preconditions.

Improved efficiency is needed to meet changing project requirements. Innovations therefore are emerging in the traditional construction sector. Lean is one of these innovations. The aim of Lean is to reduce waste and improve efficiency of construction projects. Aligning the design of the sub parts of the construction is essential when improving the efficiency of interwoven projects. The Building Information Modeling (BIM) methodology is a way of dealing with this. The design of the installations and construction can be imported in one model, which reduces the problems of misalignment that are encountered in-field. But far more is possible using BIM. BIM is mostly focused on centralising information.

In current projects, the BIM approach is used in the preparatory phase to centralise information and adjust the disciplines. Lean is not applied extensively here. When execution starts the focus deviates to Lean adjustment of tasks in order to execute the projects as smooth as possible. The BIM model is then of inferior importance.

This research aims to improve the efficiency of construction projects by focusing on the information flow. In this research a framework is created to improve the feed forward and feed back of information. In this research, the feed forward is seen as an improvement of the handover and centralization of information and knowledge. Feed back is the communication of changes to the schedule and the statuses back to the office. The framework is presented in figure 1.

The framework comprises of nine steps, in which the last four are a loop that continues until the construction is completed. First, the design of the construction is produced in BIM to ensure that architects, constructors and advisers do not need to change their way of working. In the second step, the tasks to be performed are broken down into smaller parts that are more manageable. This is done in a Work Breakdown Structure (WBS). The creation of the WBS results in a list of work packages. The third step is creating the schedule of the project; the tasks are scheduled in accordance with the earlier created WBS. The fourth step is logically linking and coupling of the project. This encompasses the linking of the schedule, WBS and BIM model and creates the 4D visualisation. When the statuses of the building elements are scheduled in step three, the communication of the statuses can be done using the created 4D visualisation. Step five to nine present the feed back loop that is used during the execution phase. Step five is the Lean adjustment meeting as it occurs on a daily basis in construction processes, aided by the
4D model. In step six, the schedule is updated, when deviations to the schedule occur or phasing is made. Then step seven; 'changes in the field' represents the physical changes that happen either at the construction site, as well as in factories or in logistics. These changes are monitored in step eight with special focus on monitoring deviations. In the ninth step of the framework, the updated schedule and live monitoring are combined to create the new 4D model that can be used in the next iteration of the feedback loop. This model is then used in step five of the next loop to communicate deviations and adjust the plans.

The research was executed in cooperation and as an assignment for JP van Eesteren. Using the research JP van Eesteren will be able to start using the framework. This is done to let BIM and Lean strengthen each other and enhance the efficiency of construction projects. Not all steps of the framework can at this moment be implemented because of software and hardware challenges. But JP van Eesteren can start to use the WBS-structure as described. This will result in the possible coupling of the BIM models and Lean plans. Apart from that JP van Eesteren should carry on implementing BIM and Lean at their projects. This will be done to get the employees more familiar with the technologies. Furthermore it is important to get more experience with BIM360Field in order to get more accurate information when in the field. Finally it is advisable for JP van Eesteren to carry out a social research. This research should provide information in enhancing the acceptance rate of innovations such as BIM and Lean. At this moment some of the employees support the technology, but others do not because they do not see the additional value. These steps will lead to more insights and a more controllable construction process. It is important for JP van Eesteren to keep innovating their ways of working to keep up with the current movements of the contracting industry.
De bouwsector is een van de meest traditionele sectoren. Sinds de economische cri-
xis van 2009 is de sector echter wakker geschud. De efficiëntie van de projecten moest
verbeterd worden om de financiële haalbaarheid te garanderen. Tevens veranderde de
vraag vanuit de opdrachtgevers. Duurzame, technische, ruimtelijke en esthetische eisen
worden nu gecombineerd met krappere budgetten en doorlooptijden. Dit leidt tot com-
p lexere projecten. In huidige projecten worden disciplines verweven om hiermee om te
gaan.

Vanwege het omgaan met de veranderende project eisen is verbeterde efficiëntie no-
dig. Innovaties zijn daarom opkomend in de traditionele bouwsector. Lean is een van
dezze innovaties. Het doel van Lean is om overschotten te reduceren en efficiëntie te ver-
hogen. Afstemming van het ontwerp van de disciplines van een bouwwerk is essentieel
om de efficiëntie van verweven projecten te vergroten. De 'Building Information Mo-
deling' (BIM) methodiek is een manier om hier mee om te gaan. Het ontwerp van de
installaties en de constructie kan geïmporteerd worden in één model om zo de proble-
men en de risico's die buiten ondervonden worden te reduceren, maar met BIM is veel
meer mogelijk. BIM draait voornamelijk om de centralisatie van informatie.

In huidige projecten wordt de BIM aanpak in de voorbereidende fasen gebruikt om
informatie te centraliseren en om de disciplines op elkaar af te stemmen. Lean wordt
hier niet veel toegepast. Zodra de uitvoering begint wordt gefocust op het afstemmen
de taken om de uitvoering van de projecten zo soepel mogelijk te laten verlopen. Het
BIM model wordt dan echter stukken minder gebruikt.

Dit onderzoek richt zich op het verbeteren van de efficiëntie van bouwprojecten door
te focussen op de informatiestromen in projecten. In dit onderzoek is om deze reden een
raamwerk gecreëerd teneinde de 'feed forward' en 'feed back' van informatie te verbete-
ren.

In het onderzoek is 'feed forward' het doorgeven en centraliseren van informatie en
kennis. 'Feed back' is de communicatie van veranderingen terug naar het kantoor. Het
raamwerk is weergegeven in figuur 2.

Het raamwerk omvat negen stappen, waarvan de laatste vier een feed back cyclus
zijn. Deze duurt tot de bouw van het bouwwerk voltooid is. Als eerste wordt het ontwerp
van het bouwwerk in BIM gemaakt. Dit zorgt ervoor dat architecten, constructeurs en
adviseurs zo min mogelijk hoeven te veranderen aan hun huidige manier van werken.
In de tweede stap wordt het totaal aan taken verdeeld in kleinere, meer overzichtelijke
werkpakketten. Dit wordt gedaan op basis van de 'Work Breakdown Structure' (WBS)
 en resulteert in een lijst van werk pakketten. De derde stap is het maken van de plan-
ning. Deze planning wordt gemaakt op basis van de WBS. De vierde stap is het koppelen
van de planning, WBS en 3D modellen. Dit resulteert in de 4D visualisatie. Wanneer de
statussen van bouwelementen of werk pakketten gepland zijn in stap drie, kan de com-
municatie van de statussen gedaan worden in de 4D visualisatie. In stap vijf tot negen,
wordt de terugkoppeling van informatie tijdens de uitvoering besproken. Stap vijf is de Lean bijeenkomst, die dagelijks wordt gehouden, deze bijeenkomst wordt ondersteund door het 4D model. In stap zes wordt de planning bijgewerkt wanneer wijzigingen in het werk of faseringen in het werk of de faseringen dit noodzakelijk maken. Vervolgens komt stap zeven waarbij de uitgevoerde veranderingen in het veld gebeuren, deels volgens plan en deels niet. Om deze te kunnen gebruiken moeten de veranderingen en ontwikkelingen in stap acht gedocumenteerd worden. In de negende stap van het raamwerk worden de veranderingen aan de planning, en de 4D model van veranderende, gecombineerd in het nieuwe integrale 4D model. Dit model kan dan gebruikt worden in de eerstvolgende Lean bijeenkomst om de afwijkingen van de planning te communiceren.

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1

General Introduction

The building sector in the Netherlands is slowly but surely recovering from the financial crisis of 2008. The main growth is seen in the civil and utilitarian sectors. The past one and a half years lots of optimism is present in the sector. Although the prices are rising slowly most benefits can be generated by working more efficiently. This can also be seen because the amount of jobs shrunk while the profit grew (FD.nl, 2016). The traditional sector has been changing. Part of this change is focusing at improving the quality of the product. Clients are willing to invest in more sustainable constructions (Winch, 1998). Also the construction process is made more efficient. The tasks are aligned to each other and the design of all the different parts are adjusted to prevent problems in the field (Arayici et al., 2011). In the construction process lots of contractors, subcontractors, and suppliers work together to create a total construction project. The project manager aims to create a process that is as smooth as possible. To do this the information handover between the parties is sometimes problematic. To improve the handover of the information between the parties innovations are occurring (Fallon and Palmer, 2007). Also, projects are under lots of pressure to increase the efficiency and to meet tighter deadlines. Communicating statuses and deviations of the parts is essential to keep up with this schedule (Bernstein et al., 2013). It is a very intensive job to oversee the status of all elements in the projects for the project managers. The status of the physical building elements that are on site can be observed. However, statuses of building elements created or transported by suppliers and subcontractor are often unclear. These building elements do have a large impact on the construction progress. Furthermore the construction process on site does not always go according to plan. Deviations to the schedule occur on a daily basis. The communication of these statuses and deviations should be improved to create a more efficient construction process.

Building Information Modeling (BIM) is a way in which the design of the different parties involved in the process is centralised making it accessible to all. This makes it possible for the different parties to see all other designs. Thereby the design can be adjusted to the others to create a fitting solution. BIM methodologies are furthermore used
to aid the communication between clients and contractors and as an information handover tool to improve the information flow from architects to contractors. BIM is about controlling and coordinating information in construction projects (Eastman et al., 2011). Lean is a way of creating a more efficient process. The construction sector now uses Lean mostly to aid the adjustment of the parties during the execution phase. The tools that are used in the construction sector are among others pull planning, early contractor involvement, and last planner. However, Lean envelops a lot more tools in order to identify and remove wastes of time, cost, and effort from the construction process (Anumba et al., 2007).

Combining BIM and Lean will result in increased efficiency of the information handover in construction projects. BIM will in this scenario be implemented because of the communication benefits and because of the centralisation of information. Lean will improve the schedules and the insight in the statuses of the building elements. This research will analyse the possibilities of implementing BIM and Lean in construction projects. The research will be executed using literature studies and case studies. Chapter 2 accurately describes the problem as experienced in the construction sector and the way this research aims to solve the perceived problem.
The methodology chapter outlines the motivations, methods, and techniques used in the research. In paragraph 2.1 the problem is addressed and described. This is done based on the problem description and research objectives and leads to the research questions. A demarcation of the research is then presented in paragraph 2.2. The research approach is given in paragraph 2.3. This paragraph presents the manner the research is executed. Finally, the techniques that are used in the course of the research are elaborated on in paragraph 2.4. This paragraph includes the way the techniques are used and the motivations for choosing these techniques.

2.1. Problems in the Construction Sector

This paragraph analyses the objectives of this research. This will be followed by the research question that is the central pillar of the research. The main research question is split in sub-questions that are answered in the research.

The construction industry has been conventional or even conservative for a long time. Some in the industry still prefer drawings to be executed in pen and paper. Other industries have adopted IT as an alternative in a far earlier phase. The adoption of the IT in construction is nowadays being expanded. The construction sector is currently striving for improved efficiency. During this economic crisis of 2008 movement towards more efficient processes has increased rapidly. Less money was available for construction projects therefore money and personnel needed to be allocated more efficiently. Innovations are now being implemented in the traditional construction sector (Underwood and Isikdag, 2011; van Geest, 2014). Innovations originating from lots of industries are implemented in the construction projects to achieve this increased efficiency (Faber and Hoppe, 2013). The innovations that were implemented can be separated into two parts; the improvements in the feed forward of information and the improvements in the feedback of information. In the improvement of feed forward of information Building Information Modeling (BIM) is a key innovation (Eastman et al., 2011). In feedback
of information the Lean approach is fundamental. Little research has however been undertaken to combine the BIM and Lean methods (Bernstein et al., 2013).

2.1.1. RESEARCH OBJECTIVE

The academic community has posed ways of combining innovations in the feed forward and feedback of innovations. However, the adoption of these in the construction sites is limited. This research is executed with the objectives of dealing with this discrepancy.

Firstly, innovations are occurring in the field of information flow within construction projects. Two of the main innovations are BIM and Lean. There are more innovations available to aid the efficiency of construction projects. These should be analysed in this research. Secondly, the executed literature research that has been done should be compared to the actual practise in construction projects. BIM and Lean are emerging in the construction sites in the Netherlands. Therefore, there is a desire to research in what way the BIM and Lean methodologies can be integrated. Finally, a framework should be created in order to organise construction projects differently to improve the flow of information in construction projects. This framework describes how the innovations and techniques should be used together to create an integrated process that improves the construction efficiency. The following objectives are therefore identified;

- Analysing innovations in flow of information.
- Comparing literature and practice on information flow
- Integrating BIM and Lean
- Create a framework to improve information flow in construction projects

2.1.2. RESEARCH QUESTION

The problem and the research objectives are translated in a research question to execute the research. This research is aimed at combining innovations such as BIM and Lean. These aim to improve the information flow in construction projects. The feed forward of information exists as well as feedback. However to improve the information flow in construction projects this research analyses possibilities to integrate feed forward and feedback in construction projects.

The following research question is defined;

“How can the efficiency of construction projects be improved, by focusing on feed forward and feedback information during the construction process?”

This question is divided in sub-questions (SQ) that to answer the main research question and deal with the research objectives;

- SQ 1 What methods can improve the information flow in construction projects?
- SQ 2 How is the flow of information in current construction projects organised?
- SQ 3 How can feed forward and feedback be integrated in an functional framework?
- SQ 4 Is this framework an improvement for project efficiency?
2.2. RESEARCH DEMARCATION: FOCUS ON BIM AND LEAN

Investigating all innovations in the construction industry is infeasible. Therefore a demarcation is therefore necessary. The focus in the construction of the framework is on the integration of BIM and Lean. BIM is described as one of the most promising recent developments in the architecture, engineering, and construction industry (Azhar et al., 2011; Eastman et al., 2011). While others have mentioned Lean techniques such as Last planner, pull planner and supply chain management as being very promising (Seppänen, 2009). This is however still quite broad. Therefore, the focus of this research will be on the enrichment of the Lean methodology. The part of the Lean methodology that will be focused on is monitoring and feedback of field information to the adjustment meetings. The enrichment will be in communication, information centralisation, and automating the process.

2.3. APPROACH TO SOLVING RESEARCH QUESTIONS

The research is split into various parts. To answer the research questions. These are described in the following list and visualised in figure 2.1;

1. **Part 1. Introduction** - The introductory part of the research comprises of two chapters. First, a general introduction will be given into the subjects and problems of the research. Secondly, the methodology chapter explains the problem, demarcation, and approach of the research and the techniques that used to execute the research.

2. **Part 2. Information gathering** - This part comprises of two chapters as well. Chapter 3 describes the theoretical literary background as well as the innovations. Furthermore, this chapter presents the initial framework to combine BIM and Lean. Chapter 4 evaluates the framework on the basis of case studies in the real world.

3. **Part 3. Framework design** - Part 3 is split in a chapter on the software that can be used to support the framework and a chapter on the eventual framework. This
framework is the result of elaborating the initial framework presented in the conclusion of chapter 3 with the real-world observations and knowledge about the software.

4. Part 4. Testing - Using verification cases and validation interviews the framework is tested in chapter 7.

5. Part 5. Conclusion - Finally the conclusion chapter comprises of the conclusions, discussion of the research, significance and recommendations to both the academic world as well as to JP van Eesteren.

2.4. DESCRIPTION OF USED RESEARCH TECHNIQUES

The following techniques are used as a part of the research. As mentioned before a Literature research is executed in the Theoretical Background chapter. The observations and interviews are part of the case study. The case study is presented in chapter 4. Finally the created framework is verified and validated. These steps and their importance are explained in the last two paragraphs of this chapter.

2.4.1. LITERATURE RESEARCH

In the literature research the existing knowledge present in the academical world and in practice are examined based on the different subjects. The aim of literature research is examining the research that has already been executed and finding lacunae in existing research.

2.4.2. CASE STUDY

Case studies are executed in many scenarios. The case study is in this research used as a method to examine the way projects are organised in the real-world scenario. The main advantage of executing a case study is that it is able to represent the characteristics of real-life events (Yin, 2003). A combination of observations and interviews is used to analyse the cases. This is done because the results of observations will be unbiased. Interviews are used to find answers to questions which cannot be observed. Multiple cases are examined and within the cases and multiple individuals are interviewed of different background to get a better unbiased view of the projects. The combination of interviews and observations creates a holistic view of the cases.

INTERVIEWS

Different approaches to interviews can be taken. Be it one interview at a time or multiple interviewees being executed at the same time. In addition, the questions in the interviews can be strict and listed or the interview can be more resembling a conversation. In these case studies the interviews were executed in an individual manner. Thereby preventing the interviewees to influence each other. Furthermore, the interviews are not a questionnaire but are more conversation wise. This is done to avoid the limiting character of sticking to questions. Interviewees tend to reveal more information in conversations instead of questionnaires. A list of questions was formed to ensure that the interviews are comparable. This list was not questioned one by one but the attempt was
made to get the answers through the conversation. As mentioned before, bias was luring in the projects. To limit this as much as possible at each case study at least three people were interviewed from the three different companies involved in the projects.

**Observations**

All interviewees were involved in the projects they were questioned about. It was therefore important to take the time to observe meetings and situations. Observing and attending a meeting often gives more information than asking an interviewee about the same meeting. Interviews consider why things happen the way they do and how they happen. Observations mainly focus on how things happen, in a more unbiased way.

**2.4.3. Verification**

A model should be tested before it can be presented as ‘working’. Therefore two tests are essential. A model should be verified and validated. The model is tested to see if it operates as it was designed. This is done in the verification test. To do this the model or framework is applied to a test case. In this research first a small pilot test case is used and then a larger case. This larger test case is more resembling of a real-world scenario. These two cases represent scenarios which can possibly be encountered during the use of the framework. The first test aims to test the basics of the framework. The second test aims to stress the framework a bit further. A model is considered verified if it operates. This means that the steps can be followed with other projects. The steps that are illustrated can be taken and software packages can communicate to each other. It should be noted that this does not necessarily mean that the process is more efficient. This is tested in the validation.

