MASTER

Quantifying the added value of building information modelling in infrastructure projects

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QUANTIFYING THE ADDED VALUE OF BUILDING INFORMATION MODELLING IN INFRASTRUCTURE PROJECTS

EINDHOVEN UNIVERSITY OF TECHNOLOGY AND ARCADIS NL

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Preface

Proudly I present this thesis, which is the result of my graduation project performed in close collaboration with the Eindhoven University of Technology and Arcadis. This thesis fulfils the last requirements for the degree of Master of Science in Construction Management and Engineering. The thesis encompasses my time as a student at the TU/e and is the starting point for a new phase in my life.

The past six months of the master track were dominated by intensive research into Building Information Modelling (BIM). The opportunity to perform my research at Arcadis (divisie: *Mobiliteit,* marktgroep: *Wegen, Verkeer & Informatiemanagement,* adviesgroep: *Informatiemanagement,* Amersfoort) enabled me to explore the current state of BIM in building projects. I became aware of the key concepts of BIM, including the BIM levels, the uses and benefits of BIM, the implementation of BIM in practice and the Return on Investment (ROI) of BIM. Closing the gap between these concepts contributed to the main purpose of this research to quantify the benefits of BIM in order to prove its added value in building projects. A theoretical approach is used to conduct this research and the findings will be supported and reinforced by practical examples.
During this research I faced several challenges. The hardest challenge was to set up with a proper methodology able to quantify the effects of BIM. Other challenges were finding a suitable topic and expertly company, interpretation of literature and analysing outcomes and conclusion drawings.

I could not have succeeded to meet these challenges and to write this thesis without the help of many people. First, I want to thank my direct supervisors: Jakob Beetz (TU/e) and Dick Grotholt (Arcadis). Jakob, thank you for your input and guidance during this research. Despite your busy schedule and your more technical view towards BIM, you freed up time to share your knowledge regarding BIM and to provide useful and critical feedback on this thesis. This was very helpful in order to study this topic in more depth. Dick, as my supervisor at Arcadis, your help was indispensable. Each meeting you asked the right questions and got me thinking about several issues. In addition, you introduced me to many people who possessed the necessary knowledge and expertise to help me with this research. Moreover, during my internship, I experienced a pleasant personal connection in a comfortable work environment.
One of those people I have met is Bram Mommers (Arcadis). I want to thank him for helping me with data gathering and with the interpretation of the findings. His promising thoughts about BIM were contagious and made me enthusiast.
I want to thank Bauke de Vries (TU/e) for the brief conversations we had and his overall supervision on the progress of my graduation project.
Even a thank for all the employees of Arcadis, which I have talked to and which helped me.
Finally, I would like to thank my family and friends for their help and support. But also for the moments of relaxation.

Enjoy reading!

Roy van Zandvoort
Nijmegen, August 2015

Summary

This research values solutions to the challenges that the traditional way of building processes is facing nowadays. According to many stakeholders in the AEC industry, building projects are too expensive, last too long, do not work as well as they could and do not have a sufficient life span. BIM is identified as a potential solution to this. It seems that the implementation of BIM includes higher efficiency and ensures reduced time and costs over the project life cycle. However, its use seems to be difficult to implement, especially in civil engineering, due to the absence of an appropriate method to quantify the added value of BIM. Until now, project managers had to decide whether or not to utilize BIM based on speculated qualified benefits. Hence, this thesis aims at quantifying the added value of BIM in infrastructure projects as an additional tool to simplify decision making with regard to the implementation of BIM.

In order to find well substantiated quantified benefits of BIM, an extensive literature study is conducted. This study is used to identify key concepts that provide insight to the added value of BIM and to investigate their interrelationships. The literature study also establishes qualitative and quantitative metrics. Whereas the quantitative metrics need to be expanded, specified and summarized, the qualitative metrics could be tested in practice directly. The metrics are tested in practice using a case study approach. Eight case studies are selected, three using a BIM approach, on which background information is gathered. All the selected case studies include infrastructure projects as the research focuses on the added value of BIM in civil engineering. The obtained data is evaluated and conclusions are provided from the data. The research framework is validated and the research solution is formulated.

The developed model combines the four key concepts that mainly contribute to the added value of BIM. The model includes the BIM levels, the uses and benefits of BIM, case studies using BIM and the ROI of BIM. By connecting the mutual concepts it becomes clear what their contribution to the research topic is. A phased methodology is used to make the model conclusive. The consulted case studies are classified based on the BIM levels, the case studies are analysed based on the uses and benefits of BIM, the BIM levels are linked to the uses and benefits of BIM, the ROI of BIM is determined, the ROI of BIM is proved using the case studies and the ROI of BIM is explained based on the uses and benefits of BIM.

The results discuss the classification of the case studies based on the BIM levels, for which an extensive description of the BIM levels is used. It also presents the BIM uses that are applied in the projects and what benefits this entailed. The results suggest that there is a difference in the uses and benefits of BIM depending on the BIM level. When a project is performed at BIM level 2, instead of BIM level 1, it benefits more from the BIM uses visualize, arrange and coordinate. As a consequence, investments are needed for a company or organization to perform their projects at a higher BIM level. The specification of the quantitative metrics leads to a financial saving of 17,6% over the project life cycle if BIM is used. This finding is derived from an extensive database that summarizes statistics from the literature, including their reliability. Although this quantified value cannot be validated in practice due to inadequate data, the contribution of each of the BIM uses to the final life cycle saving can be established. It reveals that the BIM uses visualize, document and capture contribute the most to the financial saving. These findings can be further elaborated by investigating the contribution of each of the BIM uses per stage in the project life cycle. The findings are discussed in more detail for the design, construction and operation stage.

The discussion of this research elaborates on the findings and describes how they should be interpreted. The founded financial saving is indicative only to illustrate the potential savings that can be yielded through the effective use of BIM. Actual savings depend on the specifics of each project and need to be considered on a case by case basis. Still, the quantified savings might provide appropriate evidence for building clients to implement BIM. The discussion also addresses the value of the findings for civil engineering. In this research, data from the building industry is used to draft conclusions of quantified values also in engineering. It is assumed that the benefits provide the same quantified values in civil engineering. However, the differences between applying BIM to different sectors might include deviating choices leading to differences in the final findings.
With regard to the limitations described in this research, it is recommended for future research to include time as a variable to quantify. A same methodology could be chosen focusing on time savings instead of financial savings due to the use of BIM. For companies or organisation it is recommend to start tagging BIM projects in their financial administration in order to clarify its financial results. This information could be useful to reproduce this research using adequate data available from the BIM projects to investigate whether the findings can also be recognized in practice.

The findings of this research contain societal relevancy. The implementation of BIM into more building projects was hindered by a lack of quantified benefits of BIM. This research quantitatively demonstrated that a financial saving of approximately 17,6% over the project life cycle is possible when BIM is used in building projects. Although this quantified value must be regarded as an indication, it might convince building clients to go along with the BIM approach. This might lead to increased utilization of BIM in building projects in the near future.
In addition to existing scientific articles that describe qualified benefits of BIM, this research reveals a method to quantify the benefits of BIM. The methodology used allows to conclude an indicative value of quantified values. The financial savings that are possible due to the implementation of BIM are determined at 17,6% over the complete life cycle of a building project. The findings of this research could serve as a starting point for future research.
In this research, an extensive literature review is conducted to find out what is already known about the research topic and which methods are already used to describe the added value of BIM in building projects. The articles, in general, extensively address qualified benefits of BIM, whereas there is no consensus about the quantified benefits of BIM. The main problem covered by this research was the lack of quantified benefits of BIM.
The research reveals a method, using quantified values from the literature as data input, to combine and extent findings of previous research. An extensive database is drafted, in which statistics are combined with the used method and rated with a reliability score. This methodology allows to conclude an indicative value of quantified benefits. The financial savings that are possible, due to the implementation of BIM, are determined at 17,6% over the complete life cycle of a building project.

Samenvatting

Dit afstudeeronderzoek bevat potentiele oplossingen voor de problemen die het traditionele bouwproces tegenwoordig met zich mee brengt. Volgens verschillende betrokkenen in de bouwsector zijn de huidige projecten te duur, tijdrovend, wordt er niet efficiënt gewerkt en hebben ze een onvoldoende levensduur. BIM wordt genoemd als potentiele oplossing hiervoor. Het blijkt dat de implementatie van BIM kan leiden tot een sterke reductie van de genoemde aspecten. Toch schijnt de implementatie van BIM, vooral in de civiele sector, lastig te zijn door een gebrek aan een geschikte methode om de toegevoegde waarde van BIM te kwantificeren. Tot op heden moesten betrokkenen besluiten of ze BIM wilden gebruiken of niet, gebaseerd op gekwalificeerde voordelen. Daarom richt dit onderzoek zich op het kwantificeren van de meerwaarde van BIM in infrastructuur projecten.

Om goed onderbouwde gekwantificeerde voordelen van BIM te vinden, is er een uitgebreid literatuuronderzoek gedaan. Dit onderzoek is gedaan om kernbegrippen te identificeren, die inzicht geven in de meerwaarde van BIM en waarvan de onderlinge relatie is onderzocht. Tevens stelt het ook kwalitatieve en kwantitatieve maatstaven vast. Terwijl de kwantitatieve maatstaven uitgebreid, gespecificeerd en samengevat moeten worden, kunnen de kwalitatieve maatstaven direct in de praktijk getest worden. Dit wordt gedaan met behulp van een case studies. Er zijn acht case studies geselecteerd, drie gebruik makend van BIM, waarvan achtergrondinformatie is verzameld. Alle case studies betreffen infrastructuur projecten, omdat de focus in dit onderzoek ligt op de meerwaarde van BIM in de civiele sector. De data uit de case studies is geëvalueerd en hieruit worden conclusies gevormd. Het onderzoekskader is gevalideerd en de onderzoeksoplossing is geformuleerd.
Het ontwikkelde model combineert de vier kernbegrippen die bijdragen aan de meerwaarde van BIM. Het model bevat de BIM levels, de applicaties en voordelen van BIM, case studies die BIM hebben gebruikt en de ROI van BIM. Door deze afzonderlijke begrippen te combineren wordt hun relatie tot het onderzoeksonderwerp verduidelijkt. Er is een stappenplan gebruikt om het model sluitend te maken. De geraadpleegde case studies zijn ingedeeld op BIM level en geanalyseerd op de applicaties en voordelen van BIM. Vervolgens is hiervan de onderlinge relatie bepaald en werd tenslotte de ROI vastgesteld.
De resultaten sectie beschrijft de indeling van de case studies op BIM level, waarvoor een uitgebreide beschrijving van de BIM levels is gebruikt. Ze laten ook zien welke applicaties van BIM er toegepast zijn en welke voordelen dit heeft opgeleverd. Uit de resultaten blijkt dat er een verschil is in applicaties en voordelen van BIM afhankelijk van BIM level. Als een project uitgevoerd wordt op level 2, in plaats van op level 1, wordt er meer geprofiteerd van de applicaties visualiseren, arrangeren en coördineren. Dit betekent dat een bedrijf of organisatie investeringen moet doen om hun projecten op een hoger BIM level uit te voeren. De specificatie van de kwantitatieve gegevens leidt tot een financiële besparing van 17,6% over de hele levenscyclus van een bouwproject als BIM gebruikt wordt. Deze bevinding is afgeleid uit een uitgebreide database die statistieken uit de literatuur samenvat, inclusief de geloofwaardigheid hiervan. Hoewel deze gekwantificeerde waarde niet gevalideerd kan worden in de praktijk door onvolledige data, kan de bijdrage van elke BIM applicatie aan de uiteindelijke besparing worden vastgesteld. Dit laat zien dat de BIM applicaties visualiseren, documenteren en inwinnen het meest bijdragen aan de gevonden financiële besparing in dit onderzoek. De bevindingen kunnen verder uiteen worden gezet door de bijdrage aan de

besparingen van elke BIM applicatie per fase van de project levenscyclus te onderzoeken. De bevindingen zijn bepaald voor de ontwerpfase, de constructiefase en de beheerfase.

De discussie in dit onderzoek gaat voort op de bevindingen en beschrijft hoe deze geïnterpreteerd moeten worden. De gevonden financiële waarde is een indicatie om de mogelijke besparingen door effectief gebruik van BIM te laten zien. Werkelijke besparingen zijn afhankelijk van de kenmerken van elke project en moeten case voor case behandeld worden. Toch kunnen de kwantitatieve besparingen voldoende aanleiding vormen voor klanten om BIM te implementeren. De discussie bespreekt ook de waarde van de bevindingen voor de civiele sector. In dit onderzoek is data uit de gebouwen industrie gebruikt om conclusies voor de civiele sector te trekken. Er is aangenomen dat de voordelen van BIM dezelfde gekwantificeerde waarden opleveren in de civiele sector. Echter kunnen de verschillen in het toepassen van BIM in verschillende sectoren leiden tot andere keuzes en tot afwijkingen in de uiteindelijke bevindingen.
Met betrekking tot de tekortkomingen in dit onderzoek verdient het aanbeveling om in toekomstig onderzoek tijd mee te nemen als een variabele om te kwantificeren. Hiervoor kan dezelfde methodologie worden toegepast, waarbij de focus ligt op tijd in plaats van op financiële besparingen. Voor bedrijven en organisaties is het aanbevolen om te starten met taggen van BIM projecten in hun financiële administratie om uiteindelijk de financiële resultaten van BIM in kaart te kunnen brengen. Deze informatie kan gebruikt worden om dit onderzoek te reproduceren en met behulp van geschikte data van BIM projecten te onderzoeken of de bevindingen ook in de praktijk blijken.

De bevindingen uit dit onderzoek zijn maatschappelijk relevant. De implementatie van BIM werd bemoeilijkt door een gebrek aan gekwantificeerde voordelen van BIM. Onderzoek laat zien dat een besparing van 17,6% over de hele levenscyclus mogelijk is als BIM wordt gebruikt. Hoewel deze waarde gezien moet worden als indicatie, kan het klanten overtuigen om een BIM aanpak te kiezen. Dit kan leiden tot een stijgend gebruik van BIM in projecten in de nabije toekomst.
Aanvullend op de bestaande wetenschappelijke artikelen die de gekwalificeerde voordelen van BIM beschrijven, toont dit onderzoek een methode om de voordelen van BIM te kwantificeren. De financiële besparing die mogelijk is door BIM is vastgesteld op 17,6% over de hele project levenscyclus. Deze bevindingen kunnen gebruikt worden als startpunt voor onderzoek in de toekomst.
Een uitgebreid literatuuronderzoek is gedaan om uit te zoeken wat er al bekend was over het onderwerp en welke methodes er al gebruikt zijn om de meerwaarde van BIM in bouwprojecten te beschrijven. Deze artikelen noemen gekwalificeerde voordelen van BIM, maar er bestaat geen consensus over de gekwantificeerde voordelen. Het belangrijkste probleem in dit onderzoek is het gebrek aan gekwantificeerde voordelen van BIM.
Het onderzoek laat een methode zien, die gebruik maakt van gekwantificeerde waarden uit de literatuur, om bevindingen van vorige onderzoeken te combineren. Een uitgebreide database is opgesteld, waarin statistieken gecombineerd worden met de gebruikte methode en beoordeelt worden met een betrouwbaarheidsscore. De methode zorgt ervoor dat er een indicatieve waarde vastgesteld kan worden van de gekwantificeerde voordelen. De financiële besparingen die mogelijk zijn door de implementatie van BIM zijn vastgesteld op 17,6% over de hele levenscyclus van een bouwproject.

Content

List of figures and tables

Abbreviations

2D = Two-dimensional
3D = Three-dimensional
4D = Four-dimensional
AEC = Architecture, Engineering and Construction
AGC = Associated General Contractors
BIM = Building Information Modelling
BIMMI = BIM Maturity Index
BIR = Bouw Informatie Raad
CMM = Capability Maturity Model
DTM = Digitaal Terrein Model
GIS = Geographic Information System
IPD = Integrated Project Delivery
KPI = Key Performance Indicator
MEP = Mechanical Electrical Plumbing
NBIMS = National Building Information Modelling Standard
PNH = Province of Noord-Holland
RFI = Request for Information
ROI = Return on Investment
SE = Systems Engineering
UK = United Kingdom
US = United States

1 Introduction

The introduction clarifies the specific topic under study and describes the research strategy. It explains why the problem is important nowadays, what the research questions are, how the research is designed and finally what the expected results are.

1.1 MOVING TOWARDS A BIM FUTURE IN CIVIL ENGINEERING

According to many stakeholders in the Architecture, Engineering and Construction (AEC) industry, today's building projects are too expensive, do not work as well as they could and do not have a sufficient life span. Many have identified Building Information Modelling (BIM) as the solution to this.

One of these is Patrick MacLeamy, who addresses the shortcomings in current building processes. He mentions that different stakeholders in one project, for instance architect, contractor and owner, have forgotten the need to work together . This is due to a lack of trust, which causes a risk gap. In this risk gap, instead of sharing information freely, other parties are involved who do not design or built anything, for instance lawyers (HOK (Director), 2010). This, finally, causes a growing gap between the design and operation stage of a project, resulting in lost information at the end of each stage. Its course can be seen in the lower line in the figure below, figure 1-1 .

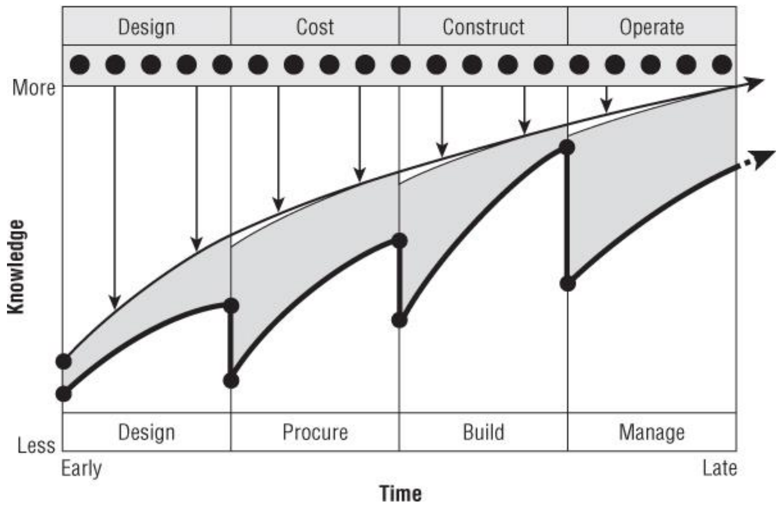


Figure 1-1 Loss of data; BIM vs. Non-BIM (Eastman, Liston, & Wiley, 2008)

The downward spikes in the line represent loss of data at the end of each project stage. On the other hand, the upper line illustrates the pattern of information exchange if BIM is implemented in a project. The line shows a flowing process without any loss of information.

The promise of BIM becomes even greater according to the MacLeamy curve, which is also developed by MacLeamy and can be seen in figure 1-2.

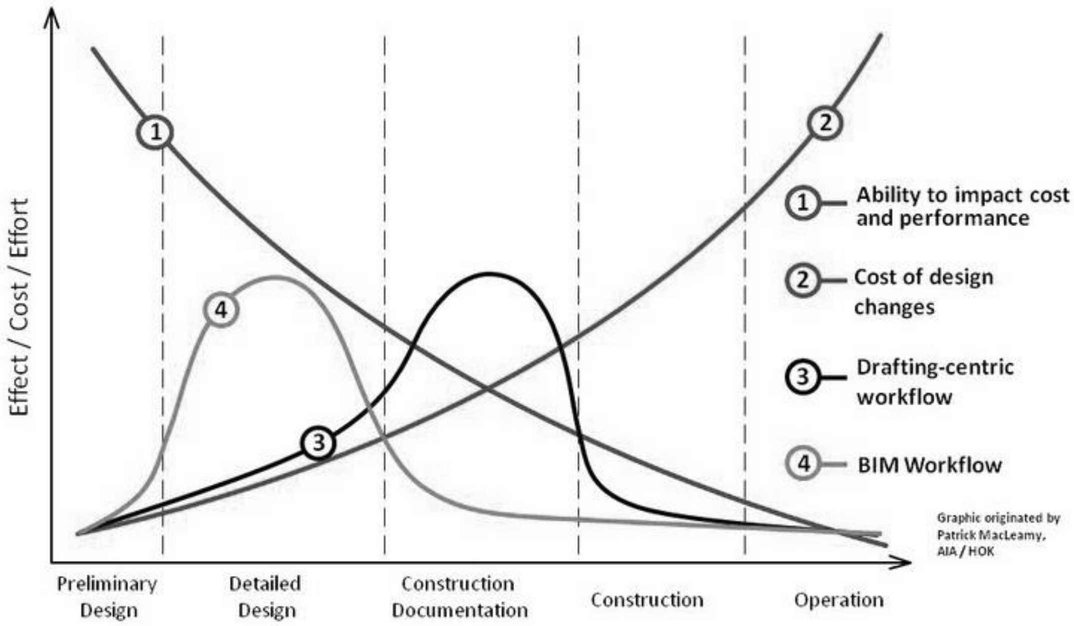


Figure 1-2 The BIM curve (MacLeamy, P.)

This figure explains the need for BIM in building projects the best. In the figure effort is measured over time.
Line number 3 shows the traditional building process resulting in a peak of effort in the middle of the figure, the construction documentation. In combination with line number 1, the figure explains that the ability to impact costs and performance is high at the beginning of the project. The opportunity for changes is very high at this moment. But, as the project proceeds and as more of the design is documented, making changes becomes difficult.
At the same time, line number 2 shows its link to line number 1, as the cost of design changes are low at the beginning and become higher at later stages of the project.
Line number 4 shows the result when BIM is implemented in a building project. BIM ensures the effort to shift forward in time. This means that more effort is putted into testing stages and developing alternatives for the design. The application of BIM also cares for less effort in documentation.

Unfortunately, these explanations seem not to be sufficient to convince stakeholders in the AEC sector to massively implement BIM in their processes.
However, if it eventually succeeds to convince the stakeholders of the many possible uses of BIM and its benefits, BIM might be more applied in building projects in the future. Besides its adaptation in the building industry, it will be also suitable in civil engineering. This will provide benefits for companies and organizations that choose a BIM approach, as well as it will care for sustainable outcomes of infrastructure projects.