**2.4.4. Validation**

The validity of a model or framework is tested in the validation. The validation aims to answer the question; ‘Does it solve the problem?’ This is done using interviews. Two experts are interviewed to discuss their opinions on the usefulness of the newly created framework. A model is valid if in the validators’ opinions, the framework reduces the original problem. The experts that are interviewed in this research have experience in the subjects concerned in the research. One of the experts is an employee of JP van Eesteren and the other is not. This is done so the results are less biased. In this research valid means that the created framework improves the feedback and feed forward of information in a construction projects. Because the information handover within the projects is improved the execution process is of a construction project can be made more efficient.
In this chapter is focused on answering the first sub-question of chapter 2.1.2. "What methods can improve the information flow in construction projects?"

The answer to this question is divided over five paragraphs. First an overview of the construction industry is presented in paragraph 3.1. Then paragraph 3.2 and 3.3 describe the innovations that are found in the feed forward and feedback of information in construction projects. Paragraph 3.4 then describes the way methods can be combined. The chapter ends with paragraph 3.5 in which the initial framework is presented on which the rest of the research is based. This framework aims to answer the sub-question by mentioning what methods are useful to use and elaborates this by explaining how the methods can be applied to a case together. A representation of the steps is given in Figure 3.1.

Figure 3.1: Literature structure
3. THEORETICAL BACKGROUND

3.1. TRADITIONAL CONSTRUCTION INDUSTRY

First an overview is presented of the construction process in its traditional way to see what is being improved in the construction industry. Then the problems that are encountered in the construction industry are presented along with some of the causes. After this, interfaces and interface management within projects are explained. This is done because it is one of the large changes that is being encountered in the construction industry. Then, problems in the feed forward and the feedback of information are elaborated on. Finally some information about the importance of communication at construction sites is also presented.

3.1.1. CONSTRUCTION PROCESS

Traditionally there are six phases in the life cycle of a construction project: design, prepare, execute, operate, maintain, and demolish. For the purpose of this research, the focus will be on the first three phases. A construction will be designed, then it will be planned, after which it is executed.

1. In the design phase, the list of demands by a client is translated to the design of the construction. The designer produces drawings, specifications, and material documents. The collection of these is the design as produced by designers, architects, and constructors (Eldin, 1991).

2. In the preparation phase, the design is translated into workable documents for the execution phase. There are many tasks undertaken in the preparation phase. Two of the important ones are; the cost oriented part and the schedule oriented part (Heesom and Mahdjoubi, 2004). The cost-oriented part takes care of the creation of the budget. The schedule is created in order to serve as a main set of deadlines and guidelines to produce the construction (Arditi et al., 2006).

3. The execution phase is the period from the start of the execution until the project is delivered. In this phase, the design and preparation are put to use to create the construction. The execution is coordinated by the main contractor, with the aid of the subcontractors, suppliers, and consultants (Eizakshiri et al., 2011).

The sources describe the way the construction process is executed accurately. It describes the way of translating the list of demands. Then it couples this to the cost and schedule of the execution accurately. The third phase of the construction process translates the initial demands to the physical construction using the created schedule and budgeting. It is however also mentioned in these sources that the distinction of the phases is not strict but the phases tend to flow through each other.

3.1.2. PROBLEMS IN THE CONSTRUCTION SECTOR

In construction projects many problems can occur. There are four main ways problems can manifest when problems between clients and contractors are concerned. A project can be delivered later than expected (time), it can be more costly than expected (cost), the quality of the result can be lower than expected (quality), and the project can influence the image and reliability of the parties involved (social) (Tumi et al., 2009). Causes
for these problems are diverse. In literature the causes of problems at construction sites are split into four groups (Majid and McCaffer, 1998).

1. **Non-Excusable** - These problems are caused by a contracting party. Overestimation of productivity, bad scheduling, and construction mistakes are a few of them. The contractor is fully responsible for these problems.

2. **Excusable non-compensable** - These problems are unforeseeable for the client and contractor. The problems cannot be attributed to either the client or the contractor. The contractor is responsible and therefore does not receive compensation for the costs of the problems. An example of this is a delay caused by building permits that are not awarded.

3. **Excusable compensable** - These problems are problems that are attributed to the client. The client has to pay the contractor for these problems. Most common are; changes to design or demands and different site conditions than communicated.

4. **Concurrent** - In these problems the owner and the client are both partly responsible. An example of a concurrent problem is when a project is forcefully accelerated by an externally party. The costs of these problems are most often split amongst the parties (Azhar et al., 2002).

This research focuses on problems that can be prevented by the contractor. These problems are non-excusable problems. To find causes for delays in construction projects Kazaz (2012) executed comparative a study among 17 different countries. The largest causes of non-excusable delays mentioned in this research are; construction defects, deviating productivity of labor, conflicts between parties, bad communication between parties, and poor site management (Kazaz et al., 2012). Lo (2006) also compared the work of other researchers. The research aimed to list problems and the attitude towards them as observed by clients, contractors, and consultants. The most influential problems that were found are; site conditions, bad site management, communications between the parties at, conflicts in design, and the complexity of the construction (Lo et al., 2006). Kazaz (2012) and Lo (2006) create a view of the possible causes of problems that could be prevented by the contractor. This focuses the research into communication between parties, site and misconceptions about the productivity of the workers.

### 3.1.3. Interfaces and Interface Management

One of the causes of problems in construction projects is the communication between parties. Interface management is a way of dealing with the (need for) communication within construction projects.

In recent construction projects the demand of the client has changed. Projects are desired to be fully integrated. This implies that the different parts of the project are fully adjusted to each other to create one seamless result. For most projects this means that construction, architecture, and installations (both mechanical and electrical) are combined as if being one (Baiden et al., 2006). Having projects and disciplines that are integrated leads projects to have lots of interfaces that need to be managed. Interfaces
are the boundaries between people, systems, equipment, or concepts. Multiple disciplines and teams have to work together to create modern large projects. To create a fully integrated project a lot of interfaces have to be dealt with. Management of the interfaces in projects has been poorly executed in a lot of projects that encountered delays (Nooeboom et al., 2004). Pavitt and Gibb (2003) state; "Interface, joints, and connections between different elements or sections cause more problems than most of the rest of the building. There are challenges during design, manufacture, and construction."

There are three types of interfaces that need to be considered;

- **Physical** - Actual physical connections between building elements.
- **Contractual** - When building elements are grouped to execute for instance the design. Interfaces exist between these groups.
- **Organisational** - Interactions between parties that perform tasks at a construction site (Gibb and Brand, 1996).

The management of interfaces comprises of the design, manufacturing and construction process of the elements or work packages that are connected. The alignment of the design before the construction phase starts, will result in less problems being encountered during the construction process (Pavitt and Gibb, 2003). Rewards for effectively applying interface management include the reduction of adjustments that need to be made on a last minute basis. These are a large cause for delays and extra costs in the projects (Nooeboom et al., 2004). An other benefit of the management of interfaces is that the building becomes more buildable and understandable. The design of the building can be optimised for quality, compatibility, constructability, costs, risks, or functions. This is done to meet the needs and demands of the clients. Chan (2005) describes a framework for handling interface management in the construction of an Olympic stadium in China. The following four steps were taken in this case; Identification, Simplification, Prioritization, and Matching, which means that interfaces are found, explained, quantified, and managed (Chan et al., 2005). In managing interfaces, Chua (2006) described another set of steps. These are;

1. Interface definition
2. Visibility
3. Communication
4. Control
5. Response to interface issues (Chua and Godinot, 2006)

Both approaches mention that interfaces first have to be found, and then have to be communicated in a way clear to all who are involved to make adjustment of the interfaces possible.

The literature shows the importance of interface management in construction project as well as showing that within interface management communication is an essential component.
3.1.4. Information Handover
Communication between parties is organised to handover information from one to the other. In the traditional approach, every expert works on a different part of the project. Contracts dictate who is responsible for which tasks. This handover of information can be seen as the feed forward of information through construction projects. The traditional contracts have been described as the ‘over the wall’ contracts. This is caused by the handing over of packages of information through the phases of a construction process. Handover of information occurs from client to architect, to the structural engineer, all the way to the contractors and suppliers. Every time a package is handed over a static point is established on which responsibilities is also handed over (Anumba et al., 2007). The traditional project team is described as a number of individual parties. Each of these parties contribute their distinct part to the design of the project (Evbuomwan and Anumba, 1997). A depiction of the information handover is inserted in Figure 3.2.

Figure 3.2: The over the wall approach (Evbuomwan and Anumba, 1995)

This traditional approach causes the fragmentation of the different participants. This leads to misconceptions and misunderstandings. Another problem of the traditional approach is that the fragmentation of design and construction leads to design clashes, omissions, and errors. This then leads to liability claims and a very bad atmosphere between the parties in the execution phase of the construction. Lastly the lack of communication of design rationale and intent leads to design confusion and wasted effort (Anumba et al., 2007). Innovations have since been occurring to prevent these problems. These innovations bring parties earlier together or improve the handover of information. The Building information modeling (BIM) methodology centralises the information and makes it accessible to all parties in the project without the need for information handover. A part of the Lean philosophy brings contractors earlier to the process.

The sources describe the importance of the improvement of information handover. It sketches the problems when information is not handed over properly.

3.1.5. Schedule deviations
Misconceptions about the productivity lead to progression that is different than expected. Therefore deviations in scheduling are analysed. Construction projects are scheduled to ensure the tasks to be undertaken are aligned. Different parties operate at a construction site and this leads to shared use of space, material, and time. The schedule tunes
tasks and is used to complete the construction project in time. In the scheduling procedure the tasks to be undertaken are first listed. Then durations are attached to the tasks. Finally the logic links between the tasks are drawn. This logic is created because restrictions and demands exist between the tasks. In most modern construction projects "Gantt charts" are used to execute schedules (Callahan et al., 1992). However the tasks that are undertaken are under the influence of lots of factors. This makes the schedules more dynamic. Deviations to the schedule occur. This itself is not a problem. However, when the deviation impacts other disciplines the communication of these deviations is essential to prevent problems. Innovations are emerging to communicate these changes to other disciplines as quickly and clearly as possible (Heesom and Mahdjoubi, 2004).

The sources describe the way construction projects are scheduled traditionally. It is furthermore mentioned that these scheduling techniques are now changing.

3.1.6. COMMUNICATION
Poor communication between parties has been mentioned as being a source of problems at construction sites. When projects are complexer and interface management is not executed well enough problems in communication emerge (Sambasivan and Soon, 2006). Sanvido (1992) mentions that efficient, direct, communication is one of the critical success factors of complex construction projects (Sanvido et al., 1992). Saeed (2009) mentions that, because of the characteristics of construction projects, deviations from the original plans occur. It is also mentioned that problems do not have to occur if the deviations are communicated timely and sufficiently (Saeed, 2009). Specific research in communication points out that in the construction of buildings approximately 40 percent of the extra costs in time and money is related to the transfer of information (Rilling, 1990). Al-Hammad (1993) found that lack of communication is one of the largest causes of additional problems. Not communicating the deviations at the construction site leads to errors throughout the entire building process (AlHammad, 1993).

The conclusion of these sources is that communication in construction projects should be improved. Improving the communication between the parties involved in the construction process will lead to the improvement of the efficiency of the project.

3.2. INNOVATIONS IN FEED FORWARD
It was mentioned that information handover is a source of problems. Feed forward of information is the way information flows through the project from start to finish. Three innovations in the feed forward of information are elaborated on in this paragraph. The first sub-paragraph focuses on the supply chain of construction projects. This supply chain does not only focus on the handing over of physical building elements from suppliers to contractors but also focuses on the handover of information. Secondly, BIM is mentioned as a way of centralising information. Finally organising the information and knowledge using work breakdown structures and work packages is mentioned as an innovation in the handing over of information. These subjects will be explained one by one in this paragraph after which a conclusion of the innovations in feed forward will serve as part of the answer to the earlier stated sub-question.
Supply chain management (SCM) has many different definitions. All of these focus on the alignment of parties or people from the beginning until the end of a project. The concept of SCM has been implemented at manufacturing and logistical sector for years. An increased efficiency of the handover of information is necessary to align the parties in a project better (Hugos, 2011).

The construction industry can be improved by integrating the process horizontally. This means that the activities that follow each other chronologically in the process are better interconnected. Supply chain management is a way of analysing and improving this process of integration (Tomiyama and Meijer, 2006). Parties in the construction sector acknowledge the potential of SCM and its main benefits for the sector. It is mentioned that supply chain management can help overcome the fragmentation, aid the culture, and improve the integration of processes at the construction site (Saad et al., 2002). When supply chains in constructions projects are analysed, it is found that lots of attention is given to the integration of the parties and steps within the supply chain. The contractor who takes over jobs of the architect and the other way around. Another way supply chains are changing is when clients deliver a completely executable design to the contractor instead of having parties in between (Jung and Joo, 2011). Other focus of the supply chain methodology has been on the relations that are important for the execution of the construction. The relations between the clients, contractors, subcontractors, and supplier are more elaborately researched (Bresnen and Marshall, 2000). Supply chain management is a way of improving the relations between the contractor and the subcontractors. Enhancing the clearness and information of the elements in the supply chain can enhance the performance of subcontractors (Olawale and Sun, 2010). A better exchange of information between parties in construction projects should be encouraged to reduce the amount of rework that has to be performed. The interaction between parties can be improved by introducing knowledgeable parties earlier in the process and by improving the communication between contractors, manufacturers, and deliverers. Information technologies such as web-based project management may be able to enhance the exchange of information between parties (Josephson and Hammarlund, 1999). To reduce the waste in the construction process the management of the supply chain aims to streamline the information flow through the phases of the construction process, from the design to the execution of a construction project (Fallon and Palmer, 2007).

Problems in construction projects are occurring; this has been stressed in this research and in research before. Rework is one of the causes leading to extra costs and delays. Research by Love (1999) stated; that 'Rework is seen as a symptom of a badly working supply chain'. Poor communication is one reason supply chains in the construction sector work inefficiently. The focus on improved communication and coordination in projects should be on the interfaces between parties (Love et al., 1999). Taylor (2009) stressed the importance of visualisation to aid communication of information through supply chains. The research mentioned that BIM models could possibly aid this communication. The use of the BIM model and the importance of integrating activities and parties in the supply chain are essential in improving the construction sector (Taylor and Bernstein, 2009). However, improving the information handover of the statuses of building elements through the use of visualisations was not mentioned in this research. When
BIM models are integrated with the supply chains of partners, a powerful mechanism is created for communicating signals to pull production and delivery of materials and product design information. This also helps make the supply chain more transparent (Vela, 2008).

From this literature it can be concluded that efficient management of the supply chain can aid the efficiency of construction processes. This can be done by integrating tasks of the different contractors and suppliers but also by improving the way the parties work together. The importance of integrating parties in the supply chain is described using the Early contractor involvement and the Macleamy curve. The following sub-paragraph describe the importance of involving parties earlier in the construction process.

**More knowledge earlier in the process**

In his article, Bernstein (2013) interviewed Sanvido, who stated; “We recognise that 50% of the project cost is established during the program phase, 75% during schematic phase and the rest after that.” Having experts involved in this phase makes it possible to adjust and optimise the design early on (Bernstein et al., 2013).

Early Contractor Involvement (ECI) is another way in which the construction industry is changing. Song (2009) mentioned that; "The importance of integrating construction knowledge early into the design process has long been recognized by the construction industry." As a result of this ECI contracts have been developed. The contracts bring suppliers, sub-contractors, or contractors to the design phase of the construction process (Song et al., 2009). The traditional approach would involve a contractor after completion of the design. The contractor is in this new approach consulted for their opinions and experience. The contracting form is not always applied because fixing a contractor earlier prevents competition between contractors for a lower price (DeWitt et al., 2005).

Macleamy describes the construction process by illustrating the importance of making the right decisions early in the process. Deviations to the original plan cost more time and money when executed later in the process. MacLeamy introduced a curve explaining the cost of changes in projects. The figure is presented in Figure 3.3. The main costs in the traditional approach of a change in the project become higher during the project. Many changes have to be made to fit in a deviation when a deviation to the original plans are made later on in the project. In addition, the amount of possible changes declines during the project because of what is already constructed. It is shown in the figure that ability to impact the costs decreases and the costs of design changes increases during the project. Therefore it is desired that the process focuses on making the 'right' decisions earlier in the process than traditionally by having more knowledge in this phase. This can be achieved by involving the experts earlier. However, involving the other parties early on in the process does not reduce the amount of information to be handed over. It only makes sure that the information handed over is of better quality.

Through this sub-paragraph it can be concluded that involving parties with lots of knowledge early in the project improves the efficiency of the projects. The downside of this is that selection of parties must occur far earlier in the process. This is only shortly touched upon in the sources. The impact of selecting parties this early affects the costs of the processes greatly. Furthermore selecting parties this early might be hampered when European tendering is mandatory.
3.2. INNOVATIONS IN FEED FORWARD

3.2.2. BIM AS INNOVATION IN AIDING INFORMATION HANDOVER

"Building Information Modeling" (BIM) has a lot of different uses. BIM is a way of centralising information within project. Thereby the handover of information is improved. "BIM is emerging as an innovative way to manage projects" (Azhar et al., 2011). The BIM model is not just a 3D representation of the design but it also contains background information of the parts and elements. "BIM can be used to achieve the goals set by the team that is executing a construction project" (Kymmel, 2008). The BIM model is based on centralising characteristics and design of the building elements (Zhang and Hu, 2011a). Thereby the BIM model is a digital representation of the physical and functional characteristics of the construction to be built. It can be used in the entire life cycle of a building, from designing and execution, to maintenance and deconstruction (Yalcinkaya and Arditi, 2013). Hardin (2009) mentions that the BIM model can be used to aid projects that are multi-disciplinary because visualisations of the design can be created. These visualisations are identifiable, for all parties that are involved in the project (Hardin and McCool, 2015).