In the next section this brief introduction is expanded and the actual problem of the implementation of BIM in civil engineering is discussed.

1.2 PROBLEM DEFINITION

Although the popularity of Building Information Modelling (BIM) increases rapidly, its use seems to be difficult to implement in civil engineering. In order to convince sceptical civil engineers, proponents all over the world are seeking for a general method to prove the added value of BIM. Is seems that the implementation of BIM includes higher efficiency, more effectiveness, reduced time and errors and improved quality. By the absence of an appropriate method to quantify the added value of BIM, a lot of uncertainties occur as project managers have to make the decision whether or not to utilize BIM based on speculated benefits and confidence in the contractor (Barlish & Sullivan, 2012).

Even more, they experience technology, process and people barriers to the implementation of BIM. Rather than the technological considerations involved in BIM, it is a lack of authentically validated data that becomes the greatest barrier to the acceptance of BIM (Li et al., 2014). The aim of this research is to address this issue by quantitatively comparing BIM uses and their benefits in real life projects.

Hence, this thesis aims at quantifying the benefits of BIM to clarify its added value to civil engineers in order to make them enthusiastic to the implementation of BIM. This topic is of high importance, since the need for innovative and cost-effective approaches to infrastructure projects has never been greater or more urgent, as the projects become more complex. Besides the advantages of implementing BIM in infrastructure projects today, a baseline is provided for the transition to new collaborative processes in the future. As the level of use and adoption of BIM is rising nowadays, future expectations mention a growth of the use of BIM in infrastructure projects. This growth can be linked to the expertise available from the building industry, as well as the high level of complexity in infrastructure projects and the growing need for greater efficiency on all aspects of infrastructure. Besides these expectations, infrastructure is more and more confronted with alternative financing and delivery methods, such as public-private partnerships. Collaboration is a critical part of these strategies and BIM is well recognized as a process that enables better collaboration. Finally, for a company or organization, deciding to adopt BIM in their processes will deliver a competitive advantage in comparison to other interested parties (Jones & Bernstein, 2012).

This research is related to previous studies as measuring BIM implementation have been widely used in research for several reasons. Some assessed BIM impacts on project outcomes to compare BIM and non-BIM projects (Barlish & Sullivan, 2012; Coates et al., 2010). Some focused on measuring the financial benefits of BIM according to the Return on Investment (ROI) (McGraw Hill, 2014). Some other researchers measured BIM to determine the maturity and capacity of BIM adoption (Sebastian & van Berlo, 2010). And finally, others tried to develop metrics for assessing BIM processing itself (Manzione, Wyse, & Candidate, 2011; Yee, Fischer, & Kam, 2013).

However, so far, no single study provides an answer to an appropriate assessment tool for measuring the performance of BIM. This causes uncertainties under clients whether to adopt BIM in their processes or not.

This research aims at contributing to the confirmation that BIM is beneficial also in infrastructure projects. And in order to reach this, several research methods, such as literature studies and case studies, are combined. This will be further elaborated in the next sections.

1.3 RESEARCH QUESTION

The problem definition reveals and explains the lack of quantified benefits of BIM, which are important to facilitate the implementation of BIM in civil engineering. It also describes why an

appropriate assessment tool for the performance of BIM is necessary. Although this research may not provide exact values for savings of the use of BIM, as each project is unique, clients will benefit from an indication value of the benefits.
The aim of this research, together with the variety of other research to quantify the added value, delivers the following research question;

> ***How to quantify the added value of Building Information Modelling in infrastructure projects?***

This research question includes proving the added value of BIM to civil engineers, as well as the search to acceptable values of benefits and savings. The research question is supported by a few sub questions. Some of them are immediately derived from the research question, others raised in following chapters of this research. However, all of them are summarized and briefly discussed below;

> 1. *Which key concepts of BIM can be identified that provide insight to the added value of BIM and how are they related?*

Answering this question is an important step before the model can be developed. Using a degree of prior knowledge, together with an extensive literature search and review clarifies the relationships and how the key concepts contribute to the research question.

> 2. *Which BIM uses and benefits can be distinguished from literature to investigate their contribution to the added value of BIM?*

A literature search will be conducted to derive the numerous uses and benefits of BIM. However, to delimit this research, not all of them are captured in the model. A clear overview of the uses and benefits is provided that occur the most in practice.

> 3. *Which BIM uses and benefits identified in literature can be recognized in practice?*

To further delimit this research and to verify the findings about the BIM uses and benefits from literature, case studies will be used to investigate their occurrence and value in practice.

In addition to these sub questions, three more sub questions raised that cover specific results and underpin the ultimate findings, these are:

> 4. *Are there any BIM benefits that are experienced more when a project is performed at a higher BIM level?*
>
> 5. *Which requirements are necessary at least to apply particular BIM uses and experience their benefits?*
>
> 6. *Which BIM uses contribute to what extent to the financial benefits found in the study?*

These final three sub questions are formulated during the research itself, due to new insights, and will be mentioned in the model description.

Which methods are used to find an answer to these questions will be described in the next section, the research design.

1.4 RESEARCH DESIGN

Subsequent to the previous section, the research design is the framework created to seek the answers to the research questions. In this research different research designs are combined. The entire research design is summarized in figure 1-1.

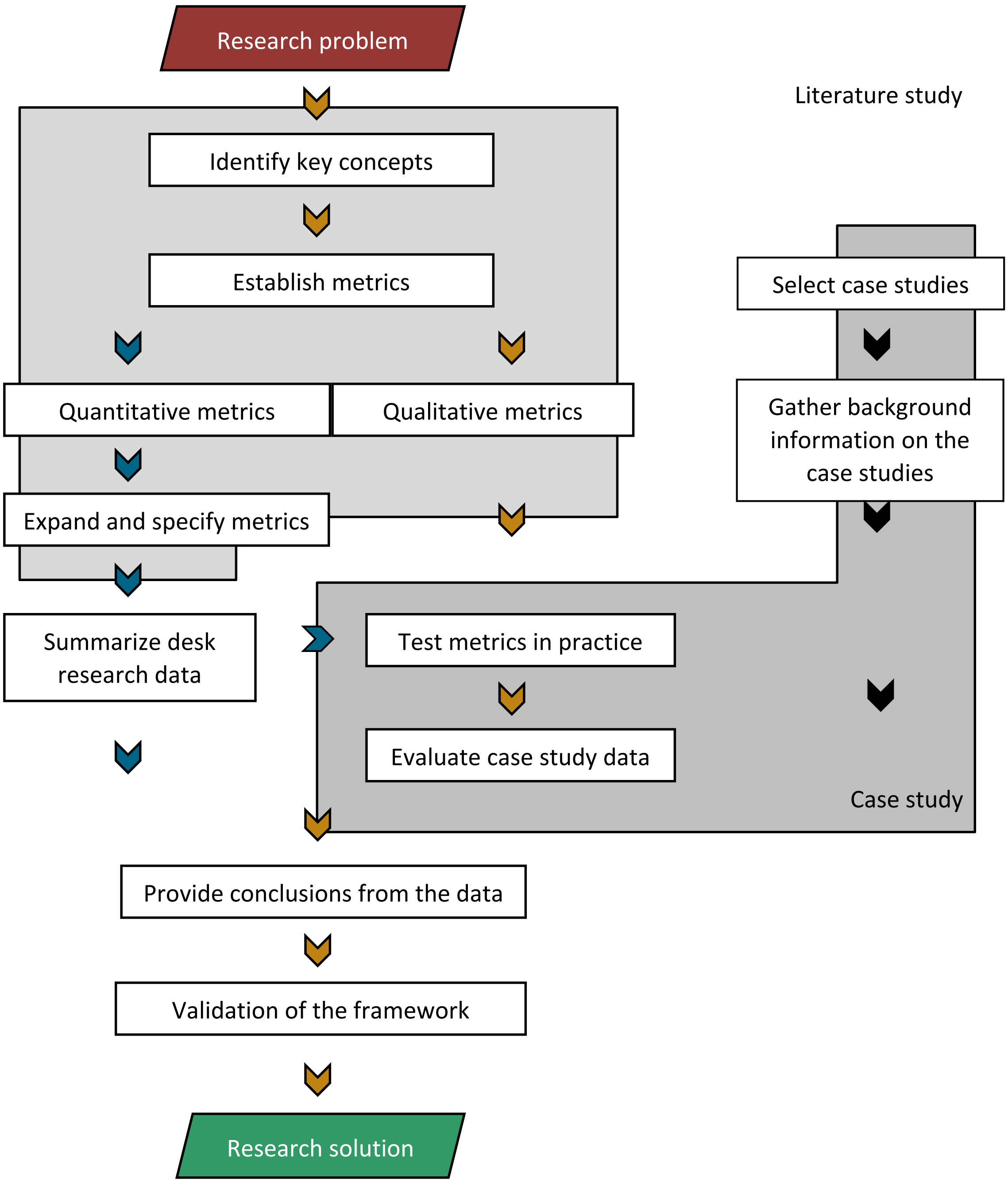


Figure 1-1 Research design

At the start of this research an extensive literature search is conducted, resulting in the literature review of chapter 3. This review includes the current knowledge, as well as theoretical and methodological contributions to the research topic. From the literature search, the most important key concepts regarding BIM are derived. These concepts include qualitative metrics, such as general benefits of BIM, and quantitative metrics, such as perceived values of savings in costs and time due to the implementation of BIM.
Now that the most important key concepts are understood, and both, qualitative and quantitative metrics are established, the research design proceeds according to a parallel structure. Whereas the qualitative metrics could be directly tested in several case studies, the quantitative metrics are expanded and specified first. This is necessary because a broad range of quantitative values are mentioned in the literature, all concluded from different types of methods. These different types of methods are all associated with a certain amount of reliability. To find values that can be tested in practice, these aspects are investigated and discussed first.
At the same time, several case studies are selected. Using a sample of past projects, eight case studies are conducted. In the study, a recently constructed project with BIM is compared to a similar project without BIM. The first step in this case study approach is to gather background information on the case studies, for instance the assignment, size, scope and experiences of employees.
At this point the defined metrics can be tested against the case studies, together with the background information. The results are evaluated further in chapter 5, using a case study approach.
The final steps of the research design include providing conclusion from the earlier approaches and to validate the framework.
When the research design is continued until this step, the final research conclusion can be formulated.

1.5 EXPECTED RESULTS

This section describes the initial motivation to this research. As mentioned before, the proponents of BIM are convinced about its added value, also in infrastructure. But there are still sceptic civil engineers at this moment. Proponents are trying to clarify the added value of BIM, mainly by consulting the qualitative benefits of the approach. They ensure that it saves time and money to implement BIM and mention some of its applications as the detailed visualizations or the smoother information exchange among different stakeholders. Because, until now, this seems inconclusive to implement BIM in infrastructure projects on a large scale, they are searching for quantified values in order to prove that BIM works. They believe that these values will assist their beliefs as they for instance largely expect financial benefits from 10% up to 20% savings per project.

From the beginning of this research it was clear that the quantification of the values would be the hardest part, as there is little quantified data available. The ideal situation to quantify the values is investigating the same project, once constructed using a BIM approach and at the same time constructed without any use of BIM. In that case the resulted can be compared easily and immediately considered to be valid. All metrics, even time, should be the same in such an approach. This is unfeasible as time and place are already conflicting metrics for instance. A realistic similar method has to be composed. Also, this ideal situation will never occur in real life projects, as at a certain moment the stakeholders should agree upon each other whether to choose a BIM approach or not.

The result of this approach is that the findings can be validated extensively, but that they will always depend on the type of project. The final conclusion will be formulated using a saving range, rather than an exact value. This range provides the proponents guidance to convince their clients in civil engineering. And the clients no longer have to rely on qualitative benefits only, but will obtain an indication of the quantitative values. Because they do not ask for an exact value, this indicative values will strongly contribute to prove the added value of BIM. The final expectation is that the quantified values turn out to be beneficial and provide an increased number of the implementation of BIM in civil engineering.
The expected results can be summarized in a hypothesis for this research, which is stated below;

> *The findings of this research will contribute to prove the added value of Building Information Modelling. The expectation is that the findings can be quantified and that they turn out to be beneficial in terms of costs and time. If they do, BIM is expected to be increasingly implemented in infrastructure projects. Based on promises, costs savings about 10%-20% would be achievable if BIM is used in a building project.*

In the next section, a brief thesis outline will be given, which shortly describes which information can be found in which chapter. The thesis outline serves as a guidance for the reader of this thesis.

1.6 THESIS OUTLINE

This first chapter presents the problem with the implementation of BIM in infrastructure projects. The importance of quantifying the added value of BIM is emphasized. In addition, the research design is explained, including the problem statement, research questions, boundaries and methodology.
Chapter 2 presents a theoretical framework regarding this research. This chapter is included to clarify the scope of this research and to specify its demarcation. The term BIM is defined, as well as its used are clarified. Infrastructure projects, in its entirety, is divided into specific research topics. The case studies focus on road development projects, which is further subdivided based on the stage of a project. Also the project life cycle is explained, providing a corresponding classification in the research. The project starts with the planning stage, and, through the design and construction stage, it ends with the operation stage. The use of BIM in each of these stages is briefly mentioned. At the end of the chapter, the prior knowledge regarding the Return on Investment (ROI) of BIM is given.
In chapter 3 a literature review is presented. The literature study contains; an introduction, the multiple definitions of BIM, as well as uses, the benefits of BIM, its implementation, especially in civil engineering, the BIM maturity models and finally the conclusion. The literature review describes prior research and the current situation of the problem and how this research responds to this. Due to this part, an opinion can be formed about the research problem.
The fourth chapter includes the structure of the model. In order to reproduce the research, a roadmap is developed that describes each step of the model.
The results of the research, that should be considered separately from the model, are presented in chapter 5. To follow the model, the results are also explained step by step. At the end of this chapter, the main findings are summarized in a conclusion.

The findings of this research will be discussed in chapter 6. The interpretation of the findings will be discussed, as well as recommendations for future research will be provided.
Chapter 7 follows on this discussion and describes the answers to the research questions, societal and scientific relevance of this research.
The thesis further includes an extended list of appendices. The different text fragments reference to the corresponding appendix.
The next chapter, chapter 2, provides a theoretical framework for this research. It describes the most important definition, classification and research boundaries related to the problem definition.

2 Theoretical framework

2.1 DEFINITION OF BUILDING INFORMATION MODELLING

In the next chapter an extensive literature study will be conducted, which describes that there is no consensus about a single definition of what BIM is. To follow the research design, this definition has to be clarified before the model can be developed.
In this research the complete definition of BIM is used, including the entire approach of processes, instead of only considering BIM as a 3D model. This implies that BIM is a process of working together. It also implies that BIM is a tool rather than a goal on its own. BIM can be seen as virtual design, because making detailed visualizations is one of its main applications. Implementing BIM provides better communication and information exchange among all the stakeholders involved in a building project. This is in addition to the idea that BIM works supporting to integrated project delivery (IPD). BIM is applicable during the complete life cycle of building projects and, due to its features, failures can be discovered early on in this life cycle. Finally, the complete definition implies that BIM is not working without appointments or structures. This last feature holds for instance the Systems Engineering (SE) process to structure information in infrastructure projects.
Besides these features, it is also helpful for the scope of this research to clarify the misunderstandings of the definition of BIM. As the definition of BIM implies that not everyone is working on his own. Secondly, BIM is not a goal on its own as it is neither a software tool only. Another clarification is that BIM cannot solve everything and it does not provide one all-encompassing database. BIM is not for sale as a package, because various investments are necessary before it can be used in a building project. Finally, BIM is not working according a uniform methodology and the process of using it is not fully developed yet. These definitions are summarized in table 2-1.

BIM is	BIM is not
Working together	Everyone on his own
A tool	A goal on its own
Virtual design	Software only
Better communication	Solving everything
Information exchange	An all-encompassing database
Supporting to integrated project delivery (IPD)	For sale as one package
Applicable during the complete life cycle of building projects	Working according a uniform methodology
Early discovery of failures	Design only
Not working without appointments or structures	Fully developed

Table 2-1 What is BIM? (derived from "VIRTUEEL BOUWEN / BIM IN DE GWW Voorstellen," n.d.)

To avoid misunderstandings and uncertainty in this research, it is chosen to retain one definition of BIM that best represents its foregoing features. The definition of BIM in this research is;

> *"BIM is the process of creating and using one or more (3D) object oriented databases of a construction in its environment, relevant for the design, realisation, maintenance and repurposing of that construction during its life cycle." (Arcadis, 2014)*

When BIM is discussed further on in this research, this definition is meant. Besides the definition, it is also relevant to limit the BIM uses that are investigated in this research.

2.2 CLASSIFICATION OF BIM USES

Information about the BIM uses from literature clarifies that the uses are mostly organized by project stage (design, construct and operate). However, this classification does not fully match the scope of this research, given its limitations. First of all, as most BIM uses can occur in multiple project stages, a use does not reside within one single stage. It is debatable if every use of BIM can be applied during any stage of the life cycle. Secondly, the proposed structure has few levels, categories or classes of BIM uses. This structure is not adaptable to change, for instance when there is a need to add new BIM uses. A classification system is needed that standardizes the list of uses in terms of names and definitions.
The main advantage of a proper classification system of the BIM uses is that it provides a common language, causing teams to communicate clearly about the implementation of BIM. For this research the classification system from the Pennsylvania State University is used (Rg Kreider & Messner, 2013). This system is explained using a poster to communicate the precise purpose and context of implementing BIM on a capital facility project. According to this classification system, the BIM uses in this research are not classified by facility stages, but on the purpose of implementing BIM.
The system is developed through a comprehensive ontology methodology. The methods used to classify the BIM uses are: defining domain and scope, acquiring domain knowledge, identifying domain terms, integrating the terms, evaluating the classification system and documenting the classification system. Content analysis, software analysis, brainstorming and industry practice analysis are used to develop the classification system. The 550 documented terms are subsequently grouped by common attributes into approximately 30 groups. These groups are organized into larger categories of BIM uses and into a hierarchical structure. Based on internal evaluation, the ontology is updated and validated externally. Based on the external feedback, from interviews and group meetings, the structure is updated and documented (Rg Kreider & Messner, 2013).
This classification system will be retained during the complete research, for instance when determining the BIM uses in the case studies.

2.3 SELECTION OF INFRASTRUCTURE PROJECTS

The focus in this research is on the added value of BIM in infrastructure projects. To make the case studies comparable, the definition of infrastructure projects is specified.
Infrastructure can be summarized as the basic physical and organizational structures and facilities of a country, city or area, including for instance transportation, communication, sewage, water and electric systems. Because of the availability of data, the focus in this research is on transportation, which can be further concentrated on road development. Road

development can be further specified based on its activities in the design, construction and operation stage.
Road development in the design stage includes designing a road for its environment in order to extend its longevity and reduce maintenance.
The design information serves as an input for the second stage, the road construction. The information has to be moved from the plan to the ground, which is mostly accomplished by staking. There a several tactics to do this. The next step after in road construction, after staking, is clearing and grubbing the project area. Furthermore, some construction is sub graded, which is filled afterwards.
Finally, road maintenance is essential in order to preserve the road in its originally constructed condition. Furthermore, it protects resources and guarantees user safety and it provides efficient traveling along the route. Because maintenance was often neglected in infrastructure projects, a built plan is used nowadays. This ensures the planning for the road maintenances needed (Fao, 1998).

Although all the selected case studies are about road development projects, the activities vary over each of the mentioned road development stages. However, this distinction does not limit the implementation of BIM in a project, as its uses might be applicable at all of the stages. The different BIM uses in road development projects will be examined at a later stage of this research and described in chapter 5.

2.4 EXPLANATION OF THE PROJECT LIFE CYCLE

In project development, a frequently mentioned notion is the project life cycle. This term needs to be defined in order to use it in this thesis unambiguous. The definition of a project life cycle in the AEC industry in this research is;

> *Project life cycle refers to the view of a building project over the course of its entire life - in other words, viewing it not just as an operational building, but also taking into account the planning, design, construction and operation (Kotaja, 2003).*

As this definition presents, consecutive stages can be identified in the entire project life cycle. For the purpose of this research the project life cycle is broken down into a planning stage, design stage, construction stage and operation stage. The typical project life cycle of an building project is summarized in figure 2-1.

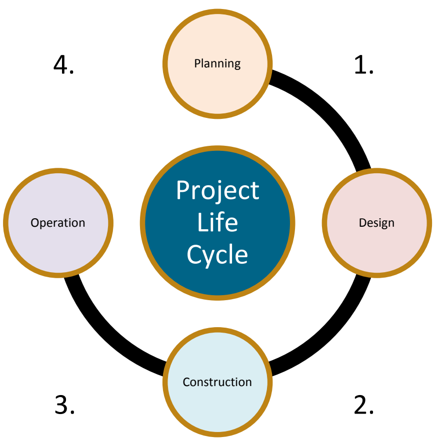


Figure 2-1 Project life cycle

According to section 1.1, BIM is expected to be useful and provide benefits at all of the stages of the project life cycle. The explanation of the project life cycle is important, because the added value of BIM might differ depending on the stage of the project life cycle.

2.5 RETURN ON INVESTMENT

The added value of BIM in the entire project lifecycle is often weighed by measuring the ROI of BIM. The ROI, in this research, is a part of the quantification process of the added value of BIM in terms of costs savings. A ROI calculation for BIM is difficult as there are a lot of other variables than investment costs and revenues that play a role. New software, upgraded hardware and training of employees are requirements necessary to successfully implement BIM. The specific costs of these investments depend on the current state of a company or organization and are therefore hard to determine. An additional difficulty is that the measurement of ROI is often challenged by the complexity and uniqueness of a building project. Besides these limitations, ROI is often unable to represent intangible factors that are important to a project or a company, such as avoided costs or improved safety.

Due to the shortcomings of this method, the final values in this research are not claimed to be definitive percentages, but rather an analysis from which trends and patterns can be identified. Because the investments needed for BIM are hard to determine in terms of costs, the findings focus on financial savings as a result. The results can have relevance beyond determining whether or not to adopt BIM.

3 Literature review

Before the explanation of the model, a literature review is conducted to find out what is already known about the research topic and which methods are already used to assess the implementation of BIM in certain building projects. The review motivates the research topic, describes key concepts regarding BIM, defines the boundaries of the research, reviews relevant literature, develops a model to guide future research and presents a conclusion for investigators and project managers.

3.1 INTRODUCTION

BIM is becoming more and more important to manage complex communication and information sharing processes in collaborative building projects. A growing number of design, engineering and construction firms have made attempts to adopt BIM to enhance their services and products. However, there are many uncertainties regarding the implementation of BIM and the actual performance. This is because there is no common benchmarking tool to objectively assess the performance of BIM (Barlish & Sullivan, 2012; Sebastian & van Berlo, 2010).

In the absence of this benchmarking tool, it is necessary to clarify the added value of BIM to project managers in order to ensure a successful implementation. Usually these managers have to decide whether to invest in the implementation of BIM or to proceed with a non-BIM approach. The utilization of BIM has not been clearly established to be beneficial to the overall outcomes of a building project (Barlish & Sullivan, 2012; Li et al., 2014). The most efficient method to care for these managers willing to invest in the implementation of BIM is to show them the applications and benefits of BIM. However, the first step in the implementation is to ensure that all stakeholders involved in a project have the same interpretation of BIM. As the perceived benefits differ across stakeholders, comparisons of benefits across projects become difficult to obtain and not valid (Barlish & Sullivan, 2012; Bryde, Broquetas, & Volm, 2013). In several countries attempts are made to provide an overview of all relevant definitions of BIM, but despite these attempts there remain heterogeneous definitions of BIM (Sebastian & van Berlo, 2010). According to the conducted literature study there are countless definitions of what BIM is. The frequency and variety of the definitions of BIM illustrate the confusion in quantifying BIM and putting it in terms of potential benefits (Barlish & Sullivan, 2012). In fact, most articles attempt to define BIM in their own terms. Some of them will be discussed in the next section.

3.2 DEFINITIONS OF BIM

In the literature, numerous reviews of the implementation of BIM and definitions of BIM exist . But, up to now, there is still no single satisfactory definition of what BIM is (Miettinen &

Paavola, 2014). With regard to the innovation due to BIM, Hardin (as cited in Azhar, Khalfan, & Maqsood, 2012), in 2009, argues that BIM is a revolutionary technology and process that has quickly transformed the way buildings are conceived, designed, constructed and operated. Four years earlier BIM was especially perceived as a software tool, among others by The Associated General Contractors of America (AGC). Their definition of BIM describes the development and use of a computer software model to simulate the construction and operation of a facility. The result consist of a data-rich, object-oriented, intelligent and parametric representation of this facility. From this model users' requirements can be extracted and analysed to generate information that contributes to the decision-making processes (AGC, 2005, as cited Azhar et al., 2012). The National Building Information Modelling Standards (NBIMS) committee of USA appoints a more extensive definition of BIM and defines it as a digital representation of physical and functional characteristics of a facility. This definition not only includes the digital representation but also the opportunity to share knowledge and information in order to facilitate decision-making. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle (NBIMS, 2010, as cited in Azhar et al., 2012). Succar (2009) defines BIM as a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the life cycle of buildings. Succar' s definition of BIM above highlights its integrated intention, which includes not only software but also project management related processes. According to this holistic definition BIM provides the opportunity to a better collaboration between stakeholders and to reduce the time necessary for a building project (Bryde et al., 2013). According to Glick and Guggemos, BIM also supports the concept of Integrated Project Delivery (IDP) which is a novel project delivery approach to integrate people, systems, business structures and practices into a collaborative process to reduce waste and optimize efficiency through all phases of the project life cycle (Glick and Guggemos, 2009, as cited in Azhar et al., 2011).

Based on these definitions, BIM is not only about software, but it also tries to make progressive changes in the workflow and project delivery processes (Hardin, 2009, as cited in Azhar, 2011). Azhar (2011) defines BIM as a virtual process that encompasses all aspects and systems of a facility within a virtual model, allowing all team members to collaborate more efficiently than using traditional processes.

Several articles discuss surveying building professionals for their perceptions of BIM and their definitions. Resulting in a conclusion from Zuppa et al., who found that BIM was most frequently perceived as a tool for visualizing and coordinating AEC work and avoiding errors and omissions (Barlish & Sullivan, 2012).

According to the preceding subparagraphs, for some, BIM is a software application, for others it is a process for designing and documenting building information, for others it is a whole new approach to practice and advancing the profession which requires the implementation of new policies, contract and relationships amongst project stakeholders (Barlish & Sullivan, 2012). It encourages all stakeholders to participate in order to optimize efficiency through all stages of the building process. BIM proposes frameworks and technologies for the integration of large amounts of information in the model and it effectively centralizes information sharing among stakeholders from different disciplines (Sebastian & van Berlo, 2010).

The shift of the definition from software tool towards a complete change in workflow is supported by findings of researchers in the United Kingdom construction sector. They conducted survey questionnaires amongst the major contractors in the United Kingdom to recognize BIM understanding and awareness. Over 62 percent of the respondents defined BIM as 3D modelling, analysis and documentation for the building life cycle (Khosrowshahi & Arayici, 2012).

This definition of BIM as a complete change in workflow is increasingly used by contractors in building projects nowadays. BIM is defined by international standards as a shared digital representation of physical and functional characteristics of any built object, which forms a reliable basis for decisions (ISO Standard, 2010, as cited in Volk, Stengel, & Schultmann, 2014). Although this more extensive definition is more and more widely adopted by contractors in building projects, a narrow and a broader perspective can be distinguished. Once again BIM in a narrow sense solely contains the digital building model itself. The broader perspective of BIM can be divided into interrelated functional, informational, technical and organizational issues. The model can be used to support expert services with regard to the interest of different stakeholders, for instance energy analyses (Volk et al., 2014).
Based on these findings from the literature there are so many definitions of BIM that it is difficult to find a proper one. And there is no consensus of the outcomes that stakeholders will receive from its utilization in a building project. One can imagine that the frequency and variety of these definitions cause confusion in defining BIM. It not only complicates the collaborative processes between stakeholders, but also the measurement of the performance of BIM, as it is too general and qualitative. This uncertainty clarifies the need for a relevant methodology to evaluate the expected benefits of BIM (Barlish & Sullivan, 2012).

3.3 APPLICATIONS OF BIM

On the one hand the many definitions of BIM might cause confusion about what BIM is and how it can be used and provide benefits, on the other hand these materialize BIM to be widely applicable during the project life cycle. The applicability of BIM during the complete life cycle of building projects will be discussed in the next section.

BIM can, for example, be used for visualization, fabrication, code reviews, forensic analysis, facilities management, cost estimating, construction sequencing and conflict, interference and collision detection (Azhar, Hein, & Sketo, 2007). These applications will be briefly explained in this section. The visualization application contains 3D renderings that can be generated from a model at any time of the project life cycle. Due to fabrication applications shop drawings can be quickly produced once the model is complete. Code reviews are useful for officials, for instance fire departments, for their review of building projects. The model can also be easily adapted to illustrate potential failures, leaks, evacuation plan etc., which is useful for forensic analysis. Facilities management departments can use BIM for renovations, space planning and maintenance operations. The model can be used to create material ordering, fabrication and delivery schedules for all building components. And finally, all systems can be computationally checked for interferences, which is mentioned as conflict detection (Azhar et al., 2007). For project stakeholders the applications are defined as visualization, options analysis, sustainability analysis, quantity survey, cost estimation, site logistics, phasing and 4D scheduling, constructability analysis, building performance analysis and building management, pretty much in line with the applications mentioned by Azhar et al. (2007) (Azhar et al., 2012). Additional research shows that there is a significant distinction in the amount of use of the different BIM applications. Survey results show that the average frequency is the highest for 3D coordination, design reviews and design authoring and that disaster planning, building maintenance scheduling and asset management are still neglected. Besides the frequency the article also mentions the perceived level of benefit to the project for each applications. The results show that 3D coordination and design reviews have also the most perceived benefit (Ralph Kreider, Messner, & Dubler, 2010). In 2011, the BIM applications according to Azhar are unchanged as he mentions exactly the same applications as in 2007. He continues by arguing

that construction document development, conceptual design support and preproject planning services are the major application areas of BIM demonstrated by the results of a questionnaire survey (Azhar, 2011).
In accordance with the shift of the definition of BIM, the applicability is also changing. The most often used applications concentrated on design and visualization, procurement, manufacturing, construction management and coordination rather than on commissioning, facility management or deconstruction. But recently, planning and handover processes shift towards integrated project delivery in a collaborative environment (Bryde et al., 2013; Volk et al., 2014).

3.3.1 APPLICATION DURING THE COMPLETE LIFE CYCLE

Azhar, Khalfan and Maqsood (2012) also specify the applications of BIM especially during the project life cycle, namely in the project programming, design, preconstruction, construction and post-construction phases. The applications within this phases are expanded in the article and include, for example estimating, site coordination and constructability analysis in the preconstruction phase. This allows the project team to analyse space, which saves time. In the construction phase, BIM can be used for project progress monitoring, trade coordination meetings and integrating requests for information (RFIs). It is necessary for the project team to continuously update the model so that the information is up-to-date, which can be used in later stages of the life cycle. In the post construction phase of a building project, operations and maintenance of a facility can be made more efficient using BIM, as the model contains complete information of a facility. The post construction phase is important, as researchers discovered that about 85% of the lifecycle cost occurs after the construction is completed. Due to inadequate information access and interoperability issues during earlier stages of the life cycle, a lot of money is lost. The use of BIM in this stage can help to prevent these loses. Besides the potential use at all stages of the project life cycle, it can be used by different members of a project team. By the clients to understand project needs, by the designers to analyse, design and develop the project, by the contractor to manage the construction of the project and by the facility manager during the operation phase (Grilo and Jardim-Gonvalves, 2010, as cited in Bryde et al., 2013).
However BIM is considered to be useful at all the stages of the project life cycle, there remains a difference in frequency of use at each stage. BIM if most often used in the design and preconstruction stage of a project. BIM is used to a lesser extent in the construction stage and even less for early feasibility work. BIM is used the least in the operation and management stage of building projects. This may be due to the fact that many companies have only just adopted BIM or that other processes are the preferred choice. Another cause is that few clients are able to utilize the outputs. This will change as clients become aware of the value of BIM and experience its full benefits (Eadie, Browne, Odeyinka, McKeown, & McNiff, 2013).
In addition to the shift in definition and application, the use of BIM in the different project stages is also changing. As previously its focus was on preplanning, design, construction and integrated project delivery if building projects, it recently shifts from earlier life cycle stages to maintenance, refurbishment, deconstruction and end-of-life considerations (Volk et al., 2014). Looking to the future leads to speculation that BIM will eventually lead to a virtual project design and construction approach, with a project being completely simulated before being undertaken for real (Froese, 2010, as cited in Bryde et al., 2013). BIM will provide benefits by enabling rapid analysis of different scenarios related to the performance of a building project through its lifecycle (Schade et al., 2011, as cited in Bryde et al., 2013). Steps towards this are already taking place, with construction projects that utilize BIM typically being built virtually

30-40 times (BuildOffsite, 2011, as cited in Bryde et al., 2013). Without doubt, BIM has potential to be used throughout the life cycle of a building project. However, there is little knowledge about uses with authorities, or collaborative uses by designers and users in early stages of building design (Miettinen & Paavola, 2014).

3.4 BENEFITS OF BIM

As well as about the definitions and the applications BIM, there is still no consensus of the benefits of BIM. No accepted calculation methodology and baseline to evaluate the benefits of BIM have been established. This causes mixed perspectives and opinions of the benefits, creating a misunderstanding of expected outcomes (Barlish & Sullivan, 2012). The next section will describe which advantages are derived from the literature study. The key benefit of BIM is considered to be its accurate geometrical representation of the parts of a building in an integrated data environment (CRC Construction Innovation, 2007, as cited in Azhar et al., 2007) Other related benefits are faster and more effective processes, better design, controlled whole-life costs and environmental data, better production quality, automated assembly, better customer service and lifecycle data. The benefits of BIM can also be described more general as creativity, sustainability, improve quality, reduced human resource, reduced cost and reduced time. The results of a survey questionnaire show that the respondents believe that using BIM can save cost of design and can benefit from earlier access to the construction market. Saving money will also reduce the time necessary for the construction of building projects (Yan & Damian, 2008). These issues were also explored in a study by Becerik-Gerber and Rive in early 2009. BIM has a largely positive impact on project schedule and costs, according to their SmartMarket Report. A majority of the respondents said BIM helped cut project costs. Also printing, document shipping and travel costs were reduced when using BIM instead of traditional processes. Moreover, respondents were most likely to report that project profitability increased as a result of using BIM. The same article also focuses on the internal business benefits. With, experience users begin to see how BIM can offer added value to their companies. The five most internal benefits turn out to be marketing new business to new clients, overall better construction project outcomes, reduced errors and omissions in construction documents, offering new services and reducing rework. Besides benefits of saving time and money also better understanding in all stages of the project and better collaboration are experienced. The benefits can also be distinguished in each of these project stages. When constructing documents, BIM shows value as designs include a lot of data. BIM helps to improve communication between the design world and the building team. In the design stage the benefits of BIM are the most obvious, as more detailed models are created. BIM in the construction stage can save time and money, for instance reducing systems clashes. In the fabrication stage BIM is useful to extract data from a data-rich model, which eliminates the need of draw specifications (Young Jr., Jones, & Bernstein, 2009). The benefits are studied in depth by Bryde et al. (2013), reporting 35 cases in literature, in which BIM is used to a greater or lesser extent. Based on the results, cost reduction is most often seen as receiving a positive effect from the use of BIM. The second criterion with the highest positive benefits of using BIM is time. Also the effects of BIM on the communication success criterion were all positive. Examples are better information exchange, information is a lot easier to find and better communication of changes with the owner. Manning and Messner (2008, as cited in Li et al., 2014) identified primary benefits as rapid visualization, better decision support upstream in the project development process, the rapid and accurate updating of changes, the reduction of the man-hours required to establish reliable spaced programmes, increased communication across the total project development team and increased confidence in the completeness of the scope. According to Volk et al. (2014) major benefits consist in design consistency and visualization, cost estimations, clash detection, implementation of lean construction and improved stakeholder collaboration, quite similar to its applications according the previous section.

3.5 IMPLEMENTATION OF BIM

Based on these advantages project managers have to decide whether to implement BIM in their building projects. Not surprising that some of them are still sceptical as the benefits are not clear to them. Besides this uncertainty there are several other reasons mentioned in the literature which impede the implementation of BIM. These will be discussed in this section.

When discussing the implementation of BIM, Eadie et al. (2013) agree with the definition of BIM as a change in workflow, as mentioned in section 3.2. The implementation of BIM may have impact on all the processes within a building project and cannot be treated as a software tool only. However, to have a successful implementation of BIM, all the project team members need security of confidential data to the BIM model. The BIM model can be part of an external network which may lead to legal issues. To reduce this risk, there is a need to deal with legal issues when drafting the contract.

In 2012, Mohsen and Issa tried to evaluate the current implementation of BIM for students in civil and construction engineering curricula. They used a survey that investigated the implementation of BIM into existing civil and construction engineering in the United States. The results show that almost half of the respondents have an interest in BIM or already implemented BIM in their project. Although this rate is not bad, some academic programs are waiting for student interest, others lack faculty expertise and yet other have not determined the need of BIM in their curriculum. As a result of this research, schools in the U.S. are restructuring curriculum and hiring faculty with expertise in BIM to better prepare students for the growing demand for BIM knowledge (Mohsen & Issa, 2012).

Almost the same approach is used to draft a roadmap for the implementation of BIM in the construction industry in the United Kingdom. The paper aims to diagnose UK’s construction industry to develop a clear understanding about BIM adaptation, to form an iterative step of movements towards wider BIM implementation and to provide recommendations for the implementation of BIM. The findings suggest organizational culture, education and training and information management to be solutions to tackle technology, process and people issues in BIM implementation. The research attempts to apply existing knowledge about the implementation of BIM in Finland and conduct comparative interpretation and diagnosis of the implementation of BIM in the UK. Following on including BIM in curricula, the research mentions education and training as an important part of the implementation of BIM. The respondents confirmed that all the people involved in projects require up skilling for successful implementation. Other reasons for not using BIM are firms that are not familiar with BIM use, reluctance to initiate new workflows or train staff, benefits do not outweigh the costs, benefits are not tangible, BIM does not offer enough of a financial gain, lacks the capital to invest, BIM is too risky from a liability standpoint, resistance to culture change and no demand for BIM use (Khosrowshahi & Arayici, 2012).

Further recommendations for the implementation of BIM are provided after reviewing benefits as well as obstacles and problems. The implementation of BIM will contribute to greater construction industry efficiencies and there are many powerful BIM tools for analysis. However, these software tools solely are insufficient for an efficient implementation of BIM. Changes in work practices, staff skills, relations with clients and participants of the project

team as well as contractual arrangements are required. The obstacles are greater in small markets, where the companies have not enough resources to obtain BIM methodology. Besides the lack of expertise in different groups, another less obvious obstacle mentioned at the end of the article is the lack of information about the strict standards and rules of implementation (Migilinskas, Popov, Juocevicius, & Ustinovichius, 2013).
The most important barriers seems to be the costs of implementing BIM, for instance in terms of resources and training. Hore et al. (2011, as cited in Eadie et al., 2013) came up with the solution of subsidy by the Government to facilitate the implementation when the adoption of BIM becomes a requirement. In the same research the additional reasons for not using BIM are then investigated. The reasons identified from literature are lack of expertise within the project team and organizations, lack of client demand, cultural resistance, investment costs, lack of additional project finance to support BIM, resistance at operational level, reluctance of team members to share information, lack of immediate benefits from projects delivered to date and legal issues around ownership.
In the literature review of Volk et al. (2014) the main obstacles of the implementation of BIM are summarized once again. Often mentioned obstacles are a fragmented AEC industry, resistance to changes in employment patterns and processes, slowly adapting training of personnel, lacking customized collaboration systems, as well as prevailing problems of liability, data security and interoperability.

3.5.1 BIM IN CIVIL ENGINEERING

As mentioned before there are sceptics towards the implementation of BIM, especially in civil engineering. These sceptics have several reasons for not implementing BIM in their projects and believe that it would not make any difference. While the implementation of BIM in building industry is getting well-established, civil engineers are sceptical in adopting BIM for infrastructure projects. As BIM adaptation has become more of a standard in the AEC industry, civil engineers are wondering what BIM means for them. For civil engineers who already work with architects or structural engineers, BIM may be part of their vocabulary. But for others, BIM represents a whole new world, one that is highly relevant now and will continue to grow in importance (Strafaci, 2008). BIM is an emerging tool for civil engineers. Although few civil engineers use BIM today, they believe it will be valuable in the future. The civil engineers who already use BIM today see multiple opportunities for benefits. They see value in greater client engagement, greater community engagement, quantity take-offs and spatial coordination (Young Jr. et al., 2009).
The lack of interest can be explained because the building industry depends more on geometry and appearance than infrastructures. In civil engineering the functional requirements of objectives are more important and not fully depending on their sizes. Another case of doubt for the implementation of BIM might be that in the building industry there is a delimited area, whereas infrastructure projects may include hundreds of square kilometres. For instance pipelines are seldom scaled on a project plan, which causes a 2D-representation or Geographic Information System (GIS) to be sufficient for managing these extensive projects.
The main disadvantage of implementing BIM in civil engineering is the lack of specialists, experts and operators. It takes time and money to encourage and train civil engineers to get used to BIM (Keung, 2012).

In spite of these limitations, experts recognize opportunities for BIM to be successfully implemented in civil engineering too. More than ever before civil engineers will benefit from 3D-representation of highways, railways, tunnels and bridges, as these are no doubt 3D-structures. Beyond efficiency and productivity, BIM facilitates roadway optimization by including visualization, simulation, and analysis as part of the design process (Strafaci, 2008). The benefits regarding these infrastructure projects are mainly similar to those in the building industry, namely better inoperability, shorter construction and cost saving (Keung, 2012). According to a survey conducted on construction companies the areas that would display the largest effects when BIM is introduced are multilateral communication and increase in comprehension, increase in positive impact of marketing and increase in comprehension, increase in positive impact of marketing and increase of site safety. The survey shows that the application of BIM in civil engineering is continuously increasing and the awareness and importance becomes much higher, all towards a smoother implementation of BIM in civil engineering (Seo & Kim, 2012).

3.6 BIM MATURITY

As civil engineers want to know how much time and money it saves them using BIM, a proper assessment tool for BIM should be developed in order to clearly present its main advantages.
This literature review shows that various existing BIM maturity assessment tools are not yet sufficient to serve as a standard benchmarking tool that is objective, comprehensive and collective (Sebastian & van Berlo, 2010). The most important assessment tool is the UK maturity model. Besides this model, Sebastian and van Berlo (2012) found three well-known assessment tools, namely the BIM capability stages, the BIM maturity index (BIMMI) and the national BIM standard (NBIMS) which contains the capability model (CMM). There are also some assessment tools especially developed within the Netherlands, such as BIM Meetlat or the BIM Quickscan. The difference between capability and maturity is defined by Succar in 2009. BIM capability is the ability to generate BIM deliverables and services and BIM maturity addresses the extent, depth, quality, predictability and repeatability of these deliverables.

3.6.1 UK MATURITY MODEL

In 2008, Mark Bew and Mervyn Richards developed the UK maturity model. Although there are many versions of the base model with meaningful differences, the one shown below is the most widely used in the United Kingdom, figure 3-1.