Hellum (2015) identified many uses of the BIM model in all project phases. In her discussion it is mentioned that the possible techniques are often theoretical and not developed. The reason for this is that there is often an absence of the link between the BIM software and other software packages (such as planning software). It is also mentioned that there is a lack of trust in the BIM model by the employees at the job site. The model is seen as indicative and not as definitive. Therefore, 2D drawings are exported from the 3D drawings to create definitive plans. The 2D drawings do have the definitive character (Hellum, 2015).
The literary sources of this paragraph aim to explain the motivations and basics of BIM. The following sub-paragraphs mention the application of BIM in order to aid interface management and schedule representation.

**BIM and Interface management**
Both BIM and Interface management are innovations to aid the construction industry, both are however not extensively applied. This is partly caused because there are limited to no software packages that are able to combine the two. ConBIM-IM\(^1\) was developed to fill in this gap. It’s goal is to enhance the sharing of information surrounding the interfaces found in the BIM model. The tool combines BIM and Interface management to visually point out interfaces between elements, parties, and contracts. In this way the visualisation of the ConBIM-IM software makes it possible to communicate the interfaces which should be focused on (Lin, 2015). Lin 2015 introduces a way of managing the interfaces using BIM. Effective interface management was mentioned as being important to improve the efficiency of construction projects. The aim of ConBIM-IM is thereby an aim to improve the efficiency of construction projects. The ConBIM-IM system is however still in a developmental phase and is therefore for the moment only a concept.

**Scheduling visualised using BIM**
It is possible to extend the use of the BIM model towards the execution phase. This can be done by creating a 4D (a 3D visualisation of the process over time) visualisation of the schedule. To do this the schedule is attached to the BIM model. The created visualisation is an aid to show how a construction will be build. This visualisation can be used for contractors, subcontractors, and suppliers. It is also a communicative assist explaining the plans and schedules to the client (Sulankivi et al., 2010). The main goal of combining schedules and 3D models is to create a way of visualising a schedule and making it more insightful (Sampaio and Santos, 2011). 4D simulations of the schedule were used in the construction of the national stadium for the 2008 Beijing Olympics. The main goal of the 4D simulation was to improve the construction speed of the stadium. As a second aim the focus was to improve the constructability of the complex design of the building. The following benefits were found; graphic representation of the project, showing interdependencies of the building elements, and identify space-time conflicts. The 4D visualisation is mostly used in the planning phase to create a schedule that is executable and as efficient as possible. Using the 4D visualisation therefor leads to optimizations in the execution phase of a construction project (Zhang et al., 2008).

The BIM model can be extended beyond 4D by implementing cost, material usage, and personnel hours. Experiments with 5, 6, and 7D modelling have been executed. The 3D model is then appended with the cost, time and material content to create a accurate depiction of these resources in time (Kala et al., 2010).

Work packages are created using work breakdown structures. This is done to be able to link the BIM model and the schedule on a common property. The Work package value can be attached to the BIM model and to the schedule (Zhang and Hu, 2011b).

Scheduling and BIM can be combined. 4D models can be created to visualise the construction process. These visualisations can be used to aid communication of the

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\(^1\)Created and described in (Lin, 2015)
3.2. Innovations in feed forward

When the information is stored centrally all parties can access it. Not only letting the clients access status of the works of the contractor, but also aligning the information of the other parties within the project. All experts can therefor access the information and documents needed without losing information in the handovers. An important factor in this information centralisation is the structure of the meta-data. Meta-data aims to structure the accessibility of the information needed by appending identifiable characteristics. Without meta-data the information can be unstructured and it might be difficult to find the needed information. Attaching Work Packages to the BIM model can be seen as a way of attaching meta-data to the elements (Fallon and Palmer, 2007).

It is essential to attach identifiable ID numbers to the elements in the construction to feed forward the information through the construction process efficiently (Holness, 2007). However, creating IDs for all of the elements would be very laborious. Especially

3.2.3. Work Breakdown Structure and Work Packages

According to Koskela (2007), a not widely used technique in construction management is the Work Breakdown Structure (WBS). The technique has been used in other industries for longer but has scarcely been applied in the construction sector. WBS is used to define what should be done, by whom, when, and how much it will cost (Koskela, 2007). The WBS system is currently the most widely employed in order to structure tasks in the execution process. WBS is technique to create a functionality-based decomposition. Adequately using the WBS structure will improve the control for the stakeholders in a construction project (Chen et al., 2007). The WBS can be seen as a powerful project-structuring tool by means of which the performance can be controlled better. WBS makes it possible to identify and communicate the interfaces between the parties involved in the execution of a project. This is done by separating the total work in different work packages (WPs) which are related to each other to create the total construction (Chua and Godinot, 2006). The total project can be declustered into groups of building elements that are called work packages, splitting up the total workload and making the work more visible and controllable (Wang et al., 2004).

The creation of a WBS is a way of structuring a total project in a hierarchical fashion into unique assignable units (Ibrahim et al., 2009). Ibrahim (2007) states; “A fundamental requirement for effective project control is that the whole project is systematically decomposed into smaller, manageable units, creating a hierarchical structure generally referred to as the work breakdown structure.” Attempts have been made to automate the development of the structure. This has however proved to be very difficult because of the complexity and uniqueness of the large construction projects (Ibrahim et al., 2007).

So, in the information handover it is essential to document and label the information to make it possible to find the information needed. Work packages and work breakdown structures can be used to match BIM models and schedules. The following sub paragraph describes the way work packages can be used to improve the BIM model.

Matching Work Package and BIM Model

When the information is stored centrally all parties can access it. Not only letting the clients access status of the works of the contractor, but also aligning the information of the other parties within the project. All experts can therefor access the information and documents needed without losing information in the handovers. An important factor in this information centralisation is the structure of the meta-data. Meta-data aims to structure the accessibility of the information needed by appending identifiable characteristics. Without meta-data the information can be unstructured and it might be difficult to find the needed information. Attaching Work Packages to the BIM model can be seen as a way of attaching meta-data to the elements (Fallon and Palmer, 2007).

It is essential to attach identifiable ID numbers to the elements in the construction to feed forward the information through the construction process efficiently (Holness, 2007). However, creating IDs for all of the elements would be very laborious. Especially
because to match the BIM and the schedule efficiently the list of tasks would be enormous. Therefore, the method of creating work packages based on WBS is more feasible. Work packages are now used to plan the tasks, attaching these identification numbers to the BIM model would greatly improve the efficiency of the work. When attempting to match the schedule and the BIM model it is therefore important to attach the work package id to the elements. Deconstructing the jobs in work packages creates the possibilities to communicate the status of parts of the work (Integraph, 2012).

The literature overview presented in this sub-paragraph describes the importance and use of attaching WP values to a BIM model. The appending of the work packages to the elements makes it possible to search, find, and couple the building elements in the BIM model. When lots of data is present a system should be in place to categorise the information.

3.2.4. CONCLUSION OF INNOVATION IN FEED FORWARD
Research has been executed in improving the handover of information in construction projects. The supply chain analyses the way parties interact from suppliers to contractors. Furthermore, the supply chain management is focused on involving more knowledge earlier in the process. BIM is then mentioned as being an aid to the information handover by centralising information models. This prevents handover of information and thereby prevents loss of information from design towards execution of construction projects. Finally work breakdown is mentioned as a way of structuring the information and creating the possibilities of matching the BIM model and the schedule to each other.

3.3. INNOVATIONS IN FEEDBACK
Changes to the original schedule occur. Delays or changes of the design make it difficult to stick to the originally set plans. Communicating the changes to the original plan back to the field office to adjust for these changes is seen as the feedback of information. The aim of the construction sector is currently to remove inefficiencies and adjust for the before mentioned deviations to create an efficient construction process. Innovations to achieve this are occurring. Lean construction, status management of building elements and systems engineering are mentioned as innovations with the aim to improve the feedback of information in this paragraph.

3.3.1. LEAN CONSTRUCTION
In other industries, gains in performance have been realized using the so-called "Lean" way of working. Lean is not being applied widely in the construction sector at this moment. Lean is a methodology that aims to tackle problems concerning low productivity, poor safety, inferior working conditions, and insufficient quality. The main goal of Lean production is to avoid waste of time, money, and equipment (Alarcón, 1997). Lean encourages companies to work more efficiently by supporting external and internal collaboration. Furthermore an important focus point of Lean is to track and share data at the most granular level. This is necessary because improving the efficiency starts by focusing on the workers (Bernstein et al., 2013).

Interface management analyses the points of collision between different parties in a
3.3. Innovations in Feedback

The literature shows that the goal of Lean is to improve the efficiency of construction projects. This can be done by focusing on the interfaces of the parties within a project. But, the Lean methodology consists of many Lean practices. Last planner and Pull planning are two commonly used ways of planning projects in a Lean way (Bernstein et al., 2013). Plan-Do-Check-Acts is a feedback of information in a Lean way. The following sub paragraphs will discuss the application of Last planner, Pull Planning, and Plan-Do-Check-Act among other ways of improving the feedback of information in projects.

**Last Planner**

The Last Planner\(^2\) approach provides a way of feeding back information from the field to the office. This makes it possible to adjust the schedule for the next iteration. A schematic representation of the Last Planner system is presented in Figure 3.4. In the figure it can be seen that more and more detail is imputed in the schedule from the top down. In the most basic schedule the milestones are defined while the most accurate and detailed information is attached in the most bottom phases. The feedback of information is represented in this figure at the bottom in which the progress is tracked. This results in feedback and learning, which is to be implemented in the weekly work plans for the following week. Finally the loop is completed and the progress will be tracked and compared to the plans that were made for the progress (Smith, 2011).

The last planner systems functions best when the completion of individual tasks is measured on an operational level. The technique creates the possibilities to control and analyse the work flow of groups or individuals at a construction site (Mossman, 2013). This is mainly done using a look-ahead schedule that determines the progression and thereby the tasks to be executed. The look-ahead range ranges from two to six weeks (Paez et al., 2005). The Last Planner method assumes that progress is a variable and not a constant, therefore to be as efficient efficient as possible the schedule should be variable as well (Ballard, 2000).

\(^2\)http://www_Leanconstruction.org/
3. THEORETICAL BACKGROUND

Last planner is a Lean scheduling technique that aims to introduce the monitoring and adjusting cycle in the scheduling procedure. The Last planner is a promising technique in the improvement of the efficiency of construction projects.

PULL PLANNING

Traditionally scheduling pushed from start to finish but pull planning is a scheduling technique that starts at the finish. The finishing tasks are planned first. Then the tasks are scheduled that will precede the finishing tasks. This is then done until the starting tasks are scheduled. Working back from the finish makes sure the waiting times are reduced. In this way the efficiency is enhanced (Bernstein et al., 2013). The Last Planner aids the pulling of schedules. Pull scheduling has in literature also been called pull panning, collaborative planning, and sticky-note planning (Mossman, 2013). In the pull planning, the following phases are encountered:

1. Define work phases
2. Define important milestones
3. Create sticky note planning
4. Apply durations to activities
5. Re-examine logic to shorten duration
6. Determine the earliest practical date
7. Decide buffers
8. If necessary re-plan (UHS, nd)

The planning is then communicated to the job-site office and there the “sticky note planning” is created. All parties involved plan their own tasks in this look forward planning. Daily meetings are organised to discuss the progress at the job site and to adjust for the deviations that are encountered. These meetings are called ‘daily stand’ meetings. The parties that are involved in the process discuss their progress on the planned tasks in these meetings. The adjustments to the schedule are done by moving the sticky
notes. When jobs are completed the notes can be taken off the wall. By doing this the schedule represents the status of the physical activities in the field. Monitoring of the progress is essential to the pull scheduling technique because it is accepted that variations to the original schedule occur if the deviations are communicated. When these variations or deviations are monitored the schedules are updated and commitments are renewed. This is called as re-planning (UHS, nd; Tiwari and Sarathy, 2012).

In literature, pull planning has been described as being a hands-on way to planning which involves the workers that operate on the construction site. At this moment Pull planning is focused on planning and re-planning using post-its. The technique needs to be improved to deal with re-planning linked tasks. Furthermore the schedule is immovable and hard to communicate.

**Plan Do Check Act**

The Plan-Do-Check-Act (PDCA) model has been created by Deming in 1951. This means that it is older than Lean. However the technique covers lots of Lean ideas and has been adopted to the Lean methodology. The PDCA model refers to a cycle in which tasks are checked (Bhutta and Huq, 1999). The steps of the cycle are depicted in Figure 3.5;

![Deming Cycle](image)

1. **Plan** - Study the current situation and develop solutions for development
2. **Do** - Take measures on a trail basis
3. **Check** - Investigate the effect of changes
4. **Act** - Start standardizing on a permanent basis
5. **= 1 Re-Plan** (Moen and Norman, 2006)

The Plan-Do-Check-Act model is essential in the construction industry because the information in the field can be communicated back to the office by means of controllers. The tasks are planned, the task is executed, the monitoring verifies in the check whether the task has been executed as it should. Then if everything has occurred as planned no changes need to be made. However, re-planning will be necessary when deviations have
been monitored in the check phase. The PDCA method has been used extensively in the automotive industry but is not extensively applied to the construction sector in the same way (Meiling et al., 2014). In construction sites the cycle can be explained as being; plan the work, do the work, check if the work is executed as planned, act when deviations from the plan are found, and re-plan according to the deviations (Bhutta and Huq, 1999).

The cycle of Deming explains the importance of the feedback of information. When observations are made deviations to the original plan can be made if necessary. The Plan-Do-Check-Act method is involved in the Last planner feedback cycle.

3.3.2. Status of Building Elements

Knowing the status of the building elements improves the possibilities of enhancing the efficiency of the construction process. In construction there is a general need for visual tools because of the ever complexer degree of the design (Sacks et al., 2009). An example of software matching the 3D appearance of the construction elements and the status of the elements is the CONstant Work in Process\(^3\) (CONWIP) control system. This CONWIP system is created to visualise the model accurately. Visualisations can be used to create a completer picture. Furthermore, this makes it possible to understand situations better. The CONWIP software takes the drawings or models created of the building and attached three possible statuses to all building elements. All elements are either not under construction, under construction, delayed, or finished. The model aims to make status tracking visible (Sacks et al., 2009).

Knowing the status of the building elements is seen as an improvement to the efficiency of the project. However, little research has been executed in monitoring the status of the elements. CONWIP is one of the only known software tools monitor the status of building elements. The CONWIP software is however not used construction projects at this moment.

3.3.3. Systems Engineering

Systems Engineering is another of the large innovations in the construction sector. Systems Engineering deals with client’s demands, design considerations, and decisions in the construction process. Systems Engineering aims to reduce and prevent communication problems by saving information. The attempt is made to reduce communication by saving the information centrally. The main aim of systems engineering is to provide clear communication between contractor and client (Rijkswaterstaat, 2016). A commonly used model for implementing systems engineering is the V-diagram. In essence the V-diagram focuses on the relation between the left and right side of the diagram in order to deal with risk and complexity of projects and to compare demands of the client to the product produced by the contractor. A depiction of this diagram is visible in Figure 3.6.

\(^3\) (Spearman et al., 1990)
3.4. Research in combination of innovations

Innovations can be implemented in both the feedback and feed forward of information to increase the efficiency of construction projects. Creating a system of innovations to integrate multiple innovations is advisable. Implementing innovations separately
has been proven to be less efficient. It has been found that innovation management is needed to combine innovations smoothly. The implementation of one innovation can often hinder the effective implementation of another innovation (Miozzo and Dewick, 2002). When implementing innovations in the construction sector it is advisable to create a system of iterative steps. The construction sector is traditional. When multiple large innovations are implemented the chances of success are small. When the combination of the innovations is made this could built upon the innovations that are being implemented. Changing too much will possibly lead to failure of adoption (Slaughter, 2000). The step will likely be too big and people tend to reject the innovation when every party needs to move to a new software package. The goal is to keep as much people as possible to use the software they are used to (Harty, 2008). For this research the focus is on combining BIM and Lean as the innovations in respectively feed forward and feedback of information.

BIM and Lean are not dependent on each other. However, it has been hypothesised that synthesis can be achieved when both BIM and Lean are executed on the same project. This is because of the close interrelations of Lean and BIM. Any project considering implementing BIM could also consider that BIM is implemented to make a project more efficient and eliminate wastes. These same goals apply to Lean. BIM and Lean have in the past been proven to complement each other. However in this research the methodologies were applied in different phases of the process. The BIM model was focused on in the preparation phases and the Lean methodology was focused on in the execution phase (Sacks et al., 2010).

Sacks (2009) researched the possibilities of using visualisations as an aid for a Lean construction processes. This was done by translating the traditional bar style schedule into a four-dimensional schedule. The result of this research was the CONWIP application which was discussed earlier (Sacks et al., 2009).