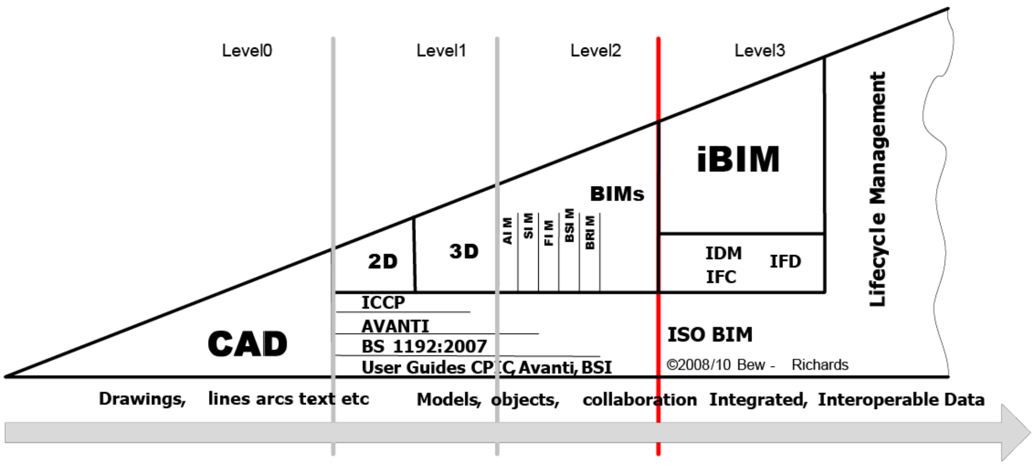


Figure 3-1 UK maturity model (GCCG, 2011)

The model includes four levels from zero up to four. Basic CAD application within a project is identified as level zero or no BIM maturity. This is the conventional way of working in the construction industry. Geometry in 2D is represented by lines between defined points. At this level sharing information is only possible by exchanging separate forms of information, like Word or Excel documents (Jayasena & Weddikkara, 2013). Level 1 contains object orientated models and is also known as parametric design. Objects can be seen as virtual abstract representations of real life homogeneous things, such as windows, doors or columns. Objects have properties as descriptions, specifications, planning and costs. All the objects together is the model. Main advantage of this approach is that teams work in a virtual model providing better understanding and making it easier to change things. Other benefits can be obtained by re-using objects from earlier projects. The next step, level 2, is to integrated the created models into a single federated model. This is a joined up view of multiple, separate models which enables the analysis of integrated aspects of the design. The model can also be connected to planning software, which is called 4D BIM. To reach this level of BIM it is necessary to enable models from different disciplines to be used together. The configuration of different software-tools including the tooling for viewing and analysing the federated model is called the BIM architecture. The next step is to work together with external partners in integrated models, which is also known as Big BIM. In practice, BIM on level 3 is barely used in building projects.

3.6.2 CAPABILITY STAGES

BIM capability stages does not mainly concern the performance of BIM, but more to which extend the companies are ready for its implementation. The BIM capability stages define the minimum BIM requirements that need to be reached by a team or an organization as it implements BIM (Succar, 2009 as cited in Sebastian & van Berlo, 2010). It is a quick way to assess an organization' s ability to deliver BIM services. BIM Stages contains a fixed starting point (the status before BIM implementation), three fixed BIM stages and a variable ending point, which allows for future advancements. The tool consist of three stages namely object-based modelling, model-based collaboration and network-based integration. These three stages are preceded by the pre-BIM status and sealed by the integrated project delivery (Succar, 2009). Figure 3-2 demonstrated the BIM stages.

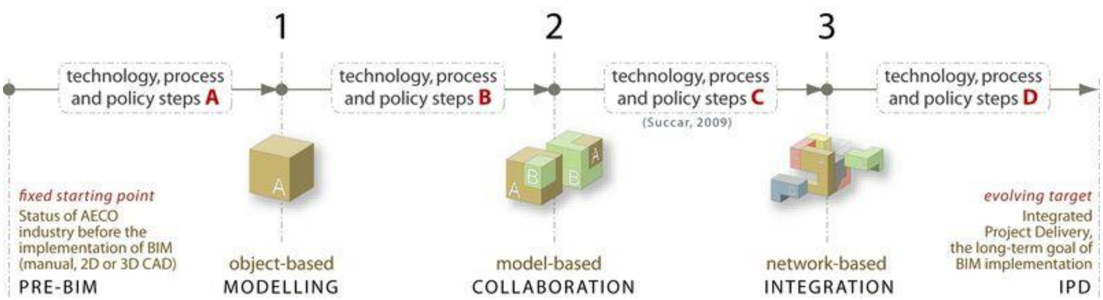


Figure 3-2 BIM capability stages (Succar et al., 2012)

For example, to achieve stage 1, an organization needs to have deployed an object-based modelling software tool similar to Revit. An organization needs to be engaged in a multidisciplinary model-based collaborative project to reach BIM capability stage 2. To be considered at stage 3, an organization needs to be using a network-based solution which links to external databases and shares object-based models with at least two other disciplines

(Succar, Sher, & Williams, 2012). The method is mainly used to evaluate if BIM projects or processes reach the desired level of functionality. Ten levels of BIM maturity are defined for categories of: spatial capability, roles, data richness, delivery method, change management, business process, information accuracy, life cycle views, graphical information, timeliness and response as well as interoperability and industry foundation class support (Volk et al., 2014).
A limitation of this tool is that it cannot assess the capabilities beyond the minimum requirements. Another limitation is that is does not include the possibility to distinguish two organizations that are ate the same BIM stage (Sebastian & van Berlo, 2010). Because Succar' s study was at a conceptual stage, further research is needed to validate the results in the AEC industry (Mom & Hsieh, 2012).

3.6.3 BIM MATURITY INDEX

Because of the limitations of the capability stages, BIMMI was developed by Succar. BIMMI also focuses on the current state of organizations for the implementations of BIM. It differs from capability by mentioning the ability of a company or organization to excel in performing tasks or delivering BIM services. BIMMI contains of five maturity levels, namely initial, defined, managed, integrated and optimized. The higher maturity levels care for better control, better predictability and forecasting, performance cost and greater effectiveness. This assessment tool is more detailed and provides a clearer overview (Sebastian & van Berlo, 2010). The BIM maturity index is presented in figure 3-3.

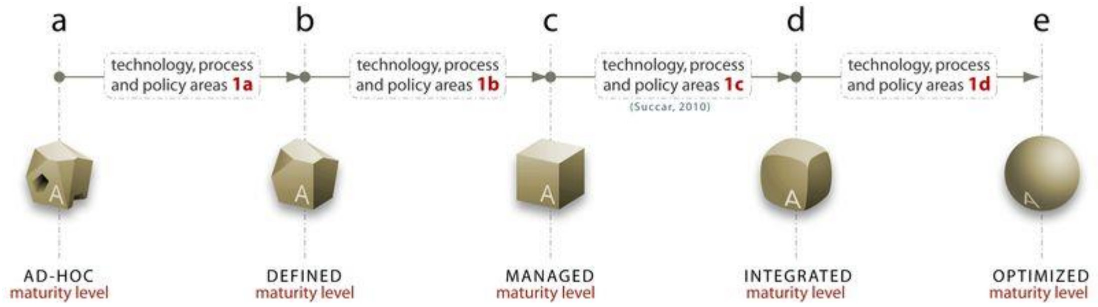


Figure 3-3 BIM maturity index (Succar et al., 2012)

3.6.4 NATIONAL BIM STANDARD

NBIMS CMM is a method that assesses the actual performance of BIM instead of focusing on organizations. NBIMS CMM is the most commonly used assessment tool in the USA (McCuen and Suermann, 2007, as cited in Sebastian & van Berlo, 2010)). It is a matrix with 11 areas of interest on the x-axis and 10 levels of maturity on the y-axis, as van be seen in figure 3-4. Some examples of possible areas of interest are graphical information, business processes or data richness. The y-axis is divided from zero up to 10, with 10 being the most mature. The method is usually performed in Excel, in which different input options are possible. A company can be assessed by minimum BIM, certified, silver, gold and platinum. By reaching a better maturity on each of the eleven components, the assessment approaches platinum. One of its limitations is that NBIMS CMM is not able to compare different models or BIM implementations. This assessment tool has been adapted in the Netherlands and known as BIM Meetlat (Sebastian & van Berlo, 2010).

Maturity Level	A Data Richness	B Life-cycle Views	C Roles Or Disciplines	G Change Management	D Business process	F Timeliness/ Response	E Delivery Method	H Graphical Information	I Spatial Capability	J Information Accuracy	K Interoperability/ IFC Support
1	Basic Core Data	No Complete Project Phase	No Single Role Fully Supported	No CM Capability	Separate Processes Not Integrated	Most Response Info manually re-collected - Slow	Single Point Access No IA	Primarily Text - No Technical Graphics	Not Spatially Located	No Ground Truth	No Interoperability
2	Expanded Data Set	Planning & Design	Only One Role Supported	Aware of CM	Few Bus Processes Collect Info	Most Response Info manually re-collected	Single Point Access w/ Limited IA	2D Non-Intelligent As Designed	Basic Spatial Location	Initial Ground Truth	Forced Interoperability
3	Enhanced Data Set	Add Construction/ Supply	Two Roles Partially Supported	Aware of CM and Root Cause Analysis	Some Bus Process Collect Info	Data Calls Not In BIM But Most Other Data Is	Network Access w/ Basic IA	NCS 2D Non-Intelligent As Designed	Spatially Located	Limited Ground Truth - Int Spaces	Limited Interoperability
4	Data Plus Some Information	Includes Construction/ Supply	Two Roles Fully Supported	Aware CM, RCA and Feedback	Most Bus Processes Collect Info	Limited Response Info Available In BIM	Network Access w/ Full IA	NCS 2D Intelligent As Designed	Located w/ Limited Info Sharing	Full Ground Truth - Int Spaces	Limited Info Transfers Between COTS
5	Data Plus Expanded Information	Includes Constr/Supply & Fabrication	Partial Plan, Design&Constr Supported	Implementing CM	All Business Process(BP) Collect Info	Most Response Info Available In BIM	Limited Web Enabled Services	NCS 2D Intelligent As-Builts	Spatially located w/Metadata	Limited Ground Truth - Int & Ext	Most Info Transfers Between COTS
6	Data w/Limited Authoritative Information	Add Limited Operations & Warranty	Plan, Design & Construction Supported	CM Capability	Few BP Collect & Maintain Info	All Response Info Available In BIM	Full Web Enabled Services	NCS 2D Intelligent And Current	Spatially located w/Full Info Share	Full Ground Truth - Int And Ext	Full Info Transfers Between COTS
7	Data w/ Mostly Authoritative Information	Includes Operations & Warranty	Partial Ops & Sustainment Supported	Implemented	Some BP Collect & Maintain Info	All Response Info From BIM & Timely	Full Web Enabled Services w/IA	3D - Intelligent Graphics	Part of a limited GIS	Limited Comp Areas & Ground Truth	Limited Info Uses IFC's For Interoperability
8	Completely Authoritative Information	Add Financial	Operations & Sustainment Supported	Implementing CM and Root Cause Analysis	All BP Collect & Maintain Info	Limited Real Time Access From BIM	Web Enabled Services - Secure	3D - Current And Intelligent	Part of a more complete GIS	Full Computed Areas & Ground Truth	Expanded Info Uses IFC's For Interoperability
9	Limited Knowledge Management	Full Facility Life-cycle Collection	All Facility Life-Cycle Roles Supported	CM and RCA capability implemented	Some BP Collect&Maint In Real Time	Full Real Time Access From BIM	Netcentric SOA Based CAC Access	4D - Add Time	Integrated into a complete GIS	Comp GT w/Limited Metrics	Most Info Uses IFC's For Interoperability
10	Full Knowledge Management	Supports External Efforts	Internal and External Roles Supported	Implementing CM & RCA and feedback	All BP Collect&Maint In Real Time	Real Time Access w/ Live Feeds	Netcentric SOA Role Based CAC	nD - Time & Cost	Integrated into GIS w/ Full Info Flow	Computed Ground Truth w/Full Metrics	All Info Uses IFC's For Interoperability

Figure 3-4 national BIM standard (Succar, n.d.)

3.6.5 BIM QUICKSCAN

The BIM QuickScan is another well-known method in the Netherlands, developed in 2009 by TNO. Its key advantage is that the QuickScan can be performed in one day only.

There are four areas of interest in BIM QuickScan, namely organization and management, mentality and culture, information structure and information flow and tools and applications. For each area of interest there are a number of KPIs, which are questioned in a survey. Each answer is assigned by a score, which sum represents the total score of BIM performance of an organization in the Netherlands (Sebastian & van Berlo, 2010).

Meanwhile, the tool is frequently applied in the Dutch construction sector providing an online self-assessment and by expert scans by consultancy companies. This resulted in 682 self-scans and 130 expert scans within the construction sector. These results are discussed in the report “Het BIM niveau in Nederland: analyse van BIM QuickScan data 2010-2012”. To analyse each of the four categories, a questionnaire that consists of 50 multiple choice questions is drafted. Also the KPIs differ per category, for instance KPIs for organization and management are defined as vision and strategy, distribution of roles and tasks, organization structure, financial resources, partnership on corporate level and quality assurance. At the end the score on each of these KPIs results in a total score per category. This provides a clear overview of the strengths and weaknesses of an organization. These results can be shown in a radar diagram as shown in figure 3-5 (van Berlo, Dijkmans, & BIM Quickscan advisors, 2012).

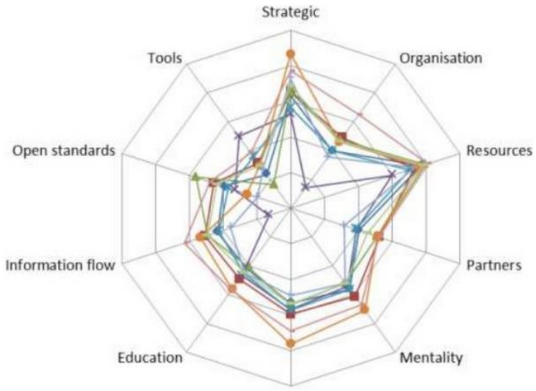


Figure 3-5 BIM quickscan (Succar et al., 2012)

3.7 CONCLUSION

The conducted literature review of about 50 publications presents the current state of the implementation of BIM in large building projects. The review clarified the uncertainties the confusion about a single comprehensive definition of BIM. When BIM was previously seen as a software tool only, nowadays it is considered to be a process for designing and documenting building information or as a whole new approach to practice and advancing the profession. Literature shows this change of the definition of BIM in the last few years. However, researchers are unconsciously working towards a consensus as they increasingly use the comprehensive definition of BIM.

In accordance with the shift of the definition of BIM, the applicability is also changing. However, visualization, manufacturing, procurement and coordination are still the most familiar applications. But recently, users become more and more aware of its applicability in planning and handover processes in favour of integrated project delivery in a collaborative environment. As focusing on the applicability of BIM during the complete life cycle of a building project, a third change may be recognized. As the focus of BIM was previously on preplanning, design, construction and to a lesser extent on integrated project management, it recently shifts from earlier life cycle stages to maintenance, refurbishment, deconstruction and end-of-life-considerations.

The final purpose is that BIM will eventually lead to a virtual project design and construction approach with a project being completely simulated before being undertaken for real. Hence, there is no doubt that the implementation of BIM is beneficial throughout the complete life cycle of a building project.

Whereas the applications and definitions of BIM become more and more clear with the time, the main issue is to clarify its benefits to potential users. This is considered to be the most effective method to convince sceptics to implement BIM in their building project. Until now, the mixed perspectives and opinions of the benefits create a misunderstanding of the expected outcomes. The most frequent mentioned benefits in the literature are saving money and time. Besides these main advantages, also the effects of BIM on the communication process were all positive. Examples are better information exchange, information is a lot easier to find and better communication of changes with the owner. Naturally, based on its difficult implementation, there are also disadvantages to notice. The main obstacles of the implementation of BIM are resistance to change employment patterns and process, slowly adapting training of personnel and a lack of supporting software tools. All the disadvantages together can be summarized as technology, people and process issues, which cause difficulties in its implementation. This hard implementation is mainly recognizable in civil engineering. Civil engineering project depend less on geometry and appearance than buildings. In civil engineering functional requirements are more important. Also the building industry cares for a delimited area, whereas infrastructure projects may include hundreds of square kilometres. Geographic Information Systems (GIS) are considered to be sufficient for managing these infrastructure projects.

There have been several attempts to clarify the added value of BIM using multiple assessment tools. The most important assessment tool is the UK maturity model. Further, the BIM capability stages, the BIM maturity index and the national BIM standard are discussed. Also the results of the BIM quickscan are part of the literature review to assess the current situation of the implementation of BIM in the Netherlands.

This literature review motivates the research topic as there is a need for a standard assessment tool for BIM. The review serves as a guideline for further research. In this graduation study the added value of BIM in infrastructure projects will be clarified.

Accordingly, an attempt will be done to quantify this added value, so that civil engineers have an indication how much money and time can be saved if they choose a BIM approach for their projects.

4 Model description

4.1 INTRODUCTION

As derived from the literature review and from information gathered from Arcadis, there seem to be four key concepts that mainly contribute to the added value of BIM. These four issues not only affect the added value of BIM in a certain project, but also influence each other. All these variables contribute to answering the main question of this research; how to quantify the added value of Building Information Modelling in infrastructure projects. How this works will be explained in the next section. First a description of all of the concepts will be given; BIM levels, BIM poster, case studies and BIM ROI. By connecting the mutual concepts it becomes also clear how the sub questions have emerged and what their context to the main question is. After the description of the main variables, a model description will be given, which enables the reader to reproduce the research exactly. The four key concepts are shown in figure 3-1.

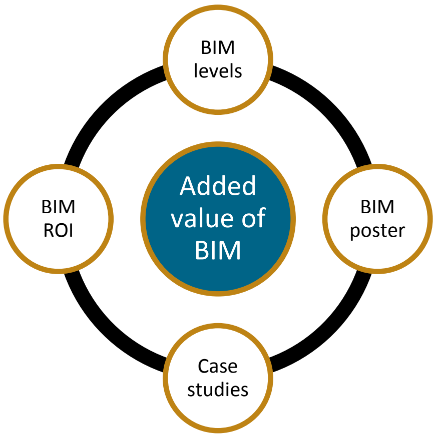


Figure 4-1 Four key concepts

4.1.1 BIM LEVELS

To assist the communication around the implementation of BIM, the Bouw Informatie Raad (BIR), at the end of 2014, came up with a leaflet regarding the Dutch BIM levels (Bouw Informatie Raad, 2014). To conduct this model, the UK maturity model by Bew and Richards has been used and adapted to national standards. The UK maturity model has also been adopted in other leading BIM countries. The Dutch model is a growth model for BIM in contrast to the many maturity models for organisations. The graph shows the degree of automation and the integration of processes into building project lifecycles.
In the most models, four different levels can be distinguished (from 0-3). Each level has its own procedure, different types of data, differing software tools, own ways of collaboration and a different culture. These levels and their characteristics will be discussed in the next sections using the Arcadis BIM white paper (Arcadis, 2014).

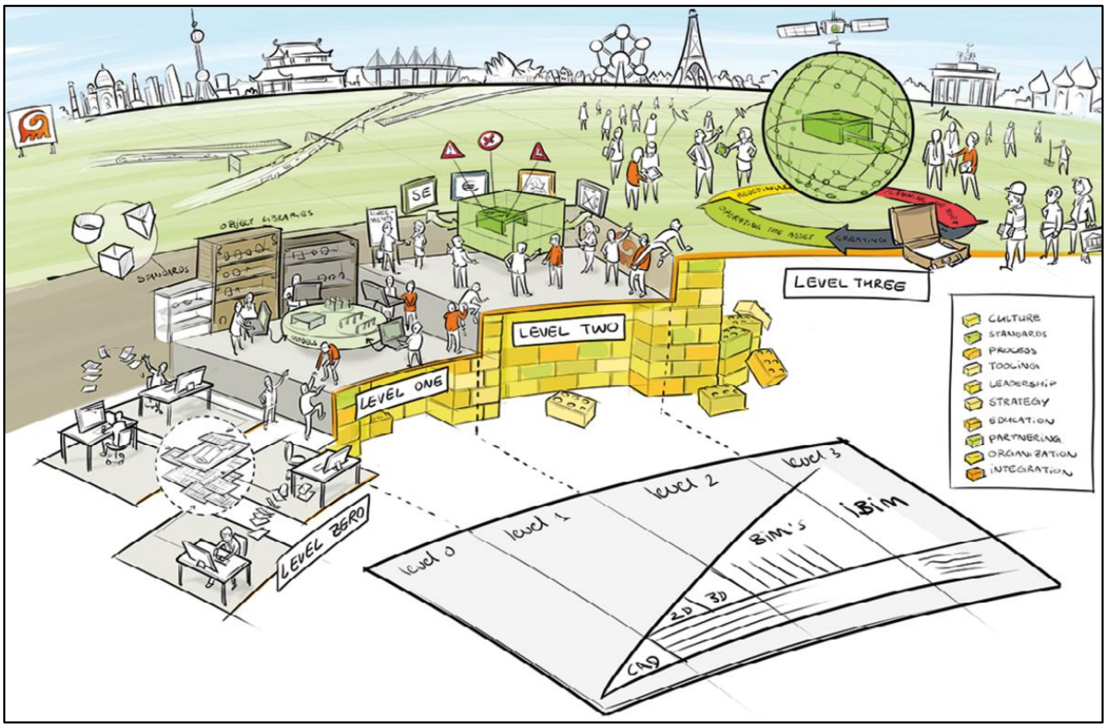


Figure 4-2 BIM levels (Arcadis, 2014)

4.1.1.1 LEVEL 0 DOCUMENT ORIENTED

BIM level 0 comprises the traditional way of working on building projects, which is still used by many civil engineers. Different software tools are used in one single project. For example drawings are created in AutoCad, text fragments in Word and calculations in Excel. There are no digital objects utilized, as everything is represented by lines, texts, curves etc. Therefore sharing information or formal handover is limited to the exchange of these paper-based documents of information.

In its simplest form, BIM level 0 means no collaboration and is therefore not considered as a BIM approach at all.

4.1.1.2 LEVEL 1 OBJECT ORIENTED

As the title of this section clarifies, level 1 contains the introduction of working with objects, which is also called parametric design. Objects are virtual representations of real life things, such as doors, windows or columns. Working with objects is often associated with working with 3D objects, however 2D objects are also suitable just as objects without any geometric description. Besides this geometrical description, objects can have properties as names, specifications, planning or costs.

A collection of these objects is called a model, which delivers the building team an understandable representation of the design and the opportunity to make changes easily. As BIM level 1 becomes the standard level of the processes, further benefits can be obtained by re-using generic objects from earlier projects.

A limitation of this BIM level is that it is not possible to integrate different disciplines or aspects. But, in comparison with BIM level 0, even when used by just one discipline, object oriented design delivers benefits. Enabling every discipline to work with its best suitable tools and link the specific outcomes is the next step in the automation and integration of building processes: federated BIM.

4.1.1.3 LEVEL 2 FEDERATED BIM

At BIM level 2 sharing object models as constructed at level 1 becomes possible. All the models of different disciplines of a building project can be integrated into a single federated model. A federated model is a joined up view of multiple, separate models which enables the analysis of integrated aspects of design. This enables proper co-operation on a project. The key analysis, derived from the federated model, is spatial coordination or clash detection. This feature is used to check if there are spatial mistakes when combining the designs of different disciplines. This ensures for design faults to be identified early in the process and increases the quality of the design. The model also allows applications such as planning (4D) and cost calculations (5D) to be linked. 4D BIM enables the team to introduce construction sequence into to the model, simulating process, checking for mistakes and looking for optimizations. The federated model will be shared between other organisations such as other designers or contractors. From that point it is important to draft a BIM protocol, which handles all aspects, such as the use of BIM, responsibilities, collaboration.

Arcadis already produced a BIM protocol, which can be brought to an international level. Effective protocols will get the best value out of the implementation of BIM in a building project.

4.1.1.4 LEVEL 3 COLLABORATIVE BIM

The next step is to use this integrated models, as described in the previous section, also when working with external partners. Working together with all the stakeholders in one model is also known as collaborative BIM, or Big BIM. Although this approach delivers more benefits than federated BIM, processes performed at BIM level 3 still hardly occur. This is mainly caused by separate contracts, which discourage the unlimited exchange of data.

Collaborative BIM involves a strong relationship between facility management and asset management as the information, at the end of BIM level 3, is shared over the complete lifecycle of a building project.

These different levels of BIM development will require different approaches all working towards fully integrated, collaborative BIM. The process of all civil engineers making such full use of BIM will take years, due to implementation difficulties as investments and training of employees. In the meantime all organisations and companies can be classified in one of the BIM stages. There will be a small gap between some and a larger gap between others to reach the final stage of BIM.

4.1.2 BIM POSTER

Besides the translation of the UK maturity model towards the Dutch BIM levels, the BIR also came up with a BIM poster appendix I. This poster informs about the most important BIM uses and its benefits and the content is derived from the publication; The Uses of BIM, from the Pennsylvania State University in the United States (Rg Kreider & Messner, 2013). Because of the different understandings of what BIM is and what it can be used for, the poster provides a common language for the BIM uses and its benefits. A BIM use is defined as;

> *A method of applying Building Information Modelling during a facility's lifecycle to achieve one or more specific objectives*

The BIM uses are categorized into five primary purposes; gather, generate, analyze, communicate and realize. These purposes can be subdivided into 18 sub-purposes as presented in figure 4-3.

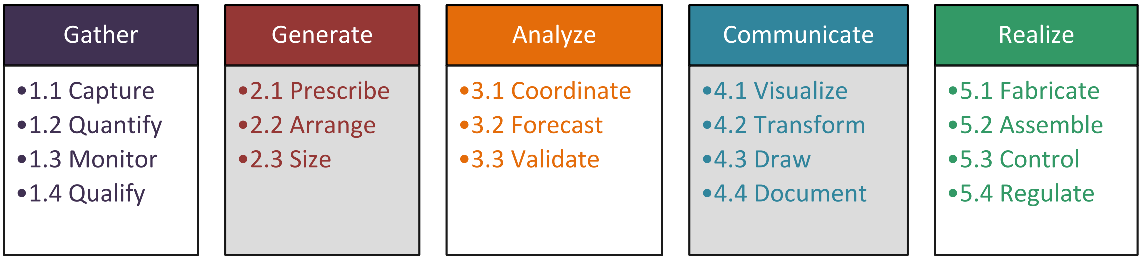


Figure 4-3 The BIM use purposes

This poster is useful for communicating this purposes for which BIM can be implemented. For example, it can be used within procurement language and BIM planning to define the requirements of the clients. Besides this, it helps to standardize the terminology about BIM. Overall, the BIM poster ensures better communication of the purposes and methods for implementing BIM throughout the complete lifecycle of a building project.

To further specify the BIM use behind the purposes, BIM use characteristics are used. The characteristics to be defined include; the facility elements, facility phases, disciplines and level of development. These characteristics help to clarify to all the stakeholders who, what, when and to what degree the BIM use will be implemented.

4.1.3 CASE STUDIES

To investigate the implementation of BIM in practice, it will be helpful to look at multiple case studies. According to Bakis et al. (as cited in Barlish & Sullivan, 2012), a case study is the most appropriate investigation method for the business benefits of new technologies, when compared to the formal experiment and the survey. The ideal scenario for this methodology would be to take a look at exactly the same projects, one conducted using BIM and the other without any knowledge of BIM. Furthermore, same contractors are preferred, as well as similar scopes of work and findings to be shared among project stakeholders. It is clear that this situation is unrealizable in the real world, as there always is a decision point in a project stage where stakeholders have to decide whether to continue with the implementation of BIM or to drop the idea. Therefore a case study approach is the best alternative. Several cases will be analysed, both BIM and non-BIM projects, and its BIM level, together with its BIM uses will be discussed.
The main purpose to this method is to investigate whether the use of BIM resulted in benefits to infrastructure projects. The data have been studied in depth to establish in which specific ways the projects benefited from the use of BIM, for instance in terms of time, costs, quality and also effective project management and communication. To ensure the results to be comparable, the case studies selected are as good as similar in terms of the contract, size and project costs. Sequentially, *A9 Heiloo, Barneveld onderdoorgang Harselaar* and *Ombouw Amstelveenlijn* have been viewed, after which the focus was shifted to the non-BIM cases.

4.1.3.1 CASE 1 A9 HEILOO

The first case in which BIM is implemented to a certain extent is A9 Heiloo. Several BIM uses can be designated in this project. This case is part of a larger project 'Wonen in het Groen', about which some new agreements are made by the Province of Noord-Holland (PNH), together with the municipalities Castricum, Heiloo and Alkmaar, at the beginning of 2014. Besides nature, living and industry, the assignment consists of a new connection of Heiloo to the highway A9. The province is responsible for the implementation of this new connection. Arcadis is asked to draft an integrated design and construct contract for the stage of contract preparation and procurement. The assignment contains processing the research findings, reviewing and adapting the preliminary design, gathering stakeholders' requirements and forecast building costs.
Finally, the Province had to choose the most suitable variant. Because they attach a lot of importance to safety aspects, they have chosen the variant that was more safe than others. As mentioned, several BIM uses have been applied during the project and each of them delivered its own benefit. These are summarized and will be discussed further in section 5.2.1.

4.1.3.2 CASE 2 BARNEVELD ONDERDOORGANG HARSELAAR

The second case study, in which Arcadis is involved in an early stage is Barneveld onderdoorgang Harselaar. In this project, on behalf of the municipality of Barneveld, a split level crossing will be developed for fast and bicycle traffic. The construction of the crossing ensures the removal of a physical separation caused by a railway line from Amersfoort to Apeldoorn. Arcadis already came up with a predesign in an earlier stage, but due to new insights and economic difficulties this design was dispensed. The activities of Arcadis consisted, among other, of drafting a list of requirements, cost estimation and drawings and design.

4.1.3.3 CASE 3 OMBOUW AMSTELVEENLIJN

Case 3, Ombouw Amstelveenlijn is a project that is still in progress. However, it is clear that several BIM uses will be covered in this case. It is decided to replace the current Amstelveenlijn by a high quality tram ride, which is an important link in metropolitan area of Amsterdam. The replacement of the current connection should provide the start of economic and spatial development.
The reconstruction of the Amstelveenlijn consists of replacing the rails, decreasing the stops, removing several stops and the most important the construction of three split level intersections. The variants of these split level intersections should be compared with each other in close cooperation with all the stakeholders. Aspects like building costs, planning, time, suitability, the flow of road traffic, maintaining the rail transport are of high importance in the decision making process. The focus of Arcadis was to realize, together with the stakeholders, a cost-effective, high-quality, safe traffic and future-proof solution and to elaborate this into a predesign.
The start of the project was in 2014 and if everything goes according the plan its commissioning will be at the end of 2020. This is equal to the planning of the Zuidasdok, of which the tram stops at the Schönberglaan will be finished at this time.
It is clear that during the entire reconstruction alternative travel options are necessary. Especially the construction of the intersection will cause a lot of trouble in the daily traffic.

4.1.3.4 *NON-BIM CASES*

To draft a proper comparison regarding the benefits of the BIM uses, it is also necessary to investigate some case studies that are completed without any use or knowledge of BIM. Most of these case studies consist of historical data, since the knowledge of BIM was negligible in those days.

The first one is the *Reconstructie N417*. The Province of Noord-Holland intends to perform major maintenance on the main driving lane of the N417, to improve the current bicycle facilities and to apply wildlife facilities. In order to increase its safety and sustainability, a reconstruction is necessary for this freeway. The reconstruction consists of resurfacing the road, the construction of new two way bicycle lanes, the construction of wildlife passages for badgers and reptiles and the construction of wildlife grids alongside the entire length of the Zuiderheideweg.

The second non-BIM case *N35* is commissioned by the ministry of Infrastructure & Environment, together with the Province of Overijssel and Rijkswaterstaat, Arcadis is asked to support exploratory research of the N35 between Nijverdal and Wierden. The safety of the current situation is not considered to be sufficient and therefore there is need to redevelop the road. A quickscan is used to capture the current situation in order to speed up the exploratory research.

In the third case *Quickscan fietskruising Vredenburghlaan* a quickscan is also used. The aim of the project is to find a solution to connect the Vredenburghlaan to an earlier designed T-junction. For this assignment it is necessary to cross the bicycle route from Gouda to den Haag and a service road for agricultural vehicles. A split level crossing is required as the bicycle road has a primary function in the area. The quickscan should provide a clear overview of the possible opportunities for the crossing. Besides this, the quickscan provides insight in the consequences of the different solutions regarding land use, its impact on the environment, traffic safety and costs.

The fourth non-BIM case is called *Fietspaden Zeewolde* and is initiated by the Province of Flevoland, which wants to develop the natural area Oostvaarderswold. For the purpose of this area the bicycle infrastructure will be adapted and expanded. To make the bicycle infrastructure in this area attractive, three bicycle bridges are proposed, over the Gooiseweg, the A6 and the Lage Vaart. Arcadis is asked to draft a tender for the complete life cycle of this project, from research to realization.

Finally, in preparation to a major maintenance that is scheduled for the N216A, Arcadis is asked to conduct a study alongside this freeway, which contains seven kilometres. The aim is to re-investigate the use of the road in its entirety and to ensure its future sustainability.

4.1.4 ROI OF BIM

As there is no consensus about a single definition of what BIM is, it is explainable that there is no widely accepted method for calculating a company’s return on investments in BIM either. But, according to a smart market report of McGraw Hill (2014), most users have a perception of the added value of BIM taking the time, money and effort they have expanded into account. Each BIM user is asked to estimate their perceived ROI on BIM. Three broad tiers can be distinguished; very positive (>25%), moderately positive (10%-25%) and negative or break-even ROI percentages (<10%). The results of the survey are summarized in the figure below, figure 4-4.

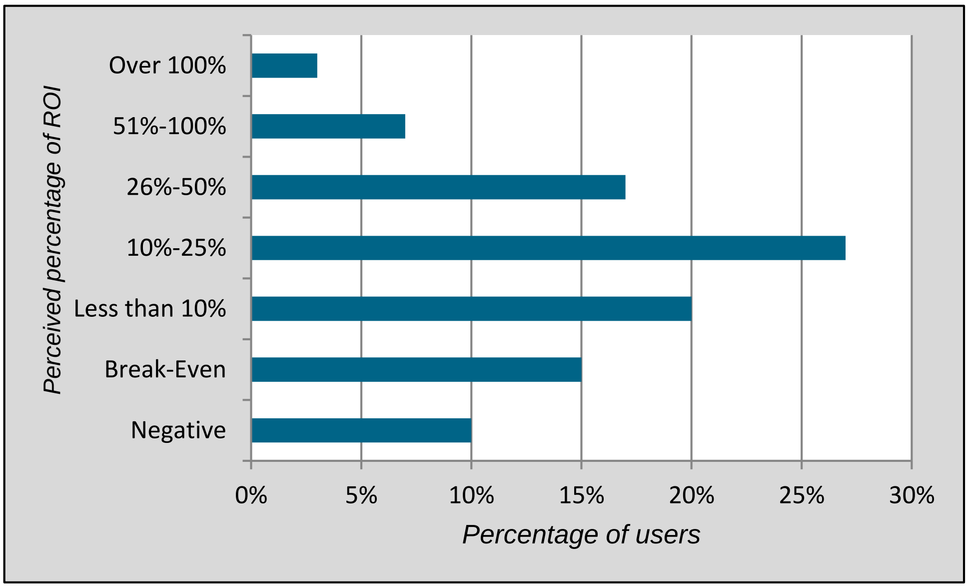


Figure 4-4 The perceived ROI on BIM

These results can be explained by a typical pattern that appears according to the BIM engagement level of companies. The negative or break-even percentages are mainly mentioned by companies that have just adopted BIM, especially the smaller companies. This effect is enhanced by recognizing that with the deepest BIM engagement report the highest ROI on their BIM investments. At this moment, 75% of the contractors say that they have a positive ROI on BIM investments (McGraw Hill, 2014).

In order to measure the ROI of BIM the most usual method is to compare the benefits of a new method to how much it costs. Usually the ROI is calculated by dividing the result of an investment by the price of an investment. The outcome is then multiplied by 100 in order to provide a percentage that tells something about the performance of the new method (Azhar, 2011). The corresponding formula is stated below;

$$ROI = \frac{Benefits\ of\ BIM - BIM\ Investments}{BIM\ Investments}\ x\ 100$$

The same survey asked the users about their three top benefits of implementing BIM. The results show that reduced errors and omissions is the top rated benefit of the implementation of BIM. This benefit also influences other benefits, such as reduced rework, construction cost and overall project duration. Another top benefit that is of high importance among the BIM users is the close collaboration with owners and design firms. This benefit includes the greater integration of all the stakeholders in a project during each different stage of the life cycle of a project.

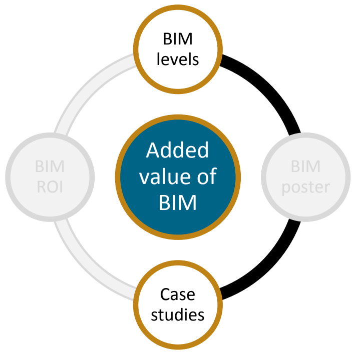
In contrast with the benefits, project managers have to invest in the implementation of BIM in order to use it to its full amount. That is the reason why some of them are sceptic towards the implementation of BIM. According to the survey, the top investment is in their internal collaborative processes, BIM training and BIM software. These three types of investments can be seen as fundamental building blocks of the implementation of BIM. These are variables to keep in mind in this research during the development of this research and regarding the ROI of BIM.

4.2 METHOD

This section describes the method used in this research. To work towards a final conclusion, first the connection among the key concepts should be investigated and explained. A roadmap, starting with the BIM level and working towards the added value of BIM, will be explained in this section step by step. This permits experienced investigators to replicate the study.

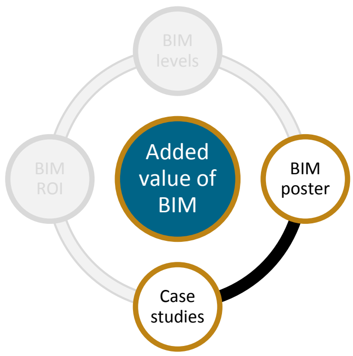
4.2.1 ROADMAP DEVELOPMENT

- Step 1 Classifying **case studies** based on the **BIM levels**



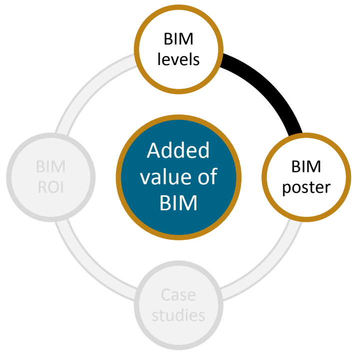
The first step in this methodology is to organize the consulted case studies based on their BIM level. The BIM levels are explained in section 4.1.1., ranging from document oriented (level 0) to collaborative BIM (level 3). Because BIM level 0 is not considered to be BIM and BIM level 3 is hardly feasible yet, the focus will be on projects using a BIM level 1 or 2 approach. To make the classifying easier, an extensive description of both levels is drafted and used in this step. This description, including main criteria, examples and focuses of each level, can be found in appendices 7.2 and 7.3.
The selected case studies include both, non-BIM projects as well as BIM projects. Background information about the consulted projects is mentioned in section 4.1.3. Naturally, all non-BIM projects are performed at BIM level 0. The case studies A9 Heiloo, Barneveld onderdoorgang Harselaar and Ombouw Amstelveenlijn will be classified at BIM level 1 or 2 according the criteria of the description of the BIM levels.
A short explanation will be given in the next section about what considerations have been decisive to classify a project at level 1 or 2.

- Step 2 Analyzing **case studies** based on the **BIM poster**



The second step of this roadmap is to analyse which BIM uses and benefits, mentioned on the poster, have been used in the different case studies. The content of the BIM poster is mentioned in section 4.1.2. Because some of the descriptions on the poster are quite general like the main purposes gather, generate, analyze, communicate and realize, and not really focusing on a typical feature of a BIM approach, only the sub-purposes are mentioned in this step. These sub-purposes can be derived from figure 4-3. To give a brief example, if laser scanning is used in a project to capture data about the current situation of a project area, the case study contains the BIM use; 1.1 Capture. In this way in most of the case studies are about four or five BIM uses recognizable. Probably there are more than four BIM uses recognizable per case, but due to the scope of this research, only those which really highlight specific BIM features are mentioned.

- Step 3 Linking the **BIM levels** to the **BIM poster**



The third step can be interpreted as a concise conclusion of the two previous steps. In the first step the case studies are classified according their BIM level, and in the second step the BIM uses and benefits from the poster are investigated per case. Because in both steps the case studies are the same, the non-BIM projects as well as the BIM projects, these can be considered as a constant value allowing to conclude something about the relationship between the other variables, the BIM levels and the BIM poster. During the investigation of this relationship, two important sub questions came forward. The answer to the first one should tell something about the advantage for a company or organization if they are able to perform their projects on a higher BIM level. This question focuses on the added value to grow from level 1 to level 2, since all the projects available are performed at BIM level 1 or 2 (or 0/non-BIM). And the second one is about the minimum requirements needed for a company or organization when they are willing to use a BIM approach in their projects. These could include software, employees or cultural requirements. The sub questions are mentioned and further elaborated below;

> 4. *Are there any BIM benefits that are experienced more when a project is performed at a higher BIM level?*

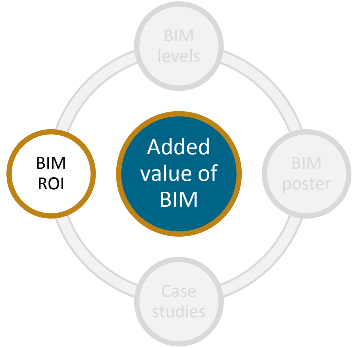
And secondly,

> 5. *Which requirements are necessary at least to apply particular BIM uses and experience their benefits?*

The first question is about the relationship between BIM levels and the uses and benefits from the poster experienced in the building projects. It focuses on the advantages for a company or organization if they decide to invest in the implementation of BIM in order to reach a higher BIM level.
To satisfactorily answer this question, not only the case studies are used, as this is a too small share of all the projects in which BIM have been implemented, but also an extensive database is consulted. This database provides information about the direct relationship of the BIM level of a project and the BIM uses and benefits of the poster. Although this database is prepared for the building industry, it displays and supports findings of the case studies in civil engineering and will be valuable to validate findings in this research afterwards. In the near future such a database will be also drafted for civil engineering projects and the findings from the two previous steps may contribute to this.

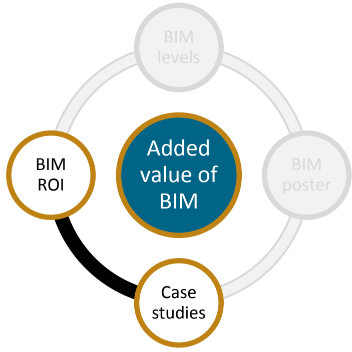
The second question is about the state of an organization or company, which is also the most common scope of the existing maturity models for measuring the performance of BIM. As mentioned before, there are investments necessary to experience all the uses and benefits of BIM. One might consider to invest in software tools as well as in education for employees to reach a higher BIM level. But to perform a project at BIM level 1 there is also a set of minimal requirements necessary, even when a company or organization has a sympathetic to use a BIM approach in their building processes.

- Step 4 Determining the **Return on Investment** of BIM



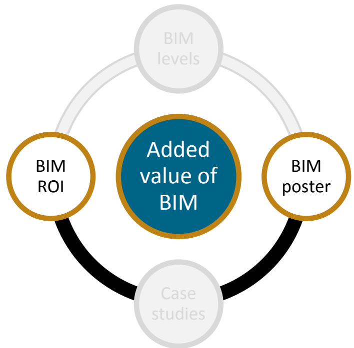
Another parallel aspect that is important to prove the added value of BIM is its Return on Investment (ROI). The ROI is investigated using an extensive desk research. More than 40 well-founded articles have been consulted in order to provide an overview of a percentage that can be used as an indicator for the performance of BIM. These articles are summarized in one database in Excel and divided in different categories. It tells something about the stage of the project (design, design and construction, construction and operation), about the perceived or potential savings using BIM in that stage, about the research methodology used and about its reliability to which a score is assigned in the last column to compute the total life cycle savings. The numbers found are multiplied by its reliability score to exclude extreme values.