Parties work together to create a complex structure in large construction projects. The cooperation between these parties leads to the collaborative execution of design, planning, and execution. A few software tools arise when the collaborative approach to planning and the collaborative design in BIM software are combined. One of these is VisiLean⁴. The VisiLean tool aims to integrate the master planning as created in Primavera P6 (a software package in which planning can be executed collaboratively), and the BIM model as created in for instance Bentley MX Road for different parties into one central model. This creates the possibility to plan collaboratively in a BIM model (Atkins, 2013) (Dave et al., 2011). VisiLean is a software package which aims to visualise plans in a 4D Lean way. The pull schedule can be presented traditionally using bar charts and using a 4D visualisation. Both the bar chart as well as the 4D visualisation can represent the schedule of the construction process. The tool was applied to a case study in 2012 in London. It was experienced to be potentially useful however the software turned out to be unstable when sub-contractors are involved. Furthermore the software is reliable on using the specific input software packages (Dave et al., 2013). The remark should be made that Lean is in the VisiLean simplified to pull scheduling alone. Other software packages that are able to attach time to BIM models are present however scheduling Lean is not supported in these packages. Hardin (2009) mentioned the possibilities

⁴http://visiLean.com/
of Navisworks to visualise 4D planning using BIM models (Hardin and McCool, 2015). However, this only includes adding time to a 3D model and encounters problems when Lean is applied more extensively.

In the analysis of the combination of the innovations it was found that lots of possibilities of combining innovations have been researched. However combining Lean and BIM to improve the feed forward and feedback of information in construction projects has only been examined using VisiLean. VisiLean however only consists of combining pull planning and the BIM model. Furthermore the software limits itself to specific software packages. It is thereby in the basics sufficient for the rest of the research. However, the software is not complete to improve the feed forward and feedback as desired. To solve this the next chapter illustrates a basic framework for improving the efficiency of the construction sector.

3.5. CREATION OF INITIAL FRAMEWORK

Many promising innovations are emerging in the construction sector. Lean, BIM, Interface management, supply chain management, systems engineering and more. All of which aim at achieving increased efficiency in projects. However, in order to improve information flow through construction projects combinations of these should be made. However these are not occurring much. When BIM and Lean are chosen to be the most promising innovations. These are therefore combined to improve the efficiency of information handover within construction projects. A new framework to combine BIM and Lean is created because no complete combination is currently present.

The initial framework to improve the feed forward and feedback of information should implement more than just BIM and pull scheduling. The Last planner system is the bases for this framework because it represents the basis of the innovations in feedback of information. It is enriched with BIM and Plan-Do-Check-Act to create the basic framework. This framework is presented in Figure 3.7.

The steps represented in the figure are;

• **1a. Complete Design** - The creation of the design in a 3D BIM software package with the WBS attached for matching later.

• **1b. Schedule** - The schedule is created to plan the way the construction will be built. This not only schedules the construction of the work packages but also defines the supply chain the elements follow.

• **2. Coupling of design and schedule by work break down level** - When the Design and the Schedule are imported in the 4D software these can me linked on the basis of the work package and work breakdown identification numbers.

• **3. 4D status visualisation** - The created coupling of step 2 should represent the actual status of the construction site. This also means that if deviations are observed these should be changed in the schedule as well so the 4D status visualisation is accurate.
4. **Lean meeting** - Assisted by the 4D visualisation this meeting discusses the progress and look-forward. Deviations that are found and identified in the visualisation are discussed. Changes to the schedule resulting from these deviations aim to prevent problems during the execution.

5. **Site monitoring** - When changes in the field occur these should be monitored. The monitoring will be done by changing the schedule as created in 1b to represent the actual status of the elements.

This framework needs to be checked for usefulness using case studies. Also the possibilities of the interactions between the software packages should be checked. This is done in the next chapters.
The chapter aims to answer the second sub-question as presented in chapter 2.

“How is the flow of information in current construction projects organised?”

The focus is on evaluating the use of Building information modeling (BIM), Lean, feed forward and feedback of information. A framework of using these together was presented in chapter 3. The case study aims to analyse how the techniques are used at the moment. The case study analyses two projects in which the same three parties are working together to create the result. The parties that are involved in the projects are described in the first paragraph of the chapter. The second paragraph describes why the cases were selected. After which the third paragraph describes the result of the case study at the Hotel Amstelkwartier (HAK) project. The fourth paragraph describes the Holland Particle Therapy Centre (HPTC) case. The last paragraph presents the conclusions resulting from the case studies.

4.1. INVOLVED CONSTRUCTION PARTIES

In the selection of the cases the decision was made to analyse projects that are undertaken in an integral fashion. At JP van Eesteren integral projects are seen as projects undertaken by companies that all belong to the TBI holding. In the selected cases JP van Eesteren is the contractor, Croon is the party responsible for the electrical installations, and Wolter & Dros\(^1\) is responsible for the mechanical installations. The projects are undertaken in an integral fashion to improve the coordination of design, procurement and execution between the contracting partners. Integral projects were chosen as cases because it is more easily to access multiple companies within the same projects.

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\(^1\) It should be noted that during the research a merge between Croon and Wolter & Dros was executed. However the companies started separate and the characteristics of the newly constructed CroonWolter&Dros still consist of disjointedly operating departments. Therefore it is decided to keep the two parties separated in the report.
and thereby creates the possibility to examine the cases from multiple angles. Furthermore improving the interactions between these companies will affect projects in the future because the parties work together often. Improvements for these cases will thereby be more durable.

**JP van Eesteren (JvE)** The first party that is involved in both cases is JP van Eesteren. JP van Eesteren is a construction company that has been operating in the utilitarian sector since 1932. It has undertaken large iconic construction projects in the Netherlands such as the Stadium 'De Kuip' in Rotterdam in 1937. More recently the redevelopment of the 'Rijksmuseum' in Amsterdam was undertaken as well as the construction of the 'Markthal' in Rotterdam. Furthermore, JP van Eesteren is part of TBI. Currently JP van Eesteren employs about 500 people and is one of the larger contractors in the utilitarian sector in the Netherlands.

**Croon (Cr)** Since 1876, Croon has been a company focused on the execution of electrical engineering and electrical installations. In the current construction industry Croon focuses on industry, non-residential, marine & offshore, and infrastructure projects. Croon is also part of the TBI aegis and this makes the companies closely connected. About 2000 people were employed at Croon in 2007 and well-known projects executed by Croon are the outfitting of ships of the Royal Dutch Navy, and maintenance of the marine vessel, the Karel Doorman. In the construction sector Croon was recently involved in the construction of the electrical installations of the “Rotterdam CS” project and “Sluiskil tunnel” project.

**Wolter & Dros (W&D)** is a mechanical installer focusing on the utility, health care, industry, infrastructure, and housing industries. Wolter & Dros aim to make constructions comfortable, healthy, and safe. The company was founded in 1875. Currently Wolter & Dros employs 1500 workers and is spread throughout the Netherlands. Wolter & Dros is also part of TBI and executes the mechanical installations in projects such as the ‘Paleis van Justitie’ in Amsterdam and the “Tweede Coentunnel”.

### 4.2. Case Study Selection

The main purpose of doing a case study is that it allows the investigator to grasp a holistic and meaningful picture of the characteristics of a real-life event (Yin, 2003). Different kinds of case studies are available. All of these have different purposes. Control of behavioural events was in this research not demanded. The focus of the research was on contemporary events. Therefore it was decided to execute two case studies on projects executed by JP van Eesteren. To increase the unbiasedness of the research it was chosen to select cases in which it was possible to analyse the project from multiple angles. Therefore, integral projects were selected. Finally, active cases were selected to create the possibility of interviews as well as observations. This led to the HPTC case, in Delft, and the HAK case in Amsterdam. The cases have a basis in executing works in a Lean fashion, and work with BIM. Two cases are seen as being sufficient because of the extensive possibilities of interviews at these projects. Furthermore the results of the case studies will be compared to the existing literature to create a validated reflection on the initial framework.
4.3. Hotel Amstel Kwartier

The first case that is analysed during the case study is the construction of Hotel Amstelkwartier. The study at the construction project was done by means of a site visit, five interviews, and attendance at a Lean meeting. The Hotel Amstelkwartier project (HAK) is situated in Amsterdam. HAK is a hotel that is designed with a height of 70 meters and is situated close to the centre of Amsterdam. The client has set the precondition that the environmental performance meets the LEED (Leadership in Energy and Environmental Design) platinum certification. This is a certification for the environmental performance of the construction, maintenance, and the operation of the building. The initial aim was to deliver the project in March 2016. However this deadline has been moved because of problems in the structural complexity and because the client has not approved the design of the interior and installations. An artist impression of the construction is presented in figure 4.1. The project is complex because it needs to achieve the environmental requirements, the design is innovative, the location is in the centre of Amsterdam and is difficult to reach, and the construction site is small.

The project started in 2011. In this year the selection process of the contracting parties started. The project is separated in two parts in the tender phase. One part is the construction of the hotel. The other is the interior and installations part of the hotel. The tender of the construction was won by JP van Eesteren; the tender of the installations was won by the cooperation of Wolter & Dros and Croon. It was decided to execute the project in an integrated manner after some discussion with the client and coordination of TBI.
4.3.1. **HAK Project Execution**

Croon, Wolter & Dros, and JP van Eesteren operate as one party in this project. This means that agreements are made about the distributions of funds, risks, gains, and responsibilities. The project has gone through the following phases;

- **Design** the design is executed in BIM using ArchiCAD. This was done to solve problems concerning the interfaces between the construction and the installations. This makes that the installations and constructions fit perfectly. Thereby problems in the execution phase are reduced.

- **Plan** as the design process starts, the scheduling process is also created. The planning phase consists mainly of calculating the costs of the project and creating the schedule. Special attention is given in this phase to the logistics of the construction site because the site and surroundings have limitations in supply and storage.

- **Execution**, is the most distinguishable step in the construction process of the Hotel. This is the part where the building arises.

- **Control**, because the client set demands on the environmental performance and other performance indicators. These will be checked by an independent party before the building is delivered to the client.

- **Adjust**. Some adjustments might have to be done if the set of demands deviates from the executed works.

- **Delivery** The building is handed over to the client if the client and contractor both agree that the Hotel meets the requirements and demands.

These are basic steps of any construction project. The execution of the hotel is undertaken in a Lean manner. The basic schedule for this project is created in the planning phase. This schedule consists of a list of deadlines. The detail planning is created in the field using a six-week look ahead scheduling. This detail schedule is created by the subcontractors that have certain tasks to be executed in the following six weeks themselves. The project leaders plan the tasks using sticky notes on the "Lean wall". This schedule is updated daily in the ‘daily stand meeting’. The statuses of the tasks and construction elements of each of the parties are discussed with the subcontractors. Adjustments are then made to the six-week look-ahead schedule. Lots of knowledge is present at the project leaders, who have a overview of what is going on in the field. However this knowledge is mostly discussed, instead of monitored in central information models available to all in the project.

The project now nears the finishing of the structural work. Almost all prefabricated facades are mounted. Furthermore, the mechanical and electrical installations are largely in place. The metal stud of about half the floors is constructed. The fit-in package has at this point not been approved so this is not started yet because of communication problems with the client.
4.3.2. **BIM at HAK**

The BIM process in the HAK project was organised to improve the efficiency of the production process. Part of the reason was that many elements of the construction were prefabricated. The architect was Mulderblauw. They designed the architectural and structural models in ArchiCAD (BIM software produced by Graphisoft\(^2\)). This is not as planned because it was expected that the constructor would design their part in BIM as well. However this was converted by the architect to create one model. The BIM model was created in detail so the prefabrication party could use the models as a basis for their design. The prefabrication works were executed by Snijders. The prefabricated elements were also designed in BIM. These parts were designed with all holes for piping and mounting points already in place. The models were the basis for coordination between Croon and Wolter & Dros. The detail of the models were on the production detail level. This means that the design was sufficiently detailed to be able to export the execution drawings for the prefabricated casings directly. The same is done for the metal stud walls. These were designed in Revit by Kwakman. The details of these models were also at production level. The openings in the walls were tightly aligned with the planned pipes and ducts of Wolter & Dros and Croon. The result of this was that packages were created in the factory. These packages include pre cut drywall and metal stud specifically designed for each floor level of the building. The packages were then transported to the construction site. Here the packages could directly be moved to the right floor. Once there the packages could be assembled directly. A view of the created BIM model which was used to tune the designs is presented in figure 4.2.

![Figure 4.2: Hotel AmstelKwartier IFC model](http://archicad.com/en/)

It was decided to coordinate the interfaces between the subcontractors using BIM. The sizes, mounting points, and layouts of the piping and ducts were coordinated in BIM models using the BIM models created in Revit and ArchiCAD. BIM was not used in the field. 2D drawings were created when models were completely aligned to each other. These drawings were then used in the field instead of the BIM models.

4.3.3. **HAK Feed Forward of Information**

The design is executed in BIM to carry forward as much information as possible. The BIM models stay accessible throughout the construction project. The aim has always

\(^2\)http://archicad.com/en/
been to integrate all the models from the constructors, electrical installers, and the mechanical installers in order to adjust the different sub models optimally to each other. However, lots of information was lost in the translation of the BIM model to 2D drawings. The 3D drawings were not seen as being definitive because of the traditional character of the execution department. A definitive status to the design of building elements is attached to elements when a 2D drawing is exported from this central model. The structure of the packages of building elements that is used in the HAK project resembles a system of work packages. The total construction is split into packages. For instance, the interior walls of the first floor. The package was then delivered in accordance with their work package number in the schedule.

4.3.4. HAK FEEDBACK OF INFORMATION

The feedback of information is done using the Lean meetings. The total list of tasks for the coming days is handed around in the meeting and the status of the elements is then discussed. Rescheduling of the sticky notes on the wall occurs when deviations to the original schedule are found. There is lots of talk during the meeting to see what the effect of a deviation is. However the BIM model is unfortunately not used. A strict logistical schedule is present because there is little space at the construction site. This schedule is updated weekly by checking what is delivered and what therefore should be delivered the next week. This is in term communicated to the suppliers.

4.4. HOLLAND PARTICLE THERAPY CENTRE

The Holland Particle Therapy Centre (HPTC) is the second project that was analysed for the purposes of the case study. The case study was carried out by means of a site visit, four interviews, and attendance at a Lean meeting. To realize the first cancer treatment centre using proton beam therapy in the Netherlands the medical centres of "Erasmus Medisch Centrum" and "Leids Universitair Medisch Centrum" have joined with the "Technical University Delft". Proton beam therapy is a way of treating cancer that can only be executed in a special proton centre. The new clinic will be built in Delft next to the Reactor Institute. A render of the project is presented in figure 4.3.

The design and construction of the proton clinic is complicated by; the amount of interfaces between the construction, the complex mechanical installations, and electrical installations. In addition, the requirements to the installations and concrete works that are made by Varian (supplier of proton equipment) make the project complex. It was decided to handle the project using an integral team to ensure that the interfaces between the disciplines will be as smooth as possible.

The project can be divided in two parts, the bunker and the courant. The bunker is the part of the construction in which the proton generators and the treatment rooms are situated. The courant is the part of the building that holds laboratories.

4.4.1. HPTC PROJECT EXECUTION

The project is executed in a similar way as any complex construction project. However, a large difference is a half way deadline. This was dictated by the large subcontractor Varian. This was the supplier and installer of the cyclotron (proton generator) and
the gantries (radiation equipment). Large fines are issued if the deadlines are not met because of the importance of this subcontractor. This deadline is called the Ready for Equipment, or RFE.

- **Design**, the Design was executed in Revit and was the result of the translation of the list of demands produced by the clients.

- **Plan**, the planning and preparatory phases of the execution of the project consisted of the creation of a detailed schedule and more detailed calculations of the costs of the construction.

- **Execution exterior**, the first phase, in the execution of the HPTC building is the construction of the exterior. This consists of the foundations, bunker, part of the courant, and parts of the ceilings.

- **Control RFE**, at the RFE control, Varian comes to the site to control the state of the list of demands for the RFE deadline.

- **Adjust**, in this phase, the result of the control phase is handled. If any demands are not met, these have to be adjusted.

- **RFE**, as mentioned the Ready for Equipment is the moment Varian joins the construction. From the start of the RFE, the cyclotron, gantries, and more specific installations are installed by Varian.

- **Execution finishing**, the finishing of the construction is executed after the largest parts of the installations are lifted in the building. This means that the floors, roofs, walls, windows etc. are placed.
Execution installations, Croon and Wolter&Dros have been involved throughout the process. Having the ducts in the walls the right way is important to them. However, the actual installing of the installations can only start after the building is watertight.

Testing, extensive testing will be executed before delivery of the medical centre to the client to make sure that the demands of the client are met in the result.

Delivery, finally the medical centre will be delivered to the client and the project can be seen as being completed from the viewpoint of the contractors.

When the execution is analysed in more detail it is found that the execution of the HPTC building is undertaken in a Lean manner as well. To ensure the optimal cooperation among the involved parties. To do this the main schedule is made in the preparatory phase, which sets the deadline for activities to be completed. The work for the parties involved is planned out using a six weeks look-ahead schedule and by means of sticky notes. As in the HAK project, the daily stand meetings discuss the status of the planned tasks. The design is executed in BIM. The different disciplines used the BIM model as a basis for coordination.

Currently the project is about 5 weeks behind schedule, which is caused by problems in the concrete works. This delay has to be made up in other tasks to ensure the RFE deadline is met. In order to speed up the rest of the process extra personnel is hired and the technical rooms are preassembled at another location.

4.4.2. BIM AT THE HPTC PROJECT

The focus of the use of BIM at the HPTC project was mainly at the harmonization of the installations to be cast in the walls of the bunker. There is a large amount of cables, pipes, and ducts that need to be cast in the walls that need to meet the demands set by Varian. It has been found that efficient coordination of the design and execution of the three parties could only be achieved by using BIM models. The models of the HPTC bunker section were taken to the field by the use of BIM360Field. This is a software package created to get insight in the BIM models on iPads when the workers are in the field. Apart from the Bunker the rest of the building was executed relatively traditionally. A depiction of the IFC model is presented in figure 4.4.