- Step 5 proving the **Return on Investment** of BIM using the **case studies**



The ROI found in step 4 is based on a lot of well-founded articles. But to prove the value it would be reliable if the value corresponds to savings in real life projects. To do this, financial data will be consulted, that provides information about each expense during the complete life cycle of a building project. In this step BIM projects will be compared with project that do not use a BIM approach in order to check if the ROI value is valid. The analysis examines the extent to which the compared projects are comparable. There is sought to projects that are as similar as possible regarding the interrogation of the project, the size, the scope and financial values. These financial values will be derived from a business software tool, called SAP.

- Step 6 Explain the **Return on Investment** based on the **BIM poster**



To complete the method, the last step is to explain the founded ROI value. In step 4 a ROI value is founded based on a lot of scientific articles and this value is validated in step 5. So at this stage the reliability of the founded value is already known. Whatever the answer may be, the result is probably explainable using the BIM uses from the poster. The associated sub question is;

6. Which BIM uses contribute to what extent to the financial benefits found?

If a certain BIM use turns out to be very profitable, relative to others, an organization or company should include it in their standard building process. In the same way a BIM use can be discovered that is often used in building projects, but barely contributes to the founded ROI. Such a use may be for instance beneficial in increasing the engagement of stakeholders.

5 Results

In this section the analysis performed on the collected data is summarized. All results, including those that are opposed to the expectations, are reported in this section. The results will be discussed according to the roadmap developed in the previous section.

5.1 BIM LEVELS OF THE CASE STUDIES

5.1.1 CASE 1 A9 HEILOO

The first case study, A9 Heiloo, is a typical project that is performed at BIM level 1. This will be explained using the extensive BIM description of level 1, mentioned in the previous section and in the appendix. The project contains the most criteria of level 1, whereas it does not meet any of the criteria associated with BIM level 2.
Working with defined objects in a project is the most characteristic of BIM level 1. This could include both, 2D as well as 3D objects. In this project, the objects are defined in a tree of objects, which delivers a structured overview of the parts of which the system, that has to be designed, consists. The tree of objects answers the question which object is necessary to fulfil a certain function. For instance, the main function of the system is completed by the object 'S01. Ontsluitingsysteem', as can be seen in appendix IV. In the tree of objects the main object is divided in several other objects. The shortcoming, making the project not complying with BIM level 2, is the lack of integration among different disciplines. Mutual appointments are made about standards and processes during the different project stages. As an example, it is nog possible in this project to work together in the same model at the same time. This is mainly caused by a lack of knowledge, time and costs. These difficulties caused the neglect of several aspects of BIM as its added value is still not proven.
Besides the most important characteristic of BIM level 1, there are several other characteristics of this level recognizable in the projects. The communication, for instance, goes according the traditional approach using offline communication as presentations or phone calls in case of important project changes.

5.1.2 CASE 2 BARNEVELD ONDERDOORGANG HARSELAAR

This project is performed at BIM level 2. According the ambition of Arcadis to gain more experience with the application of BIM, this project is appointed as a BIM pilot. The project Barneveld onderdoorgang Harselaar is perfect for this as it includes a project that is technically easy, but multidisciplinary. In advance of the project, several goals for the application of BIM are drafted. The most important is to design a clear structure of objects that can be used among every discipline in the project. An example of this could be a tree of objects as

mentioned earlier in the first case. Another priority is to design a jointly model in Navis Works and use this to perform a clash detection. To even reach a higher BIM level, the intention is mentioned to link a phasing of the project in Navis Works to a 2D/3D model in order to present a short movie to all the project members.
Besides the main criteria that the different models can be combined in a single view model in Navis Works, other criteria of BIM level 2 are also achieved. Each discipline uses BIM software in which the information is stored object oriented, the 3D model in Revit , the 3D model of the crossing in MX, and the possibility of clash detection is performed in Navis Works.
One of the reasons that this project is still far from BIM level 3, is that the information sharing among different parties exceeds within a single organization. Sharing of BIM software at level 3 includes the involvement of multiple extern parties.

5.1.3 CASE 3 OMBOUW AMSTELVEENLIJN

Ombouw Amstelveenlijn is performed at BIM level 1. The main idea of choosing a BIM approach for this project was to provide visualizations of the different designs in the 3D-environment of Amsterdam. In this way potential failures would occur early, which ensures unnecessary delays and costs overruns not to be an issue. To draft simplified visualizations of a building project is a typical feature of BIM level 1. These are mainly used to present the different design studies to non-technical stakeholders, for instance the end-users of the line.
As in the first case, the main cause for classifying this project as a BIM level 1 project is the defining of objects. And again the objects are divided in a tree of objects that is used as a clear overview and linked to the different functions within the project.
Another criteria of BIM level 1 that is met in this project is the awareness among the project team of using a BIM approach. This cares for better communication among all stakeholders and for better decision making due to the transparency of information. In this way a general mind set among the employees is created, knowing why they use BIM. Namely that BIM is the key to quality, decline of failure costs and a better solution for customers. They also experience a general motto; BIM, driver for collaboration and work-sharing. The BIM model serves a starting point, which can be further developed in later projects stages.
Because the information in this project is mono-disciplinary and not interoperable, this approach is not sufficient to consider it at BIM level 2.

5.2 BIM USES AND BENEFITS PER PROJECT

The BIM uses and benefits per project are analysed. To provide a quick overview, in each of the following section the findings are summarized in a table, including the name of the project, project description, its BIM level and the BIM uses in the project.

5.2.1 CASE 1 A9 HEILOO

BIM project:	BIM uses:
A9 Heiloo	1.1 Capture
Connection to the highway	2.1 Prescribe
BIM level:	3.2 Forecast
1	4.3 Draw

Table 5-1 The BIM uses in A9 Heiloo

1.1 Capture

To represent or preserve the current status of the facility and facility elements

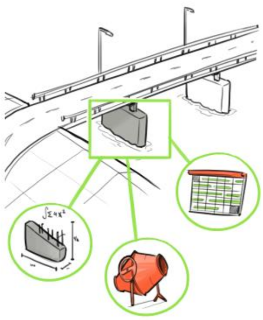
During an intern meeting the current status of the facility is presented to the project team. The data is presented in a spreadsheet and shows the surrounding area at the start of the project. Also a Digitaal Terrein Model (DTM) is made, of which the data is collected manually and which shows the line-shaped topography in AutoCad. The DTM presents a realistic 3D view of the entire project area. Also all significant heights and contours are determined, as well as the road geometry. In addition, the history of the project area, since 1900, can be consulted by simplified maps. The DTM is presented in appendix IV.

- Structured information available at the start of the project that can be re-used in downstream BIM processes;
- Avoids overlap e.g. during survey activities
- Creates the basic conditions for the quality and therefore reduction of failure costs.

2.1 Prescribe

To determine the need for and select specific facility elements

To determine the functional requirements and wishes of all stakeholders, some interactive meetings are organized. The gathered demand will be listed in an up-to-date database in Relatics. By specifying explicitly what the requirements of the clients are, it is possible to verify and validate these requirements during the complete life cycle of the project. The requirements will be initially presented in the Relatics-environment of Arcadis and subsequently imported in the Relatics-environment of the Province of Noord-Holland. Relatics is also used in the project to prescribe system requirements, object types and interfaces. A tree of objects is presented in appendix V.



- By specifying explicitly in a BIM what the (functional) requirements of the client are, it is possible to verify and validate these requirements in the design, construct and operate phase
- This BIM technology is used for systematic quality assurance

3.2 Forecast

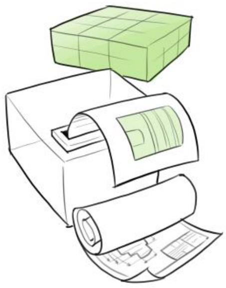
To predict the future performance of the facility and facility elements

To optimize the building process and the performance of a facility an extensive planning is drafted. Abiding these planning will help to identify and solve logistical problems. Besides a planning of the construction process, cost forecasts are done. The building costs are calculated, as well as the costs for construction, operation and maintenance. These are summarized using an Excel sheet.

- Simulation on the virtual facility substantiates decisions and supports policy
- Reduces the total costs of ownership
- Optimises the construction process and the performance of a (planned) facility

4.3 Draw

To make a symbolic representation of the facility and facility elements



During the same intern meeting multiple drawings of the design are presented to the project team. These (2D) drawings are generated in AutoCAD, including detailing and annotation. The presentation at the same time provides photographs of the relevant locations for the design proposals. An example is presented in appendix VII.

- Consistent drawing from one information source
- Producing drawings is often a big share in the total design

costs. This BIM-use will reduce costs significantly, whilst increasing the quality.

5.2.2 CASE 2 BARNEVELD ONDERDOORGANG HARSELAAR

BIM project:	BIM uses:
Barneveld, onderdoorgang Harselaar	1.1 Capture
Constructing an underpass	2.1 Prescribe
BIM level:	3.1 Coordinate
2	4.1 Visualize
	4.2 Transform

Table 5-2 The BIM uses in Barneveld onderdoorgang Harselaar

1.1 Capture

To represent or preserve the current status of the facility and facility elements

As in the previous case, the BIM use capture is applied in this project. Since Arcadis is involved in a later stage this time it is important to obtain specific and complete information from the previous stages. The data is recorded manually and presented to the project team using a spreadsheet. An example can be seen in appendix VIII, which shows the project area and its environment. Besides these spreadsheets a report is provided, in which all previous activities are described.

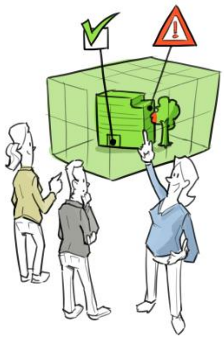
2.1 Prescribe

To determine the need for and select specific facility elements

In an early stage of the project several objects will be defined and stored in an list of objects. This list will be captured in a database, for which Relatics will be used. To ensure that the project will run fluently, it is important that the database is widely accessible and user-friendly. A single operation that needs to be done is organizing the database. Besides a list of objects, also user requirements and verification and validation information will be stored in Relatics. A small part of the functional requirements can be seen in appendix IX. This database will serve as a blueprint during the complete life cycle of the project and be used as starting point for each design. This ensures that the entire project team has the same information about the project and its changes.

3.1 Coordinate

To ensure the efficiency and harmony of the relationship of facility elements



One of the most important BIM uses is also recognizable in this project, namely coordinate. When all the objects are recognized by Navis Works, the next step is to perform a clash detection. The learning point at this stage is how objects can be made interoperable, so that Navis Works recognizes objects from Revit or MX. This is closely related to the BIM use transform, that will be explained later in this section. Another question is whether it is possible for Navis Works to work with 2D designs.

- This BIM use will ensure an integrated consistent facility based on its various disciplines in the life cycle
- Spatial conflicts between elements in a facility are detected in time, in an efficient process, and solved before manifesting during construction or operation

4.1 Visualize

To form a realistic representation of a facility or facility elements

To form a realistic representation of the underpass the design is elaborated in 3D. The underpass is developed in a Revit model and the crossroads in MX. It is tried to import the MX designs in Navis Works as complete objects. The visualizations provide a clear overview of the design proposal to all stakeholders involved in the project. One of these visualizations can be seen in appendix X.
In addition to these visualizations and in order to link to applications at a higher BIM level, there is also a video made for this project. The video includes phasing issues and proposes a building sequence for the entire construction of the underpass. A snapshot of the video is provided in appendix XI.

- Visualizations produced from the BIM allow non-technical stakeholders to participate fully and interactively in projects
- Realistic visualizations and 'walk troughs' avoid misinterpretations and speedup the decision making process.

4.2 Transform

To modify information and translate it to be received by another process

As described before, to perform a clash detection in this project all the information should be compatible with Navis Works. In the project different software tools are used. Whereas the complete information model will be consulted in Navis Works, the designer of the road works in MX Civil and the designer of the underpass prefers Revit. Finally, some requirements necessary for this step are stored in SEVILLA in MS Access. This process is summarized in appendix XII.
Now, the exchange of this information can be done in different ways, provided that it happen object oriented. To perform the

transformation, there are two methods applicable. It is possible to export the information from SEVILLA to Revit and MX directly. The other possibility is to export the information from SEVILLA to Navis Works. The second method turned out to be the most favourable as it only requires one single interface to work with and it uses the object defined at an earlier stage of the project. The final result is that each designer can choose its favourite software tool and at the end all the information together can be consulted by each stakeholder in Navis Works.

- Transform makes it possible to exchange BIM information, regardless of differences in software used.

5.2.3 CASE 3 OMBOUW AMSTELVEENLIJN

BIM project:	BIM uses:
Ombouw Amstelveenlijn	1.1 Capture
Constructing split level intersections	2.1 Prescribe
BIM level:	4.1 Visualize
1	4.3 Draw

Table 5-3 The BIM uses in ombouw Amstelveenlijn

1.1 Capture

To represent or preserve the current status of the facility and facility elements

Prior to the start of the activities of Arcadis, background information is provided by the client, Dienst Metro. Different types of formats are used to inform the contractor about the current situation. In this case, Dienst Metro provided for instance drawings in AutoCAD, aerial photos, height maps and Geographic Information System (GIS) documents. Some of these documents are directly adopted by the contractor, others are adapted into workable documents. During the project the ideas and designs are mainly presented using a spreadsheet in PowerPoint. An example of this can be seen in appendix XIII, which presents one of the design proposals in the current project area. This provides an clear overview and ensures all the stakeholders to have the same imagination of the design.

2.1 Prescribe

To determine the need for and select specific facility elements

As in the previous cases, the BIM use prescribe is also recognizable in this case. From planned design sessions that take place during the project and involving all stakeholders, the most important customer requirements are derived. Some of them can be seen in appendix XIV. The results are processed using a Systems Engineering (SE) methodology. After each of these sessions the requirements discussed are summarized in a tree of requirements. This tree will also be used at a later stage of the project to verify and validate the proposed designs.
Systems Engineering was particularly suitable in this project because there were a lot of intern similarities, as well as extern similarities. An intern interface may occur between rail systems and artworks, whereas an extern interface may include the influence of the designs on the traffic flows. Besides this, SE cares for a common language amongst all the stakeholders involved in the project. Another advantage of SE is that it clarifies relationships within the projects, for instance by providing a tree of requirements, a tree of functions, a tree of objects, work breakdown structure, but also planning, risks and costs. The aim of SE is to prevent for

undesired extension of the scope of the project as well as unexpected costs. Finally, the application of SE in this project guarantees better communication with all the stakeholders, as the information can be easily accessed.
The application of SE will be project specific, ensuring a controllable tool to work towards the goal of the project. During the project the costs are constantly monitored, because overruns necessarily were not allowed to occur.

4.1 Visualize

To form a realistic representation of a facility or facility elements

The use of the BIM model visualizes the different designs in the 3D-environment of Amsterdam, which is supposed to be recognizable for all the stakeholders. One of these visualizations is shown in appendix XV.
Visualizations ensure bottlenecks are discovered at an early stage of the project, which prevents for unnecessary costs and waste of time. Besides this, the model cares for better communication among all stakeholders and better decision making due to transparent and accessible information for directors. The BIM model can be elaborated at the next stages of the projects. During the development of the design, new insights are constantly gathered and also the clients' requirements keep changing. BIM is the solution to store, use and maintain all relevant information during the design and construction process. At later stages the BIM model could be combined with requirements, object information, GIS, planning and phasing and at a higher level with risks and costs.

4.3 Draw

To make a symbolic representation of the facility and facility elements.

For the design assignment, different possibilities are proposed by Arcadis. To present these variants to all stakeholders, 2D drawings including detailing and annotation are generated. One of them, drawn in AutoCAD is included in appendix XVI.
Besides these drawings in AutoCAD, also hand sketches are available in the project. These are drafted during the intern design sessions, mentioned earlier in this section. These sketches are means of communication for discussing the proposed designs and serve as starting point during the succeeding, intern meetings. The sketches also provide information about the conditions and requirements, which are of importance and about the decision-making regarding the different variants.
The sketches are used at the early stages of the projects. Since the sketches are mainly used in this project to explain the first ideas and concepts, the scale of the drawings is not relevant yet.

Now that the case studies have been investigated, both on their BIM levels and their BIM uses and benefits, the next step links the BIM levels to the poster, as the case studies remain constant variables in the two previous steps. The next step also provides an answer to sub question 4 and 5.

5.3 BIM USES PER BIM LEVEL

As mentioned before, this third step can be seen as a conclusion of the two previous steps. Because the case studies do not vary over both studies, there is something to say about the relationship between the BIM levels and the BIM poster. Project managers are curious whether their possible investments, in order to reach a higher BIM level, is worth their money.
Therefore this step can be the evidence of benefits when performing a project at a higher BIM level. To answer the first sub question; *Are there any BIM uses from the BIM poster that are experienced more when a project is performed at a higher BIM level*, the three projects in depth seem to be to less to draft a proper conclusion. Hence, an extensive database of 51 building projects is consulted, providing information about the BIM level and the applications of the BIM poster that are used in the project. These projects are summarized in a database in Excel and can be seen in appendix XVII. The main findings are summarized in figure 5-1.

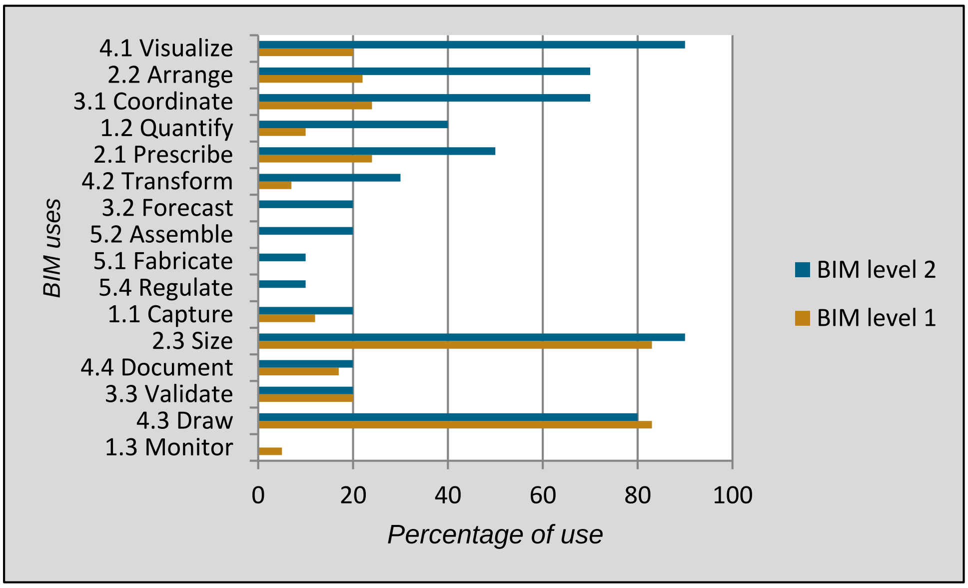


Figure 5-1 The differences in BIM level per use

The 51 projects give a complete overview of the BIM uses per BIM level. 41 of the projects of the database are performed at BIM level 1, whereas in 10 of them a BIM level 2 approach is used. In this way, the amount of occurrence of each BIM use per level is measured and converted to a percentage. This is done by dividing the amount of occurrence by the number of projects at level 1 (41) or level 2 (10). Using this percentage explains in how many of the projects at level 1 or level 2 a certain BIM use is used and clarifies the differences. The values associated with BIM level 1 are subtracted from the values at BIM level 2 in order to clarify the added benefits when deciding to use a higher BIM level approach.
The top three differences in uses are highlighted in the appendix using a green colour gradient, with the use *visualize* resulting in the largest difference between both levels. In 9 out of 10 (90%) of the projects at BIM level 2 benefits are gained using visualizations, whereas this happens in only 20% of the projects at BIM level 1, causing a difference of 70%. When an analysis is made about this BIM use it shows that the visualization are far more detailed than the couple of visualizations, which can be discovered at a BIM level 1 approach. The visualizations are beneficial to clarify ideas about the design and its environment, ensuring each project member to have the same thoughts and expectations about different variants.

The visualizations often consist of multiple views of a single design and are mainly used to inform non-technical people about the project. Its added value towards end-users for example is outstanding. Because the most projects at BIM level 2 use more extensive software packages, a relationship can be made between the investments at the one hand and its benefits at the other hand. It shows that if an organization or project manager decides to invest in software packages, the BIM use visualize shows its value by providing more detailed visualizations of a project. They may consider whether there is a demand for this in a certain project before they decide to grow to the next level using investments in appropriate software to create such visualizations.

The second largest benefit can be seen in the BIM use *arrange*, which shows much less of a difference than the first BIM use. The difference of use and its benefits are 48%, with 70% occurring at BIM level 2 and only 22% at BIM level 1. Arrange is mostly used to determine the exact location and placements of facility elements. This use is applicable during the complete life cycle of a building project, running from rough to fine elements. It can be seen that the projects at BIM level 2 all use a common library, to which objects can be simply added. This turns out to be very cost effective, as the objects and knowledge from previous projects are stored clearly and can be reused. To bring this use at level 2, it is necessary to invest time and money in using the right database to store the objects. In the projects consulted in this section, mostly Relatics is used for this. An organization should consider whether they want to invest money and educate personnel during a single projects, to gain its benefits at a later stage or even during a subsequent project.

A slightly less large difference is discovered between the BIM use *coordinate*, resulting in a difference of 46% between both levels. Just as the BIM use arrange, this use is applied in 70% of all the projects at BIM level 2, but more often at BIM level 1 (24%). Coordinate is the first sub use of the purpose analyze and ensures the efficiency and harmony of the relationship of facility elements. This is a typical BIM use that is more often used at BIM level 2. One of its main application is clash detection, also known as collision avoidance, design coordination and interference management. Clash detection is mainly used to detect spatial conflicts between elements in a facility in time, so that they can be solved before the next project stage. The use coordinate to this extent is used almost only at BIM level 2, as it requires the combination of different designs into one single model, software package or view. The case Barneveld onderdoorgang Harselaar, which is studied in depth and discussed in the previous sections is a great example of a project at BIM level 2 using clash detection. In that project Navis Works is used to provide a jointly model. Navis Works is the most familiar program that is used for clash detection, but in case rule based clashes are required Solibri Model Checker is an appropriate alternative. To grow to BIM level 2, in order to take advantage of the benefits of this BIM use might require an investment in a software package, but rather it demands a complete change in workflow and standard processes. Each project member should keep in mind that it is intended to combine all the files in one jointly model making them aware of the interoperability of the proposal in their own discipline. This might be even harder to implement as each longer existing company will encounter conservatives, who have to be convinced of the added value of BIM before they are willing to go along with the new approach. This is often called a change in culture, which is also mentioned earlier in this thesis as a difficulty towards the implementation of BIM.