Figure 4.4: Holland PTC IFC
4.4.3. HPTC FEED FORWARD OF INFORMATION

It is seen that the use of BIM is essential in this process when the feed forward of information is analysed. The design is executed in BIM, which is converted to 2D drawings for most of the design. This is done because the workers at the job site are more used to working with 2D drawings than with 3D visualisations. However, in this project BIM is used in the field for the first time for many workers. The BIM model is uploaded on iPads and can be consulted when technically complex elements of the design are analysed in the field.

Another example of the feed forward of information in the HPTC project is the feed forward of the schedule. The schedule created in the plan phase then it is transplanted to the execution phase by means of deadlines. The schedule in the plan phase is setup in a broad way. When the detail schedule of the six-week look ahead schedule is created, the deadlines of the plan phase are drawn out first.

As in the HAK project, the work breakdown structure (WBS) is applied here. However the WBS is focused at the procurement department. Payments are made when the contents of a work package are delivered. For the execution phase the WBS is not extensively used.

4.4.4. HPTC FEEDBACK OF INFORMATION

The project managers at the HPTC project mention that it is important that there is a feedback of information in the project. The project is therefore executed in a Lean manner. This means that the planning is executed in the Lean room as explained before. The deviations in the field are discussed in the Lean meeting on a daily basis. An example of feedback of information in the project is the pouring of concrete. Because of unexpected problems with the pouring of parts of the concrete floors a delay occurred. However to limit the effects of the delay on the deadlines rescheduling of the other tasks took place to speed up the rest of the process. The changes from the original schedule are observed and translated to the meetings by updating the sticky note schedule by hand and by mentioning the deviation in the daily stand meetings. The effects of the deviations are then extensively discussed with the attendees. It should be noted that in the Lean meeting it is not always possible to have a representative of all subcontractors present. It is important to have as many representatives of the subcontractors as possible present at the meetings because they are the ones that possess the knowledge about the status of the building elements and the delays. To get the status of building elements and tasks that are not present at the construction site project managers have to compare bills of procurement with the drawings and bills of procurement with tickets of delivery. These statuses are not easily accessible for a project manager although it is mentioned that the availability of this knowledge is desired for better adjustment of the schedules in the Lean meetings. The availability of this information is an improvement desired and demanded by the project leaders for next complex projects.

4.5. CASE STUDY CONCLUSION

The feed forward and feedback of information in construction projects were analysed in the case studies. It was observed that in the literature a more optimal scenario was
encountered than in a real world scenario. Firstly, the BIM or 3D model is apparently not accepted in all projects as being a final version of the design. Changing this is essential to optimize the feed forward and reduce the loss of information due to handovers. In the feedback of information automation would make it possible to oversee more tasks and statuses. In addition, more different status types could and should be appended so more information can be present in the daily stand meetings. Combining the feed forward and the feedback loop together is essential for the flow of information in the project. This means that the elements from the BIM model should be coupled with the tasks in the schedule. The observation was made in both projects that introduction of innovations was applied. But these innovations were not combined. Either BIM or Lean is focused on in the phases of the projects.
SOFTWARE COMPARISON

This chapter is created in-between the case study chapter (ch. 4) and the framework creation chapter (ch. 6) because it combines the knowledge of the used software packages at JP van Eesteren with the possible alternatives. Comparing the possible software packages is done to decide which packages should be used in the creation of the framework. The chapter therefore is not related to a specific research question but bridges the gap between the case study and framework creation focused on the software. To do this, this chapter lists different software packages and then explains why these have or have not been selected for the rest of the research. An overview of the actual hardware and software that were used in the research is presented in Appendix B.

5.1. DESIGN/MODELING SOFTWARE

Constructors and architects can decide to use Building information modeling (BIM) software specialised for Design and modeling for design complex projects. The two largest software packages that are used in the field of Design and Modeling are ArchiCAD and Revit. Both software packages have advantages and disadvantages, which are stated below.

5.1.1. ARCHICAD

The ArchiCAD software is mainly used by architects that use the OSX operating system and is said to have a more user-friendly interface. Furthermore, the software works more efficiently with multi-threaded processors. But ArchiCAD is not made by the Autodesk\(^1\) software designer. This means that the interactions with the other Autodesk software packages are less smooth. ArchiCAD was the first BIM software and was created in 1984 (Quirck, 2016).

\(^1\)http://www.autodesk.com/
5.1.2. Revit
Revit was created in 2000 to deal with constructions that are more complex. The Revit software was written in C++, which means that it was possible to program based on objects. Revit is nowadays owned by Autodesk. This has made it possible to have close interrelations with other software packages produced by Autodesk. Revit has plug ins with BIM360Field, Glue, Navisworks, Infraworks and more (Quirck, 2016). The preference would be to use this package because Revit is used at JP van Eesteren.

5.1.3. Consideration
Because the sub-designs that make up the total are often created with other software packages when they are subcontracted. The BIM software packages have created a harmonisation file type between the software packages. The file-type is commonly referred to as IFC-format. This format aims to facilitate communication between the different BIM software packages. IFC thereby facilitates the use of different software packages by different contractors. Therefore, it does not matter if Revit or ArchiCAD is used in the process.

5.2. Fabrication Software
As well as in the design or modelling software lots of packages are available in the fabrication software. Fabrication software is focused on the work packages that will be executed by subcontractors such as installers. In the end, the Design and the Fabrication software combined create a full design of the construction. All for different purposes and all have different advantages and disadvantages. Two of the fabrication packages are Tekla and Inventor.

5.2.1. Tekla
Tekla is a tool for the design of construction elements. It is used in the modelling of stadiums, offshore structures, plants, factories, and more. Tekla is mainly used for the modelling of the steel sub-frames of the constructions. The benefits of using Tekla are that materials can be modelled, it can handle very complex structures, is able to create executable models, and lets information flow from design to the construction site. Apart from that, it is possible to export the model in the IFC file type. This makes the model better linkable to models constructed in other software packages (Tekla, 2016).

5.2.2. Inventor
Inventor is another software package created by Autodesk. The software is aimed at the design of the mechanical installations. The software is not only able to model the design of elements of mechanical installations but it is also able to evaluate stress within the materials and more. The software is able to export to IFC making it possible to integrate with the other BIM software packages.

5.2.3. Comparison
For the purpose of this research the choice was made to not focus on one specific software package to create the design or fabrication models. This was done because of the
There is a large amount of possible software packages. It is important that the chosen software packages are able to export the model as IFC to be able to merge all designs in one single model.

5.3. **SCHEDULING**

There are three software packages that are commonly used for scheduling construction projects. All of which have input possibilities in the integrated 4D models.

5.3.1. **Primavera P6**

![Screenshot of Primavera P6](image)

Figure 5.1: Schedule using Primavera P6 (TenSIX, 2015).

The Primavera P6 scheduling software was created by Oracle. The software is not only capable of scheduling tasks but also makes it possible to schedule with more people in the same schedule at once. Furthermore, the software has the possibility to input cost estimation, execute resource management, and keep track of the current standings of a project. Finally, a work breakdown structure (WBS) created in the Excel can be imported in the schedule. A screen-shot of the software is visible in Figure 5.1.

5.3.2. **Asta Power Project**

The Asta scheduling software is created by Elecosoft. The software works quite alike the Primavera software apart from some minor differences. Figure 5.2 presents a screenshot of a schedule in the Asta Power Project software. At JP van Eesteren Asta Power Project is used; using this software is preferred in this project. However, this software program is at JP van Eesteren installed on a virtual desktop, which poses some problems when interchanging information between the planning and 4D modelling software.

5.3.3. **Microsoft Project**

Microsoft Project is a more simplified scheduling software. The software package does not support all of the characteristics that are available in Primavera and Asta but does support the basic characteristics needed to schedule projects. The Microsoft Project software is easily linked with both Navisworks and Synchro. A screen shot of the Microsoft Project is presented in Figure 5.3.
5.3.4. **Comparison**

Asta Power Project and Primavera are packages that offer broader possibilities with regard to auto-scheduling and cost estimation. However, Microsoft Project is easier to get and use. In the research, it was discovered that the scheduling software and the 4D visualising software needed to be installed on the same disk. The decision was made to use Microsoft Project because of difficulties installing Asta Power Project locally and because Primavera is not used at JP van Eesteren. All the scheduling software packages had the same linking possibilities in the 4D software, therefore Microsoft Project can easily be switched with either Primavera, or Asta in other projects.

5.4. **Integrated 4D Model**

Some software packages can be used to integrating the scheduling with the BIM model. In literature lots of research has been found on the VisiLean Package (Sacks et al., 2010).
However, Navisworks, as produced by Autodesk and Synchro pro are also available.

5.4.1. VisiLean

![VisiLean software](image)

VisiLean is a software package that has been emerging to combine the Lean methodology with BIM. The software has been elaborately described and referred to in literature by Koskela, Sacks, and Dave (Sacks et al., 2010; Dave et al., 2011; Atkins, 2013). However, after some inquiry the software turned out to be hard to obtain and in an early phase of implementation. A representation of the software is presented in Figure 5.4.

5.4.2. Navisworks

![Navisworks software](image)

The Navisworks software is a widely known and is a part of the software packages produced by Autodesk. The Navisworks software has very well integrated functions with other Autodesk software such as Revit and AutoCAD. There are two types of Navisworks, Navisworks Manage, and Navisworks Simulate. Simulate is focused on reviewing of the model. The software can be downloaded and can be used to review and communicate the project through 4 or 5D analysis and simulation (5D links time and costs to a 3D...
model). The Manage part of the software is able to run clash control and clash detection of construction elements, import a wide range of models, input 4D and 5D schedules, create photo-realistic renderings, and much more. However, the scheduling part of the Navisworks software is not extensive. For instance, the logic links between the tasks in the time-liner are lost and rescheduling the time-liner is not possible. The software is useful to create 4D visualisation of the building process. And the Navisworks software is useful for a wide range of other tasks. However it is less able to deal with schedules that are more complicated. A screenshot of the software is presented in Figure 5.5.

5.4.3. Synchro Pro

The Synchro software is an 4D software package that is specifically designed to integrate scheduling software and a BIM model. The software imports Revit files or IFC files, which can be synchronised when the design changes. The schedule can be imported from Asta, MS Project and from Primavera P6. The schedule can also be synchronised if the scheduling changes. Furthermore, the software has the ability to change the IFC file. This means that parameters can be added, removed, or changed. Figure 5.6 presents a screenshot of the Synchro Pro software.

5.4.4. Comparison

It has been found that VisiLean was not suited for the purposes in this research. VisiLean was not performing as steadily as the others were and was hard to obtain. When deciding between Navisworks and Synchro, Synchro was chosen because of the more extensive scheduling options and the possibilities to modifying the IFC file.

5.5. BIM in the field

The advantage of BIM is that lots of information is kept centrally. Laptops and desktops were traditionally required to access the centralised information. However, software packages for tablets are nowadays created to bring the developments of the BIM methodology to the work sites. In total about 30 apps are created to do this(Magazine, 2014). However, only the apps created by Autodesk and Synchro are analysed. This is done because these apps are the best adapted to work with their larger companions.
The applications that were analysed are BIM360, and Synchro Live.

5.5.1. BIM360
The BIM360 apps are separated into BIM360Field and BIM360Glue. Field is the app that is aimed toward the execution phase, while Glue is more aimed towards the planning phase. The main aim of the BIM360Field is to replace the paper on the construction site with iPads. It is possible to make observations, access the models, create pictures with an iPad using the Field application in the field. The application allows pictures and remarks to be directly uploaded into the cloud. Real time performance tracking is also possible within this app. It is however not possible to adjust the schedule in the field or monitor the status of the building elements. The application works closely with other Autodesk software packages such as Revit and Navisworks (Calkins and Hennigh, 2013).

5.5.2. Synchro Live
The Synchro Pro Mobile application is closely related to the Desktop software package of Synchro Pro. The application is iPad based and makes it possible to access the planning and the models that are present in the cloud. The model is generated in Synchro pro on a laptop or desktop and it is possible to access the models in the field. Details in the design can be reviewed, remarks can be made, tracking of tasks is possible and more. The problem with the software is that the software is not able to change the schedule as it was created in the software. This makes the app more a viewer than a possibility to adjust the source files and models (Demchak and Gray, 2015).

5.5.3. Comparison
There are many possibilities in ‘mobile applications’. There are some main features missing in BIM360 and Synchro live. For the applications to be more useful BIM360 and/or Synchro Live should create the options to adjust statuses or schedules. Therefore, it was decided to keep field applications out of the research for the time being. It is essential to involve field applications at some time in the future but the applications need to have more functions.
The improvement and the elaboration of the basic framework (created in chapter 3) is presented in this paragraph. The basic framework was improved using the knowledge gained during the case study. The improvements and elaboration of the basic framework were done to improve the feed forward and feedback of information during construction projects. The chapter first explains what changes in the feed forward in the framework in paragraph 6.1, and then what changes in the feedback of information in paragraph 6.2. Then paragraph 6.3 explains the way the framework works. The paragraph aims to answer the following sub-question:

"How can feed forward and feedback be integrated in an functional framework?"

**6.1. Changes in Feed Forward**

The research done before shows that lots of information is lost in the feed forward of information in current practice. Many handovers make it difficult to retain all information gathered. The created framework improves the feed forward of information. An integrated building information model (BIM) can be used to do this. Integrated BIM models are created to aid the information centralisation. This is done to reduce information handover and to optimize the interfaces between the models.

This is done by centralising the information, instead of handing over the necessary information. Doing so all information becomes accessible and usable for anyone in the project. A centralised BIM model was created in the observed case studies. Unfortunately, the use of the model is mainly focused on the design phase. The model is used inadequately after the design is completed. This is partly because the employees at the projects do not see the model as being a definitive representation of building elements. The definitive status is only attached when 2D outputs are generated from the BIM model.

The other use of the BIM model after the design phase was observed in the case studies at the HPTC project. At the site iPads with access to the centralised models were
distributed with the goal of clarifying complex situations in the field. There are more possible uses for the BIM model. The BIM model makes it possible to attach important information to the elements. This information can consist of information about the status, requirements, or physical characteristics of the building elements.

A Work Breakdown Structure is created in the framework to schedule the construction of the building elements. It is possible to make cost estimations and schedules for all individual building elements. However, this takes a lot of time and effort. Therefore, work breakdown structure (WBS) was used to split the total set of building elements into more controllable packages without resulting in an over detailed set of tasks.

6.2. Changes in Feedback

Planning is essential to execute large and complex projects. The tasks that need to be performed need to be scheduled. However, from the day the project starts deviations occur; this is mentioned in literature and has been observed at the construction site. This does not have to be a problem. Improving the feedback of information from the job site to the field office will increase the possibilities to deal with unexpected deviations. The planning can be updated with the actual state of the elements and the future steps can be developed. To prevent problems with deviations, the pull planning system is used combined with plan-do-check-act. When deviations occur instead of only observing, the deviations are communicated in the daily stand meetings. This is however limited by the availability of information during these meetings. In current meetings the effects of deviations of the schedule are extensively discussed. However, in most cases it takes a while to communicate reasons behind delays and effects of deviations on other tasks. This would be greatly improved if the communication of deviations was made clearer. Lots of time is lost in communicating the impact of the delays. This can be made clearer by using the already created BIM model in the communication.

The communication of deviations is essential because of the interrelation of the different tasks on a construction schedule. However, in the current situation each of the foremen monitors the status individually and visually, “I have noticed that they are working on the drywall at the 7th floor”, “Yes, I saw the window panes of the 9th floor arrive this morning” (are fictive examples of this). This is communicated in the daily stand meeting by adjusting the sticky-note planning in the field office and mentioning the deviations. It is often not documented adequately. The framework will implement the characteristics of a pull planning to ensure the feedback of information during the execution phase, which will be extended to communicate the model better.

Research on the use of 4D to visualise schedules was presented in chapter 3. However, problems arise because of the dynamic character of construction projects. Deviations to the original schedule emerge on a daily basis. At this moment it is difficult to visualise these deviations. In most instances the created 4D visualisation is only useful as a representation of the phasing of the construction process because it costs lots of time and effort to keep the schedule updated in a way that the 4D visualisation represents the actual status in the field. Thereby the visualisation cannot be used to represent the daily standings of the progress. Some companies are experimenting with these however very little research has been executed in this subject.

The 4D schedule can be used in another way. It is possible to create a schedule in
which the status of the different elements or work packages is presented. If this is coupled to the BIM model a visualisation of the statuses of the building elements and work packages can be made. This schedule must be adjusted to represent the status of the elements in the field.

Apart from 4D, more dimensions could be used. 5D, 6D and even 7D have been used to represent material use, personnel use, and costs overtime. These are however kept out of the scope of this research.

6.3. FRAMEWORK SETUP

The framework creates a process that is clearer and more controllable. It allows the BIM model to be used in the field to communicate the status of the building elements. And the framework will be able to communicate and visualise the deviations that occur in order to adjust the schedule in the Lean meeting. The framework is organised as the schematic displayed in Figure 6.1. In the figure, horizontally the different project phases are marked; Design, Plan, and Build. It must be noted that this is a simplified representation of the real world. The design is in this figure presented as being definitive. However, deviations to the design occur constantly. For the purpose of this research the adjusting of the parts of the projects is limited to adjustments of the schedule. The updating and changing of the design is not included in this research. In addition, sub-contractors and
suppliers create models, which can be imported into the models as well; this is also kept outside the model.

The figure depicts the progress flow of a project, starting in the top left and ending in the bottom right loop. This loop ends when the project is completed. In the beginning, the initial 3D design of the architectural, structural and installations is made, as well as the initial schedule. The final 3D design and the complete schedule have been created on this basis. The assumption is made that the design is often not created by the people that plan and execute the building but by an architect. To create this model it is important that identifiable parameters be added to the model. The WP number must be attached to the building elements for further use in the planning, scheduling and execution phases. The use of the BIM model through the phases and attaching the WP values involve the feed forward of information in projects.

For the feedback of information, the BIM model is combined with the pull style planning created in the scheduling software. Monitoring is appended in the loop in the right bottom of the figure. The model will represent the status of the work packages outside by updating the schedules.

A stepwise representation of the framework is presented in the following list. The actors that are most important in the steps are highlighted;

1. Design

The architect will provide the design of a construction in the first phase of construction projects. The design will be created in a BIM. The software that is used is not important because all will be able to deliver the design in an IFC\(^1\) format. There are some requirements to the IFC model, which need to be met to have a useful design for this framework. Therefore, it is important that the constructor and the client need to be involved in this phase. One demand to the IFC model is that it needs to be built up in elements. The installations can for instance not be all modelled as one element; this would hamper the coupling of the work breakdown structure to the modelled elements.

2. WBS

The work package id's are attached to the BIM model using Synchro to be able to carry more information forward during the phases. Managing lots of information during the phases on an element level will be very laborious. Therefore the total construction is

\(^1\)IFC is the abbreviation of Industry Foundation Classes file. The file type is created to improve the communication between Building Information Modeling (BIM) software programs.
6.3. FRAMEWORK SETUP

split up into work packages. The **Project Manager** decides in which way the construction project will be executed and therefore he decides the sizes and allocation of the work packages. The project manager is thereby responsible for creating the WBS.

3. Scheduling

![Figure 6.3: Scheduling (Delta, 2016)](image)

The planning of the construction project consists of amongst others; Cost estimation, labour allocation, and equipment. The focus of the research will be on the scheduling of the execution phase. The Work Breakdown structure is also the created in this phase. The final schedule will be based on this WBS. Scheduling is created in *Microsoft Project*. The schedule that is created will be slightly different to the way this is traditionally done. It is essential to schedule the status of the work packages. It is therefore essential to know what statuses will be important for the project in the execution phase. Examples of statuses that can be implemented are; "Designed", "Executed", "Under Construction", "Delivered", "Delayed", and "Delayed by supplier". The project manager, client, and work preparer have to decide what statuses are important to document. The scheduling is originally done by the preparation department. The schedule can be changes to accompany wished of the project managers and workers when the execution phase is approached. But, in the beginning the **work preparer** is responsible for the creation of the schedule although communication with the project manager is essential for including the WBS.

4. Schedule, WBS, IFC, coupling

![Figure 6.4: 4D Visualisation (Ferrater, 2015)](image)

The IFC model is imported and the WBS is appended to the model by hand. It would be desirable to import the WBS automatically but a way to do this has not been found during this research. Then, the schedule is imported and this is matched so the four-dimensional model is created. It is unfortunate that the WBS needs to be attached to the IFC model by hand at this moment this makes it difficult to make the creator of the WBS responsible for attaching the WBS to the IFC. The **project manager** should therefore be responsible for this linking. In this phase he is also responsible for importing and updating the schedule.
5. Lean Adjustment Meeting

The visualisation of the statuses is used in the Lean meeting to communicate the deviations that are occurring. Furthermore, the detailed plan for the following days can be created in this Lean meeting. The meeting is quite alike the meetings that are being held now apart from the extended use of the BIM model. Everyone attending the Lean meeting should be able to use and understand the model and be present at this meeting. The focus should be on including all workers in the Lean meeting.

6. Updated Schedule

The look forward schedule is adjusted as a result of the Lean meeting to mitigate the deviations that have occurred in the field. A planner or work preparer that follows the progress of the project is responsible for updating the schedule.

7. Changes in the Field

The schedule and the Lean meeting are aimed at preparing tasks to be undertaken in the field. The goal is that the changes in the field happen according to the updated schedule. Which was presented in step 6. Workers, sub-contractors, and suppliers are the ones responsible for changes in the field.

8. (live) Site monitoring

To make it easier to monitor the status of the work packages live, a system needs to be implemented that communicates the standings live to the Microsoft Project. This can be done by implementing a system of QR/RFID/Barcode scanning.
When a task or action to a work package is undertaken this is communicated to the software live by scanning a bar code on the work package. The desire is to measure site monitoring live. This would mean that the workers, sub-contractors, and suppliers are the ones responsible for monitoring. When checking of the building elements or construction parts a controller could also be responsible for monitoring the statuses. The change of status of the building elements is documented here. Furthermore if the change of status is not as scheduled deviations are noted. These deviations can be a result of being too early as well as too late because these are changes that have to be communicated later in the Lean adjustment meeting.

9. Update integrated 4D model
The integrated 4D model is updated based on the updated schedule and the live monitoring of the status of the work packages and building elements in the field. This is done by synchronising the schedule. This model is carried forward to the Lean adjustment meeting (step 5.). The status of the elements will change along with the colors of the building elements. When delays were monitored the elements will be colored red. The update of the integrated 4D model is the responsibility of the work preparer alike the updating of the schedule.

The advantage of the framework is in the use of this updated 4D model. The updated model represents the statuses of the building elements as they are at the moment of the updated schedule. In the past information about the building elements would be scattered at different employees at the project. Using this framework the information and knowledge about the elements is centrally present for all employees. This information consists of the knowledge about the status of the elements. Are the elements for instance procured, delivered, under construction, or completed. Furthermore elements that are behind schedule can be displayed as being "DELAYED". This means that the element becomes red in the visualisation and has to be discussed in the following Lean meeting. In this meeting a decision has to be made on how to proceed. Will there be more time to complete this element or does work need to proceed and while this element stays under construction. Knowing the status of the elements is essential in planning the next steps in the construction process. This results in a valuable model. It takes some effort to setup the model however could be used to execute more project control because of the insight in the deviations. It is also possible to document the changes on a scheduled basis (for instance weekly) so that during the analysis of the completed project this can be used. It is then possible to track where important changes have occurred and whether this was done for the right motivations.

6.3.1. Monitoring change
BIM is emerging on site using portable devices like smart phones and tablets. The information system can be carried outside more easily. In the field the BIM model can be used to verify the quality, analyse the layout of the design, and keep track of activities on the construction site, however more is possible. Other ways of applying BIM in the field are laser scanning, machine-guidance, GPS technologies, and Radio Frequency Identification tags (RFID). RFID tags can support the tracing of component delivery and
installation on site. This has been applied in projects, such as the construction of the Maryland General Hospital (Eastman et al., 2011). RFID can be used to monitor elements in the construction site. RFID has in test cases proved that it can aid construction project management in reaching goals of time, quality, cost, safety, and environmental. It is also concluded that adoption of RFID is slow. Further research was recommended in the fields of RFID itself. The connection and integration of BIM and RFID should also be examined further and integration of using RFID in construction processes has not been researched a lot (Lu et al., 2011).

The status of the parts of the work in the construction site changes continuously as a construction project evolves over time. Current surveying and quality control approaches are not effective, since they only provide data at specific locations and times to represent the work in place, and the data generated are interpreted manually and are not integrated automatically or electronically into the project design schedule (Akinci et al., 2006). This was also observed in the case studies.
7

FRAMEWORK EVALUATION

Verification and validation are applied to test the created framework. This is done by verifying the framework in paragraph 7.1 using test cases. In paragraph 7.2 the framework will be validated. Interviews were undertaken with experts. The first verification case is a quick test for the basics. Then a larger case is used as a scenario simulating the real world. The framework is in the validation tests discussed with experts. The goal of this chapter is to answer the following sub-question;

"Is this framework an improvement for project efficiency?"

7.1. FRAMEWORK VERIFICATION

The framework will be verified by testing it on two cases to test whether the framework works. First, a pilot case will be used to test the basics. This will be done by applying the framework on the construction of a Shed. This case is used to test the absolute basics of the framework. It tested; whether the software packages can be used, how framework handles a schedule importation, model importation, and auto-matching. The large test case was chosen because this case resembles real world scenarios better. A larger test case reviews how more complex projects can be undertaken using the framework. Furthermore, the second test case will be more focused on the execution of a framework. Each step is elaborated with special focus to the feedback and feed forward of information. A deviation of the schedule is created and the way this is communicated in a Lean meeting is assessed. The "Markthal" in Rotterdam, which was executed by JP van Eesteren was chosen as the second verification test. The project has Building information models (BIM) that were created at JP van Eesteren.

7.1.1. THE SHED CASE

The designing, planning, and construction of the shed is included in this verification test. When verifying the framework using the shed case it has been found that the Asta scheduling software had difficulty being imported to the Synchro software. Therefore,
Microsoft project was used. A list of the computer’s specifics and the used software is presented in Appendix B. A search query was created to assign scheduling tasks to elements based on the work package values. This was done to link the schedule and the BIM model automatically.

The following feed forward steps were taken in the Shed test case;

1. **Design** - In the first step the design was created in Revit and the design is exported as an IFC file. This was done in order to simulate a design created by an Architect or Constructor. Revit was used here.

2. **WBS Creation** - In the second phase, the model is broken down into work packages using the work breakdown structure (WBS). These are documented in Microsoft Excel and will eventually be appended to the IFC model.

3. **Basic Scheduling** - The scheduling was executed in Microsoft Project after encountering some problems with the scheduling using Asta Power Project. It is essential that the tasks that are planned include Work Package codes as created in step 2. Furthermore, the statuses of the building elements are scheduled.

4. **Schedule, WBS, IFC coupling** - The integrated 4D model can be created when the schedule, the WBS, and the design are complete. The IFC model resulting from the design is imported in Synchro. Then the WBS is appended to the building elements by hand. The scheduling is then imported. Finally, the design and the schedule are linked using the before mentioned query.

5. **Lean** - The detailed schedule of the execution of the shed can be discussed with the workers during the Lean adjustment meeting.

6. **Updated schedule** - Changes to the schedule are not made in the first iteration of the feedback loop. If deviations to the schedule are made in the Lean meeting, these are applied to the schedule here.

7. **Changes in the field** - A delay is simulated to the original schedule. The execution of the front wall is delayed. In real world scenarios the deviations in the field are found here.

8. **Monitoring change** - The deviation of the schedule as mentioned in step 7 is monitored. In this verification test the change is monitored directly as the change occurs.

9. **Update integrated 4D model** - The deviation of the schedule as monitored in step 8 is translated to the schedule. Then the 4D visualisation is updated here. Furthermore, the status and thereby the color of the front wall are changed to ‘delayed’, which is visualised in red.

- 5. **Lean Adjustment meeting** - The updated 4D visualisation can now be used in the Lean adjustment meeting to picture the deviation from the schedule as monitored in the field. This is the first step in the second iteration of the feedback of information (5, 6, 7, 8, and 9).
The first test case and therefore the first verification test concluded that the model worked. Testing can now proceed to the second phase. A more detailed explanation of the shed cases verification test can be found in Appendix C.

7.1.2. The Markthal Case

The second verification test was executed on the Markthal. The Markthal is depicted in Figure 7.1. ‘The Markthal’ was built by JP van Eesteren and is located in Rotterdam. The Markthal is a food market, a parking garage is situated below the Markthal, and houses are constructed in the shell. This makes the Markthal a combination of Retail, Parking, and Housing. The Markthal shall be elaborately described to evaluate a more complex construction project in this paragraph. The framework is explained step by step.

1. Design

The design of the Markthal consists of several models. All of the models have been created in Revit and have been exported as IFC files. The files are quite large and it was soon discovered that importing the full set of models into the Synchro software was too demanding for the laptop on which the research was executed. Therefore only the structural model was used in this research to limit the demand on the hardware. A representation of the design in presented in Figure 7.2.

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1 Importing all models was tested on a high performance laptop which was able to operate after and deal with the larger files.
2. WBS
The WBS splits the total construction into more manageable parts. A WBS was created in the real construction project. However, the WBS was created as an aid for the billing department. Because the WBS will be used to match the schedule and the model, a new WBS was created for the verification test. The construction of the structural parts of the construction was first split per level. It was important to specify the breakdown further to accurately manage the projects. Each level is split in four parts. The creation of the work breakdown tree was executed in Excel. The decision on the way the work was broken down was based closely linked to the way the construction would be scheduled. Work packages were split in levels because a level needed to be completed before the next level would be started. Furthermore, because there was a limited amount of personnel available, it was decided to split the levels further.

3. Scheduling
As mentioned in step 2, the creation of the WBS and the Scheduling happen partly at the same time. The most important decisions in the eventual phasing of the construction need to be taken into account when the WBS is created. However, in the end, it is important to finish the WBS before finishing the schedule. The WBS is needed to complete the schedule. Each task in the schedule consists of a WBS value. Furthermore, the scheduling phase is the phase in which the desired statuses need to be decided. The statuses of the work packages need to be scheduled here. For this research, a work package that simulates physical elements of the construction will first have no status, then be ‘procured’ after which it is ‘delivered’. After an element or work package is delivered, the status will remain ‘delivered’ until the ‘construction’ of the element is started. When the construction of the element is finished, the status of the building element is ‘completed’. More statuses such as designed, checked, and stored could be added if there was a desire for it. The scheduling of the construction project was executed in Microsoft Project and was finally exported as an xml file. It is essential that the planning links all the tasks, because when a delay is occurring, the other tasks should move with this delay when rescheduling is executed.

4. Schedule, WBS, IFC, Coupling
The IFC model is imported into the Synchro software. The WBS was appended by hand after the model was imported. Furthermore, the colours for the statuses were chosen. Yellow translucent was chosen for ‘procured’, purple translucent was chosen for ‘delivered’, green non-translucent was chosen for ‘under construction’, finally grey was chosen for ‘completed’. Then the schedule was imported and matched to the IFC model using queries written for
auto-matching. When the schedule and the IFC model are linked correctly, the statuses of the work packages during the duration of the project were displayed. Figure 7.3 presents a picture of the 4D visualisation of the Markthal at three quarters of the building process of the structural work.

5. Lean Adjustment Meeting
The schedule is made final in the first Lean adjustment meeting. Adjustments are made by the parties involved and the schedule would be communicated. The schedule is communicated and partially adapted to the needs and demands of the workers attending the Lean meeting in the first iteration of the feedback information loop. The Lean meeting is used to analyse and visualise the statuses of the building elements and work packages in the future meetings. Also the look-ahead schedule can be adjusted to mitigate for the deviations. Finally, in this meeting the parties that are delayed will be asked to explain the cause of their delay. This introduces ‘naming and shaming’ methods to enhance the feeling of responsibility at the workers.

In the second iteration of the feedback information loop the deviation that occurred in step 7, was monitored in step 8 and is discussed using the adapted visualisation of step 9. The visualisation is used to explain the status of elements, point out delays, adjust schedules, and illustrates phasing and schedules for the next weeks.

6. Updated Schedule
In the first iteration, nothing happened in the updating of the schedule because the original schedule was kept. In the second iteration, a mitigation was discussed in the Lean meeting. This led to the need for the updating of the schedule. For this research, the decision was made to start working on the higher level, although the other level was not completed.

7. Changes in the Field
Changes occur in the field because the construction process starts. Most of these are expected to go according to the plan. However, in this step a delay was found because part of an internal wall was not poured correctly. In this verification test only one delay was simulated. However, it can be expected that in real world scenarios many more deviations are found. Some positive deviations may enhance the production speed but some negative deviations will delay other tasks in the schedule.

8. (Live) Site Monitoring
In this phase the monitoring of the statuses of the construction process occurs. It is essential to monitor all changes, good ones, and bad ones. Therefore, it is essential that the monitoring does not take too much effort but becomes part of the job. Registering work packages and elements that have been procured by
the procurement department, scanning items that have been delivered to the construction site by the logistics department, and scanning bar codes on the pouring moulds. Using this method a deviation was monitored because one of the walls was not scanned as being completed. A representation of how this live site monitoring can look is presented in figure 7.4. This way of monitoring the status 'live' has not been applied in construction projects a lot yet. Therefore, more research in live monitoring is advisable.

9. **Update integrated 4D model**

![Figure 7.5: Site Monitoring](image)

When the monitoring is done, the statuses of the building elements and work packages are put into the scheduling software. These are then updated in the 4D visualisation to represent the current state of affairs in the field. This visualisation can then be used by the project manager or project leader to adjust major decisions in the project. Furthermore, it can be used to communicate the status of the project to the client. Finally, the updated 4D representation of the status of the project, can be compared to the original schedule, as visible in figure 7.5, and be used in the Lean meeting to adjust the schedule. In this way, the 4D visualisation can aid the increase of efficiency of the construction projects. In the figure, the element that is related to the deviation of the schedule is coloured red.

A more elaborated explanation of the Markthal case is included in chapter D.
7.1.3. Framework verification conclusion

Verification and validation is done to check whether a product or service meets the requirements. In this case the framework is the product or service which needs to meet the requirements. It is essential that the produced framework can be used. The validation tests will check if the product meets the initially set demands by means of external validation. The verification test was executed internally using two cases. One of the cases tested the basic principles of the framework, the other focused on more complex and real world scenarios. Resulting from the two test cases the conclusion can be drawn that the framework can be used in construction projects. The steps are linked logically and the software systems that are used in the steps are able to communicate well with each other.

7.2. Framework validation

The originally set research goal and research questions are in the validation phase compared to the framework. The framework was created to resolve the problems and should therefore be compared to the created framework. External interviews are used because the researcher is biased to its own research. The model validation was executed using two open-ended interviews. One interview was with Hendrik Bergsma, an employee of the central work preparation department at JP van Eesteren. He has not been introduced to the project before and therefore he is assumed to be unbiased. The other interview is undertaken with Johan Hoffman; Johan is not an employee of JP van Eesteren but works at 'van Hattum en Blankevoort' and is therefore even more impartial to the research. Because the employees were independently selected from the research, and one of the respondents was not working for JP van Eesteren, it was decided two respondents would be sufficient to validate the research.