From the table can also be seen that the top 5 differences is completed with the uses *quantify* an *prescribe*, with respectively 30% and 26% differences between both levels. In the middle of the table four uses can be distinguished, that only occurred in the projects at BIM level 2 and are not used at any project at BIM level 1 at all. The uses *monitor* and *draw*, at the bottom of the table are the only uses that occur more often at BIM level 1 in terms of percentage.

Figure 5-1 also contributes to answering the second sub question of this section, which is; *Which requirements are necessary at least to experience particular uses and benefits of the BIM poster?* The figure demonstrates that there are four BIM uses that are not experienced at BIM level 1. These are regulate, fabricate, assemble and forecast. In contrast to this, only the BIM use monitor is not experienced at level 2, whereas it is experienced at BIM level 1. These differences may signal different requirements per BIM level. The requirements that are necessary at least to successfully implement BIM are discussed in this section.

The focus on this issue is not on investments to reach a higher BIM level, but at what investments or effort is at least necessary to benefit from a BIM approach in a project. This investigation is performed under the assumption that the organization or company in question is willing to implement BIM in their processes. Resistance about its implementation due to a cultural change is not an issue.

The first requirement needed to successful implement BIM in the processes of a company, is the belief that BIM could benefit current or planned projects. This believe can be obtained by past projects that, in hindsight, could have improved by collaborative working. For instance if more benefits could have been obtained by reduce discrepancies between the different stakeholders within a project.

The investments necessary can be distinguished in tangible and intangible investments. These investments are derived from various sources in literature. The most commonly investments are mentioned. Tangible investments for BIM include new hardware and software, training and development for employees and new employees requirements. Intangible investments needed for BIM are cultural changes and changes in workflow and processes.

Software is considered as the most fundamental aspect of BIM implementation. It also involves the highest costs in the implementation process. To achieve collaborative working according a BIM approach, 3D modelling software is necessary. The most commonly software used for the modelling part of BIM is Autodesk's Revit package of Architecture, Structure and Mechanical, Electrical, Plumbing (MEP), followed by Autodesk Navis Works. Other possibilities are TEKLA, Bentley and Solibri. Also the aspect of interoperability should contribute to the determination which software to use. Information exchange with other stakeholders in the project should go easily.

With the introduction of this new software packages, the requirements on hardware also increased. Due to the implementation of BIM, high specification workstations are required to provide advanced modelling and rendering. File management and storage capacity are important during and after the project life cycle. The size of a BIM model is demonstrably higher compared to an AutoCad file. The data stored can be helpful for future projects.

The new software also brings the demand to train employees quickly to get used to the packages. The skill set of the existing staff of a company or organisation should be examined first. This can be done conducting a survey among employees to investigate gained knowledge or qualifications. In the same manner their interest towards BIM could be investigated as it will be helpful if they are enthusiast about the phenomenon. It is assumed that professionals with AutoCAD experiences need additional training to learn how to use the BIM software. In addition, learning about BIM software is beneficial for every member of a building team as they are involved in the design and modelling process. However, 3D AutoCAD expertise might be a suitable skill for BIM implementation. Other skills that can be helpful are networking knowledge, data transfer, security and sharing skills, skills to teach and encourage other employees, familiarity with data management and protocols, project management experiences, coordination skills and financial and performance measurement skills.

5.4 ROI OF BIM

To, simultaneously, investigate the ROI of BIM, a literature search is conducted. About 50 scientific articles are consulted, all saying something about the perceived or expected ROI when implementing BIM in all kinds of projects. The main findings from this research are summarized in the table below, table 5-4. The complete database can be found in appendix XVIII.

Category	Typical Life Cycle Cost Split	Saving Range	Assumed Mid - Point	Lice Cycle Saving
Design	3%	7,5% to 18%	13,1%	0,4%
Design and construct	20%	2% to 25%	11,8%	2,4%
Construction	17%	5% to 27,5%	13,4%	2,3%
Operation	80%	0,4% to 42%	16,6%	13,3%
Total	**100%**			**15,8%**
ROI	100%	4,14% to 20020%	1728,1%	

Table 5-4 Life cycle savings of BIM

As the table shows, the savings are divided in several categories to further underpin the final results.
The first column mentions the stage of the projects, called *Category.* Although BIM is considered to deliver benefits over the entire life cycle of a building project, the savings can be divided per stage. The stages *Design, Construction* and *Operation* are distinguished, including a combination of the first two stages; *Design and construct*, as not all of the articles differentiate these stages.
BIM functions during the design stage may include design authoring, design reviews, 3D coordination, cost estimation, spatial programming and engineering analysis. In the construction stage the BIM uses include 3D coordination to, together with site utilization planning and 3D control and planning. Finally, BIM in the operation stage is used for maintenance scheduling and building system analysis.
According the second column, the operation stage has the largest share in the *Typical Life Cycle Cost Split*. As much as 80% of savings can be achieved in this stage of a building project. The percentage associated with the design and construct stage is an addition of the percentages of the two individual stages design and construction.
The next column, *Saving Range*, arises from the column that describes the statistics in the entire table. Because the most of the articles not mention an exact value of savings, a range is determined. In this column the lowest value found is the minimum value and the range runs to the maximum value mentioned in the statistics. As can be seen from the table, these values are further apart in the operation stage than in the design and construction stage. Apparently the use of BIM in this stage is still in its infancy, causing uncertainty of exact values of savings. The values differ the least in the design stage.
From these saving range, *Mid-Point Savings* are derived and mentioned in the entire table. Subsequently, combining all these values and calculating the average leads to the next column that is called *Assumed-Mid-Point*. The column shows the highest value in the operation stage and the lowest value in the design stage.

The last step is to define the impact of a single stage on the complete life cycle savings of a buildings project. To draft a proper conclusion, the founded mid-point are multiplied by the typical life cycle cost split and summarized in the last column, *Life Cycle Saving*. Once again, the influence of the possible savings in the operation stage is the largest and this percentage is the smallest in the design stage. All the stages together show that a total life cycle saving of about **15,8%** is achievable.

5.4.1 RELIABILITY SCORE

Of course, now that the percentage of savings is determined, its reliability is a point of discussion. To determine the reliability of each of the statistics, several considerations are of interest. These are the purpose of the gathered data, the methodology of data gathering and the way in which the data is defined (Baarda & de Goede, 2006). The focus in this research is on the methodology of data gathering as not all of the 50 articles consulted use the same method to measure the savings and ROI of BIM.

The methods distinguished to derive the statistics from are assumptions, estimations, surveys and case studies. The first method is to conclude quantified savings by assumptions. These assumptions mostly arise from observations or own interpretation of the building process by investigators. The assumptions are not sufficiently suitable to conclude something about quantified benefits of BIM. For example, in one of the articles an unrealistic assumption is made that none of the 709 errors found by BIM validation would be found in the traditional building process. To exclude these assumptions in the final savings, a reliability score of 0 is assigned to this methodology. However, assumptions that are made in order to draft a model or a survey are not excluded provided that they are well substantiated.

The second methodology to find quantified savings of BIM is by estimations. Several investigators, such as the Construction Industry Institute, the Air Conditioning and Mechanical Contractors' Administration or other enthusiasts, used estimations to draft their statistics. Most of these estimations are based on the qualified benefits of BIM. The estimations in the database are not suitable to conclude quantified savings either, because they are based on the beliefs of investigators towards BIM and its promises. However their results are considered to be more reliable than the results from assumptions and therefore assigned with a reliability score of 1.

A more appropriate method to find quantified statistics is to conduct a survey. Surveys are widely established in quantitative research. The main advantage of this methodology is that the reasons to the answers are included, making it easier to draft conclusions. There are differences between oral surveys and written surveys. Written surveys are most often used in the preparation of the statistics in the database. Moreover, they can be completed anonymously. A disadvantage is that the investigator cannot control the completion of a written surveys, which causes a lot of incomplete surveys at the end. Furthermore, there is a difference in closed and open questions. The investigators from the research in the database mainly used closed questions in their surveys. For example, respondents were asked to classify the potential financial savings due to the implementation of BIM in one out of five categories. To make the respondents familiar with the definition of BIM, open questions might be useful at the beginning of the survey. In addition, the background and the knowledge of the respondents are of high importance. Their affinity with BIM should be taken into account as well as their profession. The answers of respondents who are familiar with BIM are more reliable than the answers of those who are not. This distinction is also made with regard to the assignment of the reliability score. Finally, the number of respondents has to be taken into

account. A survey is considered to be more reliable as the number of respondents increases. Therefore a difference is made in the reliability score that distinguishes usual surveys from surveys with more than 1000 respondents (Baarda & de Goede, 2006).
The statistics derived from research that used a case study approach, are rated with the highest reliability score. The case studies present the implementation of several BIM uses in an identifiable context. Some companies actually measured the results in order to make the savings quantitative. Statistics that appear from multiple case studies are considered to be the most reliable.

In order to deal with this issue an extra column is added, called *Reliability.* Based on the used method and the validation of the findings, a score from 0-5 is assigned to each of the articles. How this is done can be seen under the entire database in appendix XIX. When a 0 is assigned to a certain article, its findings are left out of consideration in the main conclusion. And when a 5 is assigned, the findings of this article have a large share in the final conclusion. First the reliability score is multiplied by the mid-point savings. The outcomes are added together and divided by the total reliability scores assigned in that stage. This method delivers the following table, table 5-5.

Category	Typical Life Cycle Cost Split	Saving Range	Assumed Mid - Point	Lice Cycle Saving
Design	3%	7,5% to 18%	13,2%	0,4%
Design and construct	20%	2% to 25%	10,8%	2,2%
Construction	17%	5% to 27,5%	10,6%	1,8%
Operation	80%	0,4% to 42%	19,3%	15,4%
Total	**100%**			**17,6%**
ROI	100%	4,14% to 20020%	30%	

Table 5-5 Life cycle savings of BIM including reliability

The conclusion, when the reliability of the articles is taken into account, is that the savings over the complete life cycle could be **17,6%**, which is even higher than the percentage mentioned earlier.
This value is mainly caused by a higher percentage of savings in the operation stage, namely 15,4% instead of 13,3%. The articles that tell something about the savings in the operation stage often use a method that is considered to be valid and assigned with a high reliability score. The savings mentioned in the construction stage are mainly based on assumptions or estimations as its value drops from 2,3% to 1,8%, causing a smaller share in the final life cycle saving.

To many of the articles that directly describe the findings about the impact of BIM on the ROI, a 0 is assigned as reliability score. The maximum value for instance, 20020%, is not reliable at all as it is concluded from an unreliable tracking of construction clashes in Navis Works, which is conducted in incomparable projects. Assigning a reliability score of 0 to this method, ensures that this value is not counted in the final judgement. From the 16 statistics that describe the ROI of BIM directly, even five of them are not taken into account according to this method. When taking the reliability into account, the ROI turns out to be 30%.

5.5 ROI OF BIM IN THE CASE STUDIES

According to the literature study BIM seems to be beneficial in terms of costs. Many articles mention costs savings ranging from 10%-20% over the complete life cycle of a building project. The values derived from the literature are quantified and summarized. In addition a reliability score is included in the calculation, based on the methodology used in the different articles. The conclusion, now, states that a building project performed with BIM saves 17,6% of costs over its entire lifecycle in comparison to exact the same project without the use of BIM. In this section will be tested whether this saving is also traceable in the consulted case studies.

Although the comparability of the case studies is taken into account, they still differ regarding their financial metrics, especially in size of total costs. To get around this limitation, the *Estimated Project Result* is included. The estimation process is the same in all of the case studies and excludes the divergent scale of total costs in the project. The estimated project result is compared to the actual result of the project, to see whether the BIM projects turn out to be beneficial over the non-BIM projects in terms of costs.
Besides this, due to their confidentially, the financial values are hard to derive. The subdivision in different costs and revenues is not the same for each project. In the end, the data used in this section only relies on eight case studies. It is suitable to describe whether the conclusion is acceptable, rather than confirm it as an exact value. As mentioned before, the clients in civil engineering will still be satisfied if only a saving range, as the result of the implementation of BIM is given. Table 5-6 and 5-7 present the differences between BIM projects and non-BIM projects, based on the estimated result compared to their actual result.

BIM projects		
Estimated Project Result	Result Actual	Difference
€ -69.010	€ -70.926	3%
€ 17.375	€ 16.206	7%
		5%

Table 5-6 Financial results of BIM projects

non-BIM projects		
Estimated Project Result	Result Actual	Difference
€ 23.452	€ 22.945	2%
€ -16.251	€ -18.171	12%
€ -25.699	€ -30.555	19%
€ 1.349	€ 1.041	23%
		14%

Table 5-7 Financial results of non-BIM projects

The comparison between the financial results of BIM projects and non-BIM projects presents a difference of 9%. This percentage does not imply that an infrastructure project with BIM can be performed 9% cheaper than a project without BIM, because it is based on the actual project result.

According to the data, all the case studies resulted in a lower actual result than their estimated project result. For that matter, the estimation process is consistent again.
The results of the BIM projects shows that an infrastructure project is 5% more expensive, on average, than expected. The differences of the non-BIM projects are a lot higher, resulting in an average of 14%. There could thus be argued that the implementation of BIM is beneficial in terms of costs, also in infrastructure projects, based on the difference of 9%.
Another explanation is that the actual result of a project can be better predicted if BIM is implemented in the project.
It could even be the case that the BIM use forecast is used to predict the financial results of the project. Forecasting according a BIM approach is used in case 1 A9 Heiloo, as mentioned in section 5.2.1.

Despite this attempt, the confirmation of the quantified values of BIM fails in practice. The input of the data, at this point, is not sufficient to perform a valid comparison using the case studies. To further explain the conclusion, again the scientific articles will be consulted. The BIM uses will be derived, where possible, to investigate their individual contribution to the founded ROI of BIM, 17.6%.

5.6 CONTRIBUTION OF THE BIM USES TO THE ROI

Despite the fact that the previous method is not sufficient to prove the conclusion in practice, due to inadequate data, the contribution of each of the BIM uses to the final life cycle saving will be described in this section.
Again, an extensive literature search is conducted, using the database of appendix XVIII. Each article is searched in order to recognize the BIM uses applied in the studies. Because not all of them mention the BIM uses, as they rather explain the method to calculate the final savings, the table of section 5.4 needs to be adapted. The first step is to exclude each article that does not describe which BIM uses are applied, or that did not even use one of the classified BIM uses. The results are presented in table 5-8. If the meaningless articles regarding the BIM uses are not taken into account, the final life cycle saving is set at 24,6%

Category	Typical Life Cycle Cost Split	Saving Range	Assumed Mid - Point	Lice Cycle Saving
Design	3%	7,5% to 18%	12,5%	0,4%
Design and construct	20%	2% to 20%	8,8%	1,8%
Construction	17%	5% to 9,8%	8,1%	1,4%
Operation	80%	13% to 42%	28,5%	22,8%
Total	**100%**			**24,6%**

Table 5-8 Life cycle saving of BIM, based on the BIM uses

To investigate which BIM uses contribute to what extent to this percentage, the applied BIM uses are summarized in a new column within the existing database, corresponding to the article they belong to. Some of the BIM uses can only be associated with one descriptive statistic, concluding that this BIM use contributes to its full extent to the mentioned savings. Other articles contain multiple BIM uses per statistic, resulting in a division of the specific savings by the number of BIM uses accountable.

To give an example, if a statistic describes up to 10% savings of contract value from clash detections in the design stage, and the only BIM use mentioned is coordination, then the complete savings can be attributed to this BIM use. If, besides coordination, three more BIM uses are described that are considered to cause the 10% savings, the savings are divided by four, resulting in 2.5% contribution of each of the BIM uses.

Expanding this method, finally, leads to the results presented in figure 5-2, concluding visualize as the number one contributor to the total life cycle saving. All the percentages are summarized in appendix XX.

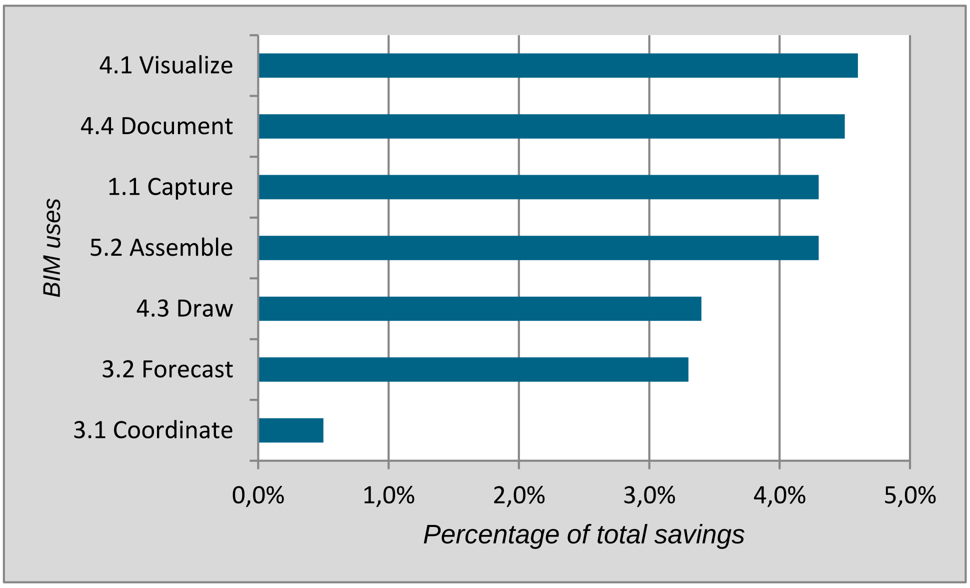


Figure 5-2 Contribution of the BIM uses to the savings

The table shows that of the 24,6% life cycle savings, approximately one sixth is caused by the BIM use visualize. The visualizations are particularly suitable for helping architects, engineers, contractors, as well as customers what is going to be built in a recognizable environment and to identify potential problems at an early stage of the project. It also provides better communication and understanding among all the stakeholders involved. Likewise, according the literature review in chapter two, visualize is often cited as having a very high impact on improving the ROI of BIM.
From figure 5-1 can be concluded that the benefits of visualization are experienced more when the project is performed at a higher BIM level. The percentages present a difference of 70% of its use and benefits between BIM level 1 and BIM level 2. If a project manager believes that better visualizations will strongly contribute to the project development, he might decide to make additional investments in order to reach a higher BIM level first.

The second most contributing BIM use is document. As explained in the introduction, inaccurate documentation results in loss of data. Figure 1-2 demonstrates that, when choosing a BIM approach, most effort is shifted back into the design stage, in which the ability to impact project performance is high and costs of making changes low. This allows for more time to test the design and less time needed for the documentation. This, finally, results in projects being completed sooner and within predictable time planning.

In addition, the documentation is more accurate due to the shifted effort, as this ensures fewer errors and omissions when the construction stage is reached. This documentation must be in electric form, providing one single model to derive documents from, such as elevation, sections or floor plans. An important condition to use documentation to its full extent is the willingness of stakeholders to exchange models and data interoperable in a project.
For better documentation, minimal BIM requirements are needed, as figure 5-1 presents that its use and benefits do not differ much between BIM level 1 and BIM level 2.

The top three contributing uses to the complete life cycle savings is completed by the BIM use capture, that is mainly used to present the current situation prior to a project. There are several tools that seem to become routine in capturing data, such as laser scanning. Laser scanning records field data that captures shapes of an environment and converts it into a cloud of data points that can be converted to a 3D model. Although it is clear that such tools reduce the time needed to capture the current situation, its costs are still a large barrier to implementation. The information captured is used by engineers to create concepts and designs.

Other BIM uses that contribute to the final life cycles savings are assemble, draw, forecast and coordinate. Some of these uses will be discussed in one of the next sections, in which the results are separated according to the stage in the entire project life cycle.

5.6.1 DESIGN STAGE

As the results also present the final savings in each of the stages of the project life cycle, the contribution of the BIM uses are also explained per stage. Figure 5-3 visualizes the results of the contribution of each BIM use to the final savings in the design stage, 12.5%.

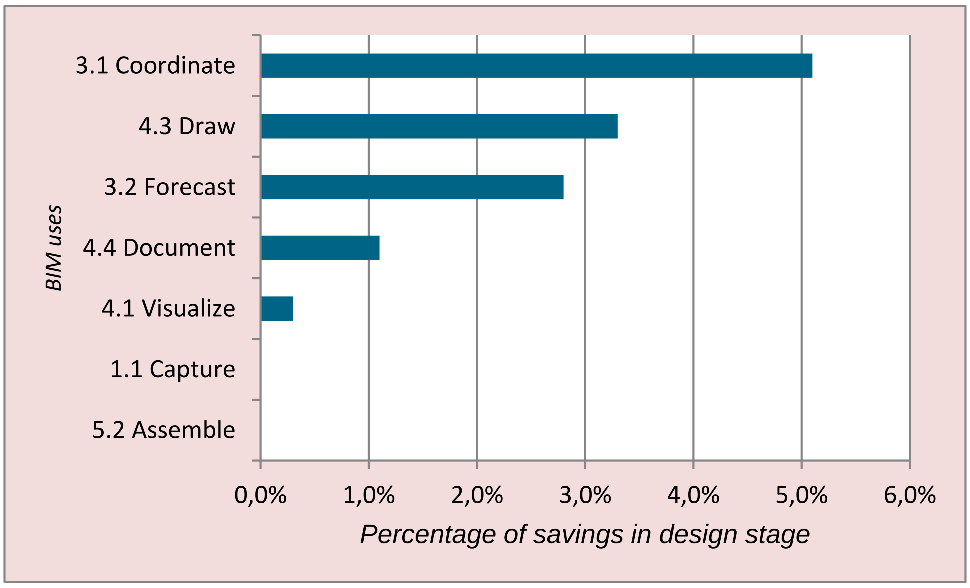


Figure 5-3 Contribution of the BIM uses to the savings in the design stage

The most striking aspect of this table is the contribution of the BIM use coordinate to the final savings in the design stage. Whereas it hardly contributes to the final life cycle savings, it is rated as the top benefit in the design stage.