7.2.1. Validation Hendrik Bergsma

In the beginning of the validation interview Hendrik was asked to name the innovations in the information handover of construction projects. Lean, BIM and WBS were mentioned. Lean is in Hendrik’s opinion a very important innovation for the execution department. However, not so much implemented in preparatory phases. Hendrik mentioned that Lean focuses on the adjustments of schedules to field developments in execution phases. Using Lean has been attempted in the preparatory phases. When Lean was used in this phase it was possible to create a more detailed schedule earlier in the construction process. BIM is also mentioned as being an innovation which has been emerging in the construction industry as an aid in the handover of information. Hendrik mentions that BIM improves the clarity of the design. Detail drawings were created on complex construction issues traditionally. Nowadays more information is present in the BIM model making design more clear. BIM is also used to retrieve the amounts for the calculation department. To Hendrik’s knowledge combinations of BIM and Lean are not applied together in construction projects in the Netherlands. There are projects that implement BIM and Lean but in different phases of the construction process or to different goals. He does think that the schedules would me more insightful and understandable if it would be implemented. Hendrik mentioned 4D as being a fun coupling of time to a 3D
model. He mentions that is mostly used as a tool for explaining the phases to the client. The conclusion is that BIM and Lean are innovations that aid the construction sector in the information flow through projects.

In discussing the framework, it has been found that a great advantage of the framework is that it resembles the current construction process a lot. This eases the adoption of the framework when applied to real projects. Hendrik says that he can see the advantage of the framework when more and more deviations arise. When projects are undertaken thirty or more deviations occur. In the verification test only one deviation is presented. The model provides the possibility to show and communicate these deviations far more clearly than is now possible in construction projects. It is typically difficult to know the status of the building elements when more prefabrication is involved in the projects. The elements are prepared in factories instead of on site. This makes communication between the factory and the site office even more important.

The framework is presented to be applied in the execution phase of construction projects. However, possibilities are there to aid the preparatory phase of projects as well. The Lean practices are now not extensively applied in the early project phases. But using this framework the status of the elements in the design and procurement steps can be communicated far better. The framework can be a Lean improvement of the way the preparatory phase is undertaken.

Overall the framework is a very good aid in the communication of status and delays of elements by using the 3D model. By improving the information handover of projects, the efficiency of the construction projects can be improved. Some downsides to the framework are also identified. First of all, the use of RFID and scanning for the live monitoring is essential for the framework to be useful. The observations have to be made and documented by hand if automated live monitoring is not used. Then it would take too long and create a visualisation this image is probably incomplete as well. Having incomplete models will be misleading. Another downside of the framework is that it takes quite a while to setup correctly. In current projects time constraints are a problem. Therefore, the time that is needed to setup the model is not there. If the framework is to be applied to a real case, extra time should be taken in the preparatory phases to setup the models correctly.

7.2.2. Validation Johan Hoffman

Johan is an expert in Lean techniques and is involved in introducing Lean in construction projects at 'van Hattum & Blankevoort'. He mentions that Lean is an innovation that is occurring in lots of construction projects because it is easy to adopt. Lean was adopted by projects at 'van Hattum & Blankevoort' as a result of the financial crisis. The aim was to improve the efficiency of construction projects. Lean is being implemented in construction projects that are moving towards the execution phase. Lean planning is also implemented to increase the feeling of responsibility at the workers. Pull planning is the technique that is used at most 'Lean projects'.

In communication and adjustments of design BIM is used. BIM is a way of centralising information during construction projects. 4D visualisations are used to present the

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2Van Hattum en Blankevoort is a construction company that specializes in the construction and maintenance of civil projects [http://www.vhbinfra.nl/](http://www.vhbinfra.nl/)
phasing of the construction project to a client. BIM is at the projects known to Johan not applied or used in Lean meetings at ‘van Hattum & Blankevoort’.

The possibilities of using the Lean and BIM together became clear while discussing the framework. It has been found that the framework improves construction projects by visualising the status of the elements. Especially when more suppliers are involved. The status of the elements at the suppliers is often not clear. The place of the subcontractors in the process is a bit unclear because the responsibilities of the people and parties involved were not mentioned. Furthermore, the communication of deviations is far more clear when the framework is used.

It was mentioned during the validation that the focus of the framework is mostly on communicating status and delays. However, Lean processes are often implemented to increase the production speed. This is not extensively included in this way of working Lean. Furthermore, ideas and innovations need to be embraced before they are implemented. Therefore, it is essential that the actions do not only take little action but also that there are gains for the people that need to do the live monitoring. This could for instance be achieved by receiving the technical drawings after the scanning of the elements. The process needs to be as easy and gainful as possible for the innovation to be adopted. Also it was mentioned that the design is not complete before scheduling starts. It is important to note that further research should be done in changing the design later in the process.

The framework communicates the supply chain of the building elements as a logistical process that is really clear. This is a great aid to the communication of the information within construction projects.

7.2.3. Validation conclusion

The validation of the framework was executed to see if the framework does what is was designed for (Boehm, 1989). The framework was designed as a result of the originally set research question. This question stated that the efficiency of construction projects should be improved by focusing on feedback and forward of information during the construction process. In the validation of the framework it was first found that both respondents found BIM and Lean to be improvements in the feedback and forward of information but they also remarked that to their knowledge there was no way of using them together. It was also remarked that BIM and Lean are not the only innovations that occur as an improvement of the handover of information but the decision was made to focus on these two and this was understood. The conclusion is that the combination of Lean and BIM could aid the construction sector in increasing the efficiency.

When the framework was discussed it has been found that the combination of BIM and Lean can efficiently be made. The created visualisation can be an aid in the communication of the statuses of the building elements and the deviations to the schedule. This would especially benefit projects in which prefabrication work is an important factor since the deviations and delays in the factory can be communicated more effectively. Communicating statuses in the supply chain using the BIM model increases the clarity of the statuses and the plans and is an aid to the Lean construction methodology.

The downsides to the model that were mentioned are that the use of RFID for live monitoring of the statuses is not used in construction projects at the moment. Further-
more, the adaptation of the framework might be hampered if the actions take too much effort. Finally, the validators mentioned that not all projects and employees might be ready for the step to embrace both Lean and BIM. Imposing the change might lead to resistance. And it was finally mentioned that the assumption that the design is complete before the scheduling starts is incorrect.

The documentation of the interviews is inserted in Appendix E.

7.3. CONCLUSION OF ‘FRAMEWORK EVALUATION’

In the verification tests the framework discussed in chapter 6 has been found to be operating. The main remark of the verification test was that the use of live monitoring is not present in the current software. The desire would be to use bar codes or RFID scanning to change the status of the building elements however this software and hardware is not present for these uses. Apart from that the framework operates and is able to show statuses and deviations to the plans creating visual help for the Lean adjustment meetings.

The validation interviews concluded that the framework can possibly be an aid to create a more efficient construction process by improving the information handover of construction projects. This is done by combining the feed forward and feedback of information using BIM and Lean. The two main remarks following the validation are that BIM models change during the project. It is an illusion that the design is complete before the execution phase starts. It is hard to implement changes to the design in the current framework. Secondly concerns about the adaptation of the framework were expressed. The employees need to adopt the framework and if the effort becomes greater without added gains the framework will not be adopted. This is the reason that live monitoring is essential for the framework to be adopted. The validation concluded that the framework is valid and an aid to the efficiency of the construction process.
CONCLUSION, REFLECTION, AND RECOMMENDATION

This chapter consists of the conclusion of the research, the reflection upon the research, and the recommendations to both the academic world and the construction company. This chapter is the final step to the research flow as presented in the methodology chapter (ch. 2).

8.1. RESEARCH CONCLUSION

The aim of the research was to answer the research question. The research question was presented in chapter 2.

“How can the efficiency of construction projects be improved, by focusing on feed forward and feedback information during the construction process?”

Sub-questions were then created to answer this main question. These sub-questions were tackled in the research one at a time in accordance with the research flow as presented in figure 8.1. The following paragraphs answer the sub-questions one at a time.

![Figure 8.1: The Research flow is as discussed in 2.3. The Parts, Chapters, and sub-questions (SQ) are visualised.](image-url)
8.1.1. SUB-QUESTION 1

*What methods can improve the information flow in construction projects?*

It has been found that there are numerous methods that were created to improve the information flow through construction projects. The distinction was made between the feed forward and feedback of information. Feed forward is seen as the handover of information from suppliers to contractors and from the beginning phases of the project until the eventual execution of the project. Feedback of information is seen as the flow of information from the field back to the (field) office. This also includes the flow of information of deviations from the suppliers and construction workers to the contractor. The analysis of the existing innovations led to the focus on Building information modeling (BIM) and Lean. After further literary research it has been found that there is one piece of software that aims to combine Lean and BIM to improve the information flow. This was VisiLean. This software package turned out to be unfit for implementation because of the inability of communication with planning software and BIM software as used at JP van Eesteren. Furthermore issues were encountered when the software was used in combination with subcontractors. The initial framework for improvement of the information flow within construction projects was therefore created in this phase. The basic framework was then evaluated during the case studies and the possibilities of the different software packages were compared. Eventually the complete framework as presented in sub-question 3 is a result of this basic framework.

![Figure 8.2: Basic Framework created in sub-question 1](image)

8.1.2. SUB-QUESTION 2

*How is the flow of information in current construction projects organised?*

A case study was done in order to analyse the ways information flow is organised in construction projects. It has been found that the projects used BIM as a way of centralising information. BIM was used in different ways in the two cases. One of the cases used BIM only in the preparatory phase. The project did not use the model when execution
started. In the other case BIM was also used in the field to receive accurate information about the design. Lean was used at both projects. Pull planning was the lean approach taken in the scheduling of both the projects. The projects both created six week look-ahead schedules to efficiently plan the weeks to come. The combination of BIM and Lean was not applied in either of the cases. BIM and Lean were implemented separately.

8.1.3. SUB-QUESTION 3

*How can feed forward and feedback be integrated in an functional framework?*

The basic framework was mentioned in sub-question 1. After the case study and the software comparison the framework was completed and elaborated. The framework aims to integrate the use of the BIM model and the Lean methodology. The framework aims to visualise the schedule, deviations to the schedule, and the status of the building elements. The possibility is there to also show the status of the building elements that are at the pre-fabricators. Live monitoring is essential to create a successful and accurate representation of the statuses and deviations. The framework is presented in figure 8.3.

8.1.4. SUB-QUESTION 4

*Is this framework an improvement for project efficiency?*

In chapter 7 the framework as resulted from sub-question 3 is verified and validated. The framework was verified using to test cases which in the end proved that the framework was operating. The steps in the framework interlinked and the software communicated to each other as desired. After this the framework was compared to the originally set research question. This was done to evaluate that the framework does what it was
designed for. This was done using two interviews. An interview with an employee of the central work preparation department of JP van Eesteren and an interview with a Lean expert at Van Hattum & Blankevoort. This was done to ensure unbiased results. The framework has been found to be a possible way to improve the efficiency of construction projects. Thereby the framework has been found to be an improvement to project efficiency.

8.1.5. RESEARCH VALIDITY

The research should be compared to the originally set research goals to determine the validity of the research and the created framework. The following goals for the research were initially set:

- Analysing innovations in flow of information.
- Comparing literature and practice on information flow
- Integrating BIM and Lean
- Create a framework to improve information flow in construction projects

In the beginning of the research the innovations in information flow were analysed. The conclusion was drawn that for this research the most potential was in the BIM and Lean methodologies. When comparing literature and practice on information flow it has been found that the literature was more optimistic in the application, acceptance, and possibilities of the innovations. Then research was done in combining and integrating BIM and Lean. It has been found that the application of BIM and Lean in an integrated manner was rarely researched. Most focus was on attaching schedules to 3D models and on the digitisation of Lean methodologies of construction projects. Finally a framework was created to improve the flow of information in construction projects focusing on the Lean and BIM methodologies.

The main goal of the research was to find a way to enhance the efficiency of construction projects using BIM and Lean. The result of this is the created and validated framework. A remark that should be added is that the research assumed that enhancing the communication of the statuses will result in a more efficient process. This has however not extensively been researched. It was mentioned in the validity interviews by both interviewees that it is likely that the efficiency is enhanced. Furthermore is should be mentioned that the research was executed for the technical university Delft and JP van Eesteren. However the created framework cannot immediately be implemented. This is due to soft and hardware related issues related to live monitoring and the updating of the design. Parts of the framework can be applied to construction projects undertaken by JP van Eesteren. JP van Eesteren can start using the framework by reorganising the way work breakdown structures are used. Furthermore JP van Eesteren should expand the use BIM and Lean at their projects and look into applying BIM more in the construction sites. More of the recommendations to JP van Eesteren are presented in the recommendations to construction company (par. 8.5).
8.2. SIGNIFICANCE OF RESEARCH

The significance of the research discusses why this research is an addition to the total body of knowledge. Before this research some knowledge was not present and this knowledge is present now. The techniques and methodologies of BIM and Lean had extensively been described as separate innovations in the management of construction projects. But the coupling of these techniques has been set as a research goal for this research. The attempt was made in the research to let BIM and Lean emphasise each other by creating a framework. This framework would describe the steps that should be taken in the management and execution of a construction project.

Visualising the status of building elements can be used to enhance the efficiency in the communications during lean meetings. In these lean meetings lots is discussed at the moment. This is done because the employees have the knowledge about the status of the building elements. The total amount of information would not be complete even if the communication would be perfect and no information would be lost in the process. The reason for this is because not all elements are at the construction site at the same moment. Some elements are in transit others are prepared in off-site factories. The main goal of the framework is to use a BIM-visualisation to communicate the status of the building elements. This is done to improve the communication in the lean meeting and to fill in the gaps of knowledge using live monitoring.

Not only the communication within the meeting will be enhanced. But another advantage is that the employees that are working on a project can all see what is going on. They are not obliged to find the person that has the information they are looking for because this information is available to everyone. This furthermore creates the possibility for a client to look at the actual status of the construction process without having to visit the site.

One of the largest advantages that can be observed is the visual tracking of the status of the prefabricated elements. In the past it was difficult to follow these because they were prepared off site. To gain information in the elements visits to the factory or extensive phone calls were needed. When the framework is completely applied the status of the elements in the factory can be displayed in the total model as well.

The research is not flawless. In the Research Reflection (par. 8.3) an elaboration of the remarks on the research are presented. One of the large remarks is that the framework was specially tuned to cope with changing plans, however it struggles when confronted with changes in the design of a structure. Another weak side of the research is that the (automated) live monitoring as presented in the framework is theoretically possible but practically not applied in any construction site in the Netherlands.

8.3. RESEARCH REFLECTION

This paragraph aims to reflect on the research and the result of the research. The reflection also includes a critical look at the motivations and decisions that were made in the research and evaluates the validity of these. Each of the research phases is discussed separately after which the total value of the research discussed.
8.3.1. **Reflection of Research Phases**

This paragraph discusses the most important decisions and motivations that were taken in the phases of the research. The phases correspond to the chapters of the research report. Not all of the phases are discussed in this part because not all of the phases were subject to these important decisions.

**Methodology**

In the methodology the basis for this research was created. The problems were explained and the approach that was taken to solve the problem was discussed. Approach consists of literature studies (which will be discussed in the Theoretical background) and case studies that involved interviews. An other approach could have been taken to answer the research questions that are sketched but I believe the current approach to have been successful and therefore will not discuss other approaches.

**Theoretical Background**

In this chapter the literature study that was executed is described. The literature study was used to shaped and further refine the research questions. The literature research lead to a broad understanding of the current practices and problems in the construction sector.

One field the literature research failed to find extensive information on is on the advantages of visualising or effectively communicating the status of the building elements. It is expected that knowing the status of the building elements will lead to a more efficient construction process. However, this is an assumption because there is little research in this field. More research is necessary to prove that efficiently communicating the status of building elements will lead to a more efficient construction process.

In the research other means of gathering information about the current construction practice could have been used. However, it is believed that the current practice provided a more unbiased and broader view of the construction sector than other ways could have provided.

In the end of the chapter the basic framework on which the research is based was created. In creating this framework it was chosen to focus on BIM and Lean as the most important innovations in the construction sector. The motivation for this will be discussed in the Framework creation because the eventual framework is formalised in that phase.

**Case Study**

In the methodology phase of the research it was decided to execute two case studies. This would be the best way of evaluating the current practice at the construction sites. In the setup of the case studies it was chosen to evaluate cases in which multiple parties were present. In this way interviews with different companies could lead to more unbiased information about the chosen cases. Furthermore two active construction projects were chosen to be the case studies so that site visits could be undertaken.

The foundation of the research are lots of interviews. Apart from that some site visits were executed. Interviews are never completely unbiased. The question can be posed if more time should have been spent on observing construction sites or on interviewing more people at the construction sites. This would have resulted in a more unbiased view
of what is going on at the construction site. This was not done because the unbiasedness of the case studies was reduced by using two cases and using interviews at employees of multiple companies. A third case study could also have been executed. This was not done because of time constraints. In this way more time could be spent on creation, verification and validation of the framework. Finally it would also have been an option to use a case that was executed by a different construction company, however because JP van Eesteren was the main client in this research the decision was made to focus on construction projects that were undertaken by them.

**Software comparison**

In the software comparison phase the different possible choices for the software to be used in the framework were compared. Lots of software packages could have been compared and selected but a selection had to be made. Therefore it was decided to involve as much of the software packages that were already being used at JP van Eesteren. The framework could be simplified (for instance by substituting the planning software for the Synchro software) but it is expected that the framework will be used by the employees at JP van Eesteren more easily when the changes for the employees are as small as possible.

**Framework creation**

In this phase the framework was created. The framework aimed to visualise the status of elements in the construction process in such a way that the efficiency of the construction process would be enhanced. To do this the decision was made to focus on BIM and Lean in an early stage of the research. The BIM and Lean techniques were applied in construction projects that were undertaken by JP van Eesteren and literature research about BIM (Eastman et al., 2011) and Lean (Alarcón, 1997) has mentioned that these are important innovations that are occurring in the construction sector. However more innovations were present which could have been analysed. For instance developments in Systems Engineering are also promising. The research needed demarcation and because of a lack of experience with Systems Engineering by the researcher this was cut out of the scope. If this would have been kept in the research the result would be completely different. The research could for instance have focused more on visualising information that is more important for the client.

A reduction of the complexity of construction projects was done when considering changing BIM models. During the course of construction projects the plans and the design change constantly. For the purpose of this research it was decided to only focus on the changes in the plans and assume that the design would not change. This is essential when attaching the dynamic schedule to the BIM model using the work breakdown structure (WBS). But, even during the execution phase the design changes constantly in real world scenarios. The framework will encounter problems when the IFC model is updated because the WBS is appended to the IFC later in the process. This WBS link is essential to be able to match the schedule and the model automatically. A way of changing the 3D model later in the process should be researched.

**Framework evaluation**

In the evaluation of the framework the framework was tested using verification and validation tests. It was decided to analyse the functionality of the framework in this phase
using two test cases. A basic Shed was used as a first test for the basics of the framework. Then a more elaborate test was executed with the Markthal to further stress the framework. If the framework would have been tested in a real world case the functionality could have been described more accurately. However, this turned out not to be hard to achieve in the time frame. The combination of the verification tests and validation interviews are believed to form a good alternative way of testing the framework although real world testing would have possibly provided other information. The social information of the employees that need to work with the framework is now only tested using the interviews. But having employees actually work with the framework would yield far more information.

Furthermore the evaluation found that live monitoring of the elements was essential to the usefulness of the framework at construction sites. This was due to the fact that monitoring this in a non automated way would take too much effort to result in improvements of efficiency. However, live monitoring techniques are not extensively used at construction sites in the Netherlands at this moments. More research in live site monitoring using RFID and QR codes is required to make the framework fully functional in the end.

It has been found that if larger files were imported in the Synchro software the hardware struggled. When all the models of a construction project are imported the model should still be accessible on all laptops used in a project. This is essential because all employees at a project should be able to access the model to gain information about the status of the project. Further research in the size and load of the model on hardware should be executed to increase the accessibility of the models.

Further remarks

In the construction sector changes are occurring. BIM and Lean are mentioned before as being innovations that are more and more implemented on construction projects. In some projects this is going very well and these projects and employees are possibly ready to start considering working with the created framework because they are educated in using the basics and see the advantages of the framework. However other projects and employees find it difficult to get support for using BIM and Lean. If this is considered to be difficult to introduce the possibility for using the framework efficiently is very small. A future research could focus on implementing changes in the construction projects that are resistant at the moment.

8.3.2. Value of the Research

It is possible to efficiently visualise the status of the building elements using the created framework. This was very difficult to do without the framework. The statuses that can be visualised are about in which phase the building element is or whether it is delayed. The statuses can be chosen by the project manager. For the purpose of this research the chosen statuses are;

- Procured
- Delivered
- Under Construction
8.4. RECOMMENDATIONS TO ACADEMIC RESEARCH

The research combines BIM and Lean to improve the information flow of construction projects. The created framework helps the construction process to become more efficient. To implement the framework it is essential that the use of live monitoring is researched further. This research proposes to use RFID or QR scanning to monitor the status of the building elements in the field automatically. More research is needed in the use of live monitoring and the links to software packages to monitor and communicate the statuses of the building elements.

Furthermore, at this point modifications to the schedule can be made but it is not possible to make changes to the 3D model later in the process. In real construction projects the design changes even during the execution phase. Extra research needs to identify a way of updating the BIM model without losing the work package connection. This is essential because the link is essential for the automatic updating of the schedules.

The size of the files were a problem in the verification phase of the framework. The size of the models has resulted in problems when accessing the BIM model in the field before. This size problem should be researched further. It would for instance be useful to export a 'lite' model which exports only the parts of the model that are needed for the 4D integrated model.

It was brought to the attention during the validation that the framework and integrated 4D model could possibly be used in the preparatory phases as well as in the execution phases. Research is needed to see if this is actually possible and provides even further efficiency improvements to the creation of constructions.

As mentioned before, little research has been executed in knowing and communicating statuses of building elements or parts of constructions. It was assumed in this research than knowing more and communicating better would improve the efficiency of
the construction projects. However, little research has been executed to prove that this was the case. Research should be executed to find out whether knowing and effectively communicating the status of building elements improves the efficiency of construction projects.

Because implementing changes in construction companies has proved to be troublesome and slow in the past it is advisable to execute a social study to implementing changes. Lots of technical and hard research has been executed in the construction sector, in these researches lots of ideas and innovations were presented. These ideas and innovations are however held back by the implementation. Soft, social research should identify ways of implementing optimizations which encounter implementation problems. This could be linked to JP van Eesteren to evaluate ways of getting more people accepting and using BIM and Lean in the projects.

8.5. **Recommendations to Construction Company**

In the research it has been found that JP van Eesteren is working more and more on projects that are executed in BIM. Lean is applied in lots of projects in the execution phase of the projects. The combination of Lean and BIM in order to improve the information use is however not effectively done at the moment. However the framework is not ready for implementation at this moment. Academic research and software development is essential before JP van Eesteren can use the framework. The complete framework can therefore not be implemented as presented in this research.

It is advisable to educate all employees in the possibilities and use of BIM and Lean. This should be done by implementing BIM and Lean methodologies in more projects. JP van Eesteren should specifically focus on using BIM in the field. This can be done by using the BIM360 software to gain information about the design and in the future about the status of the elements. Having employees that are more familiar with using Lean, BIM, and BIM360 will prepare JP van Eesteren for the modernization construction sector. This could be linked to the earlier advice that was presented in the recommendations to the academic society. This research would aim to find ways and identify problems when implementing changes in the construction projects.

Another advice to JP van Eesteren is to review the way work breakdown structures can be used. In the framework WBS is used to identify the different building elements (and groups of elements) and than couple these between the planning and the BIM model. This is a different way than it was done before. JP van Eesteren can start by implementing the first parts of the framework. This means that the WBS should be used as identification of the elements. Secondly the WBS should be attached to both the BIM model and the schedule. When this is done it is possible to create a 4D visualisation of the plans. Then for the most important parts it is possible to monitor and adjust the status of the elements to visualise and communicate the status of these large parts. This creates the possibility to start using the basics of the framework.
REFERENCES


APPENDIX A - REPORT INTERVIEWS AND MEETINGS

The interviews are not included in this version of the report
**APPENDIX A - HARDWARE AND SOFTWARE**

This list includes the hardware used during the exection of the thesis. It also includes a list of the versions of the software applications used.

**HARDWARE**

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<td>Planning software</td>
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<tr>
<td>4D Software</td>
<td>Synchro 2013; Synchro Professional x64 4.9.1.0</td>
</tr>
</tbody>
</table>
APPENDIX B - VERIFICATION; THE SHED CASE

In order to validate the framework, the framework is tested on two cases. First, a small pilot case will be used, after which the framework will be executed on a large, real world scenario. The steps in the framework will be discussed in the following paragraphs.

C.1. STEP 1. DESIGN

Figure C.1: Screenshot Revit Shed
In the first phase, the design of the construction project will be delivered to the main-contractor. In this case a small shed is created using Revit and is exported into IFC format, the exchange format that is used in BIM uses. Because in the real world is not expected that the architect or constructor will create the work breakdown structure this is not appended in the model yet. However in real world scenarios it is expected that the designers and constructors all work in their own BIM software, therefore the exchange file type is used. The design is a combination of architectural elements, and installations to show that the complete building can be executed in accordance with the framework. A screenshot of the design in Revit is visible in figure C.1.

C.2. **STEP 2. WBS**

![Excel Shed](image)

Figure C.2: Screenshot Excel Shed

For the WBS creation Excel is used to create the basic structure. In this phase, all tasks that need to be undertaken to complete the execution of the construction are mapped out and numbered. A "Smart" division of the total works is chosen to weigh extensive administrative actions and too little knowledge. It is essential that in the creation of the WBS structure, thought is given to the schedule because the tasks that will be scheduled need to have one WBS code if they are linked to an element. When the WBS is created all physical elements end up with a "Work Package" number.
C.3. STEP 3. SCHEDULING

The "Work Packages" are then scheduled. This can be done in Asta, Primavera or MS Project. In this case it is done in Microsoft project, because it turned out that the scheduling software had to be installed on the same device as the integrated 4D software. The preference would have been to use Asta Power Project because this software used at JP van Eesteren but installing this software locally turned out to be troublesome. The work packages created in the WBS are planned logically. Furthermore the different statuses that are desired need to be planned. A work package will have no status until it is procured, than it stays procured until it is delivered on site, it will stay delivered until the execution of the work package is started, and when the execution is finished the work package is completed. Therefore the statuses procure, deliver, and construct are planned. If more statuses are desired these have to be planned out too. And the work packages is logically related to the other tasks. The schedule is displayed in figure C.3.
C.4. **Step 4. Schedule, WBS, IFC coupling**

In the final phase of the feed forward of information, the integrated model is created. This integrated model bundles, the 3D model, Work Breakdown Structure, and the Schedule. This is done in Synchro. The WBS needs to be appended to the design in Synchro. The matching of the WBS and the IFC model needs to be done by hand at this point. It is essential to be able to auto-match the design and the schedule in a smart, quick way later in the process. It is also essential so the schedule can be updated to the current standings in the field while still keeping the link to the 3D model. The software enables the schedule to be played like a movie, since the schedule and the IFC model are combined. When multiple statuses are attached to the physical elements in the model a decision needs to be made how these are viewed. At this point for the pilot case it was decided to choose different colors for the different statuses. Yellow (procured), Purple (delivered), green (under construction), grey (completed), and red (delayed). This can also be matched smartly to the model making the tasks related to elements in the model and to a particular status. The result is a 3D model in which the colours simulate the status of the building elements. The result is displayed in figure C.4

**Figure C.4: Second screenshot Synchro Shed**

C.5. **Step 5. Lean adjustment meeting**

In the initial Lean meeting the schedule of the construction of the shed could be filled in, or communicated to the workers that will do the assembling in the field. The Lean adjustment meeting will become more useful when further loops of steps, 6., 7., 8., and 9. have followed.
C.6. **STEP 6. Update Schedule**

In the initial loop, no deviations have occurred and therefore no update of the schedule is probably necessary, however if, in the Lean meeting the schedule is changed, this will be updated in this phase. This could be done if, in step 5. the workers proposed a change of plans according to their experience, for example.

C.7. **STEP 7. Changes in the field**

When the construction process starts, changes occur in the field. It is assumed that when the schedule is created in a complete, correct and feasible manner, most tasks will occur according to the created schedule. However as in the pilot case, deviations can occur. These deviations are sometimes to be blamed to a worker in the field, to the design, or even to suppliers or logistics departments.

C.8. **STEP 8. (Live) Monitoring changes**

When changes occur, monitoring of the changes is essential to be able to communicate these to the other parties that are responsible in the project. In this case it is simulated that a wall is completed after schedule, this has to be communicated to the glazier, and the electrician. They either have to do their works later or have to do other tasks to prevent delays. However the deviation of the wall that is completed too late needs to be monitored. For the test case the monitoring was simulated by directly setting the new begin and end dates in the scheduling software. However the aim is, that when projects are enlarged, the monitoring has to be automated by a scanning or monitoring procedure. This could for instance be done by using an iPad, the camera on the iPad needs to be used to scan the barcode on a work package, then the technical drawings appear so the workers know what they have to do. When this scanning is done, the status is or can be changed from delivered to under construction.

C.9. **STEP 9 Update integrated 4D model**

When the schedule is changed an update needs to be made to represent these changes. All changes in the field that were according to plan do not change, however when delays occur these are colored red and rescheduling of the rest of the related tasks occurs to plan what is the expected result. The Lean meeting and adjustment of the schedule will, in the following steps aim to reduce the impact of the delay.
C.10. **Step 5. Lean Adjustment Meeting**

In the shed case, one of the walls encounters a problem. The problem is described in the note that is attached to the task. For the delayed wall, the deviation is that the construction takes 2 days longer because of a problem in the masonry construction. The delayed delivery of the wall postpones the actions connected to this wall. The result is presented in figure C.5. This visualisation will be used in the Lean adjustment meeting. The deviation will be discussed, and rescheduling will occur in the meeting to cope with the deviation. The aim is always to stick to the schedule, however if this is not possible the responsible party needs to be held accountable. The aim of the project is furthermore to meet deadlines that are set internally and to the client. Therefore mitigating measures are taken to keep to the desired schedule. This happens in the Lean meeting.
As a second verification test the 'Markthal' in Rotterdam was chosen. The 'Markthal' has been a project, executed by JP van Eesteren and is situated in Rotterdam. The 'Markthal' case was chosen because the models were created at JP and therefore all rights to the model were owned by JP as well. This made it possible to use the models in the research.

D.1. **Step 1. Design**

The 'Markthal' was designed in Revit, on the basis of the drawings created by constructors, installers and architect. Coordination files were exported in IFC format. The total model was initially split into different submodels. The model is split in construction, installation, architectural, Railings, exterior, and interior walls. After some testing it was decided to only import the structural model. The other models can also be imported but at the used computer this made the models too big and too slow. Importing multiple models can be done, and was tested on another laptop. This laptop was capable of running the total models. However for proof of concept the "light" model was used. The idea behind this decision is that the framework needs to be tested, not the models. By using a already created model, the steps in the framework can be tested which is the purpose of the verification test.
### D.2. STEP 2. WBS

![Screenshot Excel Markthal](image1.png)

For the structural model the WBS is created. Excel is used to create a list of the work packages. When all the work packages are constructed the total construction is completed. In the creation of the WBS, it is again, important to take into account the information that is desired, compared to the administrative actions that need to be executed. A screenshot of the WBS is inserted in figure D.1.

### D.3. STEP 3. SCHEDULING

After creation of the WBS the schedule is created. As mentioned before this is partly done side by side because in the scheduling of the works, decisions are made which influence the work breakdown. However in the end the WBS needs to be completed before the scheduling is because the Work package numbers that need to be appended to all the tasks that refer to physical elements.

It was decided not to use the original schedule because the different statuses of the work packages and building elements need to be planned. The schedule was created using Microsoft project. Here again Asta Power Project would have been preferred but because Microsoft Project was installed locally this would aid the coordination in the integrated 4D/BIM software. A screenshot of the schedule is presented in figure D.2. In the schedule, the status the work packages was planned to be procured, delivered, and under construction. After the task of a work package being under construction would be complete, the package is completed. Within the scheduling of the construction, some restraints were implemented alike in the construction of the real Markthal. One of these
D.4.  **STEP 4. WBS, IFC, SCHEDULE COUPLING**

To make the coupling between the BIM model, the WBS, and the Schedule, Syncrho is used. In the Synchro software the IFC model of the construction is imported. Then, by hand, the WBS is appended to the building elements. This makes it possible to, later on, auto-match the schedule. The schedule is imported in the Synchro software and is auto-matched using set rules. In the schedule the different statuses were planned. To visualise these, a use profile is created for the different statuses. The status procured changes the color of the building elements from invisible to a translucent yellow. The status delivered, changes the translucent yellow to translucent purple. Finally the status under construction changes the translucent purple to green during the construction phase and then to grey when the building elements get the status completed.

see figure D.3.

**D.5.  STEP 5. LEAN MEETING**

In the Lean meeting, the schedule that was created can be detailed further, changed or communicated to the workers. In further iteration loops deviations can be discussed and mitigating measures can be worked out.
D.6. **STEP 6. UPDATED SCHEDULE**

In the first iteration loop, the initial schedule is unchanged. Therefore not updates to the schedule are needed here. However when the progress is measured later, the schedule will be changed due to optimizations or delays.

D.7. **STEP 7. CHANGES IN THE FIELD**

When the construction starts, changes happen, trucks come and go, concrete is poured, and windows and doors are placed. As in the shed case, it is assumed most tasks happen according to plan. However sometimes deviations occur, it might be because execution takes shorter than expected however delays are also a very common sight at construction sites.

D.8. **STEP 8. (LIVE) MONITORING OF CHANGES**

Live monitoring in these big projects is essential. It is unfeasible to have inspectors checking the state of every element. Therefore a special look is given to the postal delivery sector, mentioned in the introduction. When scanning techniques using special PDAs and iPads is applied to change the status of building elements the effort of monitoring can be reduced. A worker documents what he is doing by scanning the bar codes attached to the work package. By scanning more detailed information about the design or layout of the work package is gained making the worker want to scan the bar code and getting support from them instead of receiving resistance. The software to do this is not developed yet and therefore the monitoring is now simulated by attaching the status of the elements by hand. In the case, a wall element is delayed because the cutout for one
of the doors has collapsed in the pouring of the concrete.

**D.9. STEP 9. UPDATING INTEGRATED MODEL**

After the deviation is monitored, the integrated model is updated and the deviation is colored red. This is done to emphasise the delay and improve clarity in the Lean meeting of the next morning. A view of the delay, compared to the original schedule is presented in figure D.4.

![Figure D.4: Second screenshot Synchro Markthal](image)

**D.10. STEP 5. LEAN ADJUSTMENT MEETING**

Each morning a Lean adjustment meeting takes place. At this meeting the tasks of the past and present days are discussed. Deviations are explained and adjustments are made to ensure in time delivery of the project. In this case special attention is paid to the delayed wall. The party or workers responsible for the pouring of the wall explain why the deviation has occurred and the decision could be made that works on the floor above can, or cannot start because of the delay.

**D.11. STEP 6. UPDATED SCHEDULE**

As a result of the meeting, the schedule changes and is updated in this step to be communicated to the parties involved.
APPENDIX E - VALIDATION

The interviews are not included in this version of the report.