This implies that coordination is important at the beginning of a project. When talking about BIM, mostly spatial coordination is meant. A major aspect of coordination is early clash detection, which ensures project efficiency and care for better design and operation stages. The use is applied to find where facility elements run into each other.
It is important for a project manager to be aware of the BIM stage of the project before applying clash detection. Clash detection is included in the description of federated BIM (level 2) in chapter 4, and also figure 5-1 presents large differences between both BIM levels.

The second most contributing BIM use in the design stage is draw. This seem to be remarkable, as BIM is often linked to 3D modelling, but is explainable due to the lack of trust of engineers. Doubts consist about the accuracy and completeness of the 3D models, causing difficulty in the implementation of BIM. As a result, 2D drawings including detailing and annotation are often used to exchange data from the design stage. It is important to care for the drawing process to be consistent as it is even a large share in the total life cycle costs.

Besides these two uses, it is important to implement the BIM use forecast at an early stage in the project. It allows for better prediction of projects before they are built. This prevents costs or time overruns at the end of the project. This BIM use exhibits considerable overlap to other BIM uses, as, for instance, visualizations can identify and solve planning problems at an early stage.

These three benefits contribute the least to the final life cycle savings. This can be explained by the small influence of the design stage to the overall life cycle, as the typical life cycle cost split is only 3% for the design stage.

5.6.2 CONSTRUCTION STAGE

The construction stage holds 17% of the total life cycle cost split, and the BIM uses applied in this stage might contribute to a higher extent to the life cycle savings than the uses in the design stage. The results are presented in figure 5-4, and discussed below.

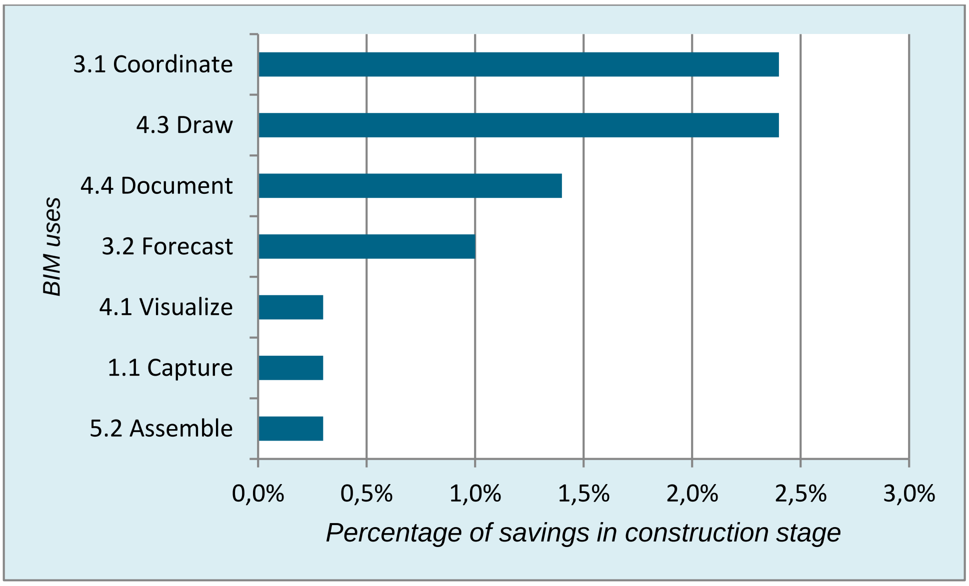


Figure 5-4 Contribution of the BIM uses to the savings in the construction stage

The construction stage can be reduced in time and costs, due to the BIM uses implemented in the design stage. However, the most contributing uses of BIM are exactly the same as in the design stage, namely coordinate and draw. At this stage, clash detection is performed in 3D models in, for instance Navis Works, and requires separated models to be already combined at an earlier stage in the project.

The conceptual drawings or sketches from the design stage are digitalized in the construction stage. In order to combine the different models to perform a clash detections, detailing and annotation is of high importance at this stage. Mostly AutoCAD is used to make these drawings.

Instead of the BIM use forecast in the design stage, documenting contributes to a higher extend to the total savings of in the construction stage, 8,1%. This is explainable, since it is too late to predict costs and draft a project planning at the construction stage. These are already simulated in the design stage and should be maintained at this stage to ensure the project being delivered in time without costs overruns. Regarding the documentation it is an advantage to choose a BIM approach as the effort of documentation is also shifted more towards the design stage. As an result the construction documentation takes less time and the preceding documentation contains less errors and omissions.

5.6.3 OPERATION STAGE

The BIM uses applied in the previous stages contain complete information about a building project as it evolves through planning, design and construction. This information causes that the operation stage can be performed more efficiently. According the typical life cycle cost split 80% of the costs of a building project occur after the construction stage.
In contrast to the life cycle cost split, the articles that omitted the frequency of each BIM use at the different stages, reveal that BIM is most often used in the design stage. BIM is used to a lesser extent in the construction stage and only a few utilize BIM in the operation stage. Some articles even mention that BIM ends in the construction stage. Owners are yet hardly involved in BIM development, although they are increasingly interested in the implementation.
There are little statistics in the table that describe which BIM uses contribute to the founded savings in the operation stage. The limited use in the operation stage might be due to the fact that many stakeholders involved have just adopted BIM.
In the operation stage, the BIM uses create information about the performance and the financial aspects of a building project.
The results of the contribution of each BIM use to the savings in the operation stage are presented in figure 5-5 and show an equal division.

Only the BIM use coordinate, or clash detection, does not contribute to the founded savings in the operation stage. Clash detections are performed in the design and the construction stage in order to discover and recover clashes before the construction of a building project.

Because the operation stage is responsible for such a large amount of the life cycle costs, future research is needed on how to use BIM in this stage. If this research is successful, BIM has without doubt potential to be used throughout the complete life cycle of a building project.

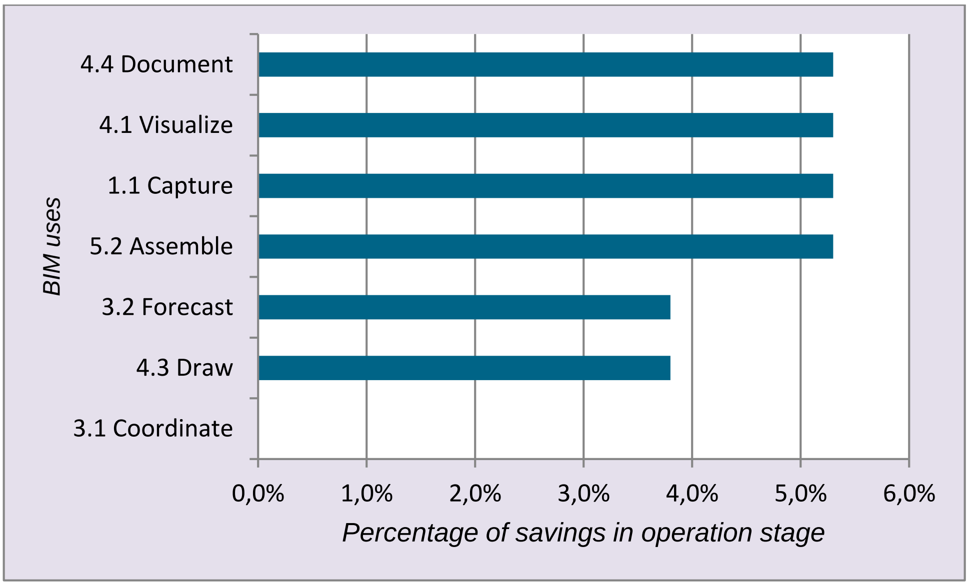


Figure 5-5 Contribution of the BIM uses to the savings in the operation stage

6 Discussion

The objective of this research was to quantify the added value of BIM in infrastructure projects and to develop a suitable methodology for this. The developed model is a representation of the key concepts identified from literature, that provide insight to the added value of BIM, and discusses their interrelationships. Together with the consulted case studies in order to verify the findings in practice, the literature search provides the research methodology. This combined approach resulted in quantified financial savings over the project life cycle if BIM is used. This section discusses the findings from the results and explains how they are related to the purpose of this research. Due to a limited period of time and also by well substantiated assumptions made, this research might contain limitations that influence the validity of the findings. This section discusses these limitations and indicates how future research can use and continue on the findings.

6.1 INTERPRETATION OF THE FINDINGS AND LIMITATIONS

The main findings of this research suggest that a building project can be performed 17,6% cheaper if a BIM approach is chosen. This quantified financial saving arises from an extensive literature study that is summarized in a database. The database includes statistics regarding quantified benefits of BIM and elaborates on the research methodology used. These methods include assumptions, estimations, surveys and case studies. Because there is a difference in the reliability of each method, a reliability score, ranging from 0-5, has been assigned per statistic. The reliability score also distinguishes the reliability based on the amount of respondents of a survey and the number of case studies for which the statistic applies. The rules to assign this score are presented in appendix XIX. When this research would be reproduced, another approach might be chosen to determine the reliability, which can lead to different findings.
However, the founded financial saving is indicative only to illustrate the potential savings that can be yielded through the effective use of BIM. Actual savings depend on the specifics of each project and need to be considered on a case by case basis. The financial savings found in this research should not be considered as an exact value, but might provide an appropriate guideline for clients, regarding the amount savings, to implement BIM. According the demand in the AEC industry, the findings will lead to an increased use of BIM in building projects.

6.1.1 COMPARISON OF PROJECTS

To validate the financial savings found in this research, BIM projects are compared with non-BIM projects. Due to the lack of infrastructure projects performed using a BIM approach, only three case studies have been studied in depth. These case studies are compared to five infrastructure projects without any use of BIM. This seems to be too few to sufficiently support the findings. The first challenge of the comparison was to exclude the differences in the total amount of costs per project. These costs were too far apart to draft an appropriate comparison. To get around this problem, the actual individual project result is compared to the on beforehand estimated project result. This is more credible since the estimation process is always done in the same way within one company or organisation. The problem with this method is that it does not necessarily measures savings, although it provides some ideas about the differences. Secondly, because only eight case studies are studied in depth, the impact of one of these might be too much. If one project, for some reason, differs from the usual building process, its results are included too much in the final findings. It is doubtful whether the financial benefits found in the projects may all be attributed to the use of BIM. They can also be caused by coincidences or by unforeseen setbacks in the non-BIM projects. Moreover, it was difficult to obtain financial data of the building projects. And in the financial administration of the projects, it was hard to find out which figures belong to the use of BIM.

6.1.2 THE VALUE OF THE FINDINGS FOR CIVIL ENGINEERING

As described in this research, the implementation of BIM is mainly difficult in civil engineering. Despite the fact that civil engineers increasingly recognize how BIM works and what benefits it brings in the building industry, they are sceptical towards the implementation of BIM. Because some project managers believe in the added value of BIM, also in civil engineering, attempts are made to quantify the benefits to clarify the results of a BIM approach. The findings of this research will mainly contribute to convince civil engineers to implement BIM in their building processes.

The qualitative metrics that are identified in literature are directly tested in the chosen case studies. This research discusses the use of BIM in infrastructure projects and reveals what benefits occur in the case studies. The case studies demonstrate that the qualitative metrics found can be recognized in practice. Each of the projects benefited of structured information, available at the start of the project that can be used again in a later stage of the project life cycle. In order to ensure that the clients' requirements are maintained in the design, construction and operation stage, these are explicitly specified in a database. In the consulted case studies a database in Relatics is used to store this information.

Whereas the qualitative benefits of BIM can be proven in practice, this does not apply for the quantitative metrics. Because the implementation of BIM in civil engineering is difficult, data derived from real life projects is inadequate. There are few examples of infrastructure projects that benefit from a BIM approach. Therefore, the database, including statistics of quantified values, is prepared using data from civil engineering as well as from the building industry. Hereby it is assumed that the same values apply to infrastructure projects. However, regarding the quantified values, it might be considered which differences may be experienced between the two sectors. The differences in applying BIM to different sectors are illustrated by a classification into geometries. Generally, buildings take a vertical form of construction, whereas this form is usually horizontal in infrastructure projects. Road development projects typically extend along a linear region. This distinction should be discussed as modelling tools and databases may not be equally effective across different forms of geometry. These considerations are useful for designers to select the most appropriate modelling tool. Different tools may be needed among the sections. In addition, the scale between building and infrastructure projects might differ. Road development projects usually cover many kilometres, whereas building projects take place at a limited location and height.

Hence, the differences between the sectors include other choices that might cause discrepancies in the final outcome.

6.2 RECOMMENDATIONS

With regard to the limitations mentioned in the previous sections, recommendations will be provided in this section to guide future research. Besides financial savings, there are more variables that could be investigated using the same methodology as in this research. For instance reduced time might be an interesting benefit to quantify. In the future, also additional data will be available. This data might contain information about the financial savings in infrastructure projects if a BIM approach is used. The data will be useful to reproduce this research or to validate the findings with the help of practical examples.

6.2.1 INCLUSION OF TIME AS A BENEFIT TO QUANTIFY

In this research, reduced time and costs necessary to perform a building project are mentioned as the main benefits of the implementation of BIM. These benefits are considered to be the most important regarding the clients' requirements as they are all interested in savings in terms of time and costs. However, since this research elaborates on financial savings as main purpose to quantify, the same methodology could provide quantified values for time savings in building projects. A similar database could be drafted, including statistics of quantified time savings instead of financial savings. In the database, also the stages of a project life cycle should be defined to investigate in which stage the highest savings are possible. Similar to the findings of this research, the final quantified value should be expressed as a percentage in comparison to non-BIM approaches. Expression in days or weeks is not possible as each project has its specific building time. In principle, time was excluded from this research, because the literature consulted mainly focused on financial savings. As well as the time to carry out this research was limited.

6.2.2 TAGGING BIM PROJECTS IN THE FINANCIAL ADMINISTRATION OF COMPANIES

In order to solve the issues regarding the validation process, two solution are proposed. The first one is to use the same approach as in step 3 of the roadmap model and to involve BIM projects from the building industry to validate the financial savings. The database could be extended and the limitations of a lack of adequate data and the influence of one project on the final result will be reduced and finally disappear at increasing project numbers. However, it remains difficult to find out what features belong to the use of BIM in the current financial administration of companies. The second solution might be to further delve into the case studies investigated in more depth to pinpoint on the costs and benefits of a singular use of BIM in the projects. To compare the results, the costs and benefits of the particular part of the process in a traditional manner should be investigated. The result of the second solution is a micro approach, which makes the projects less comparable. Therefore, the first solution is the preferred one and provides a better solution for future research. A macro approach provides a large-scale database, from which conclusions can be derived.

6.2.3 DEVELOPMENT OF BIM USES IN THE OPERATION STAGE

The processes in the operation stage of a building projects can be performed more efficiently due to the BIM uses in the design and construction stage. According the typical life cycle cost split 80% of the costs of a building project occur in the operation stage. In contrast to this, the findings of this research reveal that BIM is barely used after the construction stage. Owners are yet hardly involved in BIM development, although they seem to be increasingly interested in the implementation. In the operation stage, the BIM uses create information about the performance and the financial aspects of a building. Because the operation stage is responsible for such a large amount of the life cycle costs, future research is needed on how to use BIM in this stage. This might result in new applications of BIM, particularly suitable to use in the operation stage and delivering additional savings. If the research is successful, BIM has without doubt potential to be used throughout the complete life cycle of a building project.

7 Conclusion

The AEC industry is looking for an alternative to the traditional building process in order to reduce the time and costs needed to implement a building project. BIM is an alternative that is said to provide reduced time and costs, as well as it involves a lot of additional benefits, such as better communication throughout the total building process. Qualitative benefits of BIM have been widely recognized in literature. However, quantified benefits that provide an indication about the savings due to the benefits of BIM, were lacking. Building clients had to decide whether to implement BIM in their processes based on promised benefits without a sense of the numerical impact on the time or costs needed. This thesis, therefore, answers the research question: *How to quantify the added value of BIM in infrastructure projects?* In this section the answers to the associated sub questions are discussed.

7.1 RESEARCH QUESTIONS

> 1. *Which key concepts of BIM can be identified that provide insight to the added value of BIM and how are they related?*

The key concepts of BIM that provide insight to the added value of BIM are the BIM levels, the uses and benefits of BIM, case studies using a BIM approach and the ROI of BIM. Their self-contained definitions are investigated in order to discover the interrelationship between the concepts. Several relationships have been found. The BIM levels are strongly related to its uses and benefits. This thesis demonstrates that certain benefits are more experienced when a project is carried out on a higher BIM level. This applies in particular to the BIM uses visualize, arrange and coordinate. These BIM uses and benefits can be recognized in the case studies. Their application is discussed in section 5.2. In contrast, this does not apply for the ROI of BIM. The founded value for ROI cannot be validated by means of the benefits in the case studies investigated. The number of case studies is insufficient and it is not clear which benefits, or difficulties, can be attributed to the use of BIM. However, it can be concluded which of the BIM uses and benefits contribute to what extent to the financial savings in the study. The results show that of the total life cycle savings, the largest share is caused by the BIM use visualize, followed by document and capture.

> 2. *Which BIM uses and benefits can be distinguished from literature to investigate their contribution to the added value of BIM?*

As mentioned in section 3.3 and 3.4 there are a lot of BIM uses and benefits that can be distinguished from literature. These uses and benefits are spread out over the entire project life cycle of a building project and vary from information gathering of the current status of a facility to fabrication of elements. To delimit the scope of this research, the description of the uses and benefits from the Pennsylvania State University is used and summarized on a BIM poster. This poster is used to identify the most important uses and benefits in the case studies. The uses and benefits included in this research are demonstrated in figure 4-3.

> *3. Which BIM uses and benefits identified in literature can be recognized in practice?*

Several case studies are consulted to investigate whether the uses and benefits identified in literature can be recognized in practice. The selected case studies are infrastructure projects in which a BIM approach is used. Background information about these case studies is provided in section 4.1.3. The three consulted case studies contain a wide range of BIM uses. The BIM uses capture, prescribe, coordinate, forecast, visualize, transform and draw can be recognized. In section 5.2 is described how these used are applied in the projects and what benefits they bring.

> *4. Are there any BIM benefits that are experienced more when a project is performed at a higher BIM level?*

As mentioned in the description of the relationship between the BIM levels and the uses and benefits, there are benefits that are experienced more when a project is performed at a higher BIM level. Because the three case studies were not sufficient to underpin this argument, the database of projects using a BIM approach is expanded. 51 BIM projects in the building industry have been investigated for their BIM level and uses. These are recorded in a database that is summarized in appendix XVII. The findings reveal that there are several differences in the use of BIM related to the BIM level of the project. When a project is performed at BIM level 2 instead of BIM level 1, benefits are especially experienced more from the BIM uses visualize, arrange and coordinate. The rest of the differences is depicted in figure 5-1. These findings might impact the decision of project managers to make investments in order to enable the project to be performed at a higher BIM level. This decision can be made based on these findings and in accordance with the clients requirements.

> *5. Which requirements are necessary at least to apply particular BIM uses and experience their benefits?*

Figure 5-1 demonstrates that there are four BIM uses that are not experienced at BIM level 1, whereas they are experienced at BIM level 2. These differences may signal different requirements per BIM level. This answer discusses the requirements that are necessary at least to successfully implement BIM. Tangible and intangible investments can be distinguishes. Tangible investments are new hardware and software, training and development for employees and new employees requirements. Intangible investments include cultural changes and changes in workflow and processes.

To achieve collaborative working according a BIM approach, 3D modelling software is necessary. With the introduction of new software packages, the requirements on hardware also increased. High specification workstations are required to provide advanced modelling and rendering. The new software also brings the demand to train employees quickly to get used to the packages. Moreover, it is important that the company or organization has the belief that BIM could benefit current or planned projects.

> 6. *Which BIM uses contribute to what extent to the financial benefits found in the study?*

The findings of this research provide a quantified value for financial savings that are possible if BIM is implemented in a building project. For project managers, to decide whether to implement BIM in their processes, it is useful to know which BIM uses contribute to what extent to the financial benefits found. Their contribution is investigated using the database presented in appendix XVIII. The uses applied are summarized per statistic and their share to the total financial savings is calculated. The results reveal that the uses visualize, document and capture are the most financial beneficial over the complete project life cycle as demonstrated in figure 5-2. Based on these findings, a project manager might decide to include these BIM uses in the standard building processes of a company or organization.

7.2 SOCIETAL RELEVANCE

In modern society there is a need for improved building processes with respect to the traditional manner. The results of building projects that were too expensive or took too long are widely debated and negatively publicized by media attention. A lot of the failures are caused by insufficient information exchange methods or by not working together. Solving these issues is precisely where BIM is supposed to excel in. As nowadays the focus on building projects shifts from new buildings to renovation and maintenance, it is important that the building information is stored properly. This building information is of significant value in the operation stage of a building project.
For companies or organizations choosing a BIM approach might deliver a convenient market position relative to companies that have not implemented yet. Building clients, for instance Rijkswaterstaat, increasingly ask for a BIM approach for their assignments. This motivates companies to implement BIM to have a bigger change for winning the contract.
Moreover, the implementation of BIM was hindered by a lack of quantified benefits of BIM. This research demonstrates that a financial saving of approximately 17,6% over the project life cycle is possible when BIM is used in comparison with the traditional manner. Although this quantified value must be seen as an indication instead of an exact value, it might convince project managers to implement BIM in their processes. This might lead to increased utilization of BIM in building projects in the near future, resulting in a more efficient way of building to lower costs and within the agreed timelines.

7.3 SCIENTIFIC RELEVANCE

An extensive literature review is conducted to find out what is already known about the research topic and which methods are already used to describe the added value of BIM in building projects. The articles, in general, extensively address qualified benefits of BIM, whereas there is no consensus about the quantified benefits of BIM. The main problem covered by this research is the lack of quantified benefits of BIM.
It reveals a method, using quantified values from the literature as data input, to combine and extent findings of previous research. An extensive database is drafted, in which statistics are combined with the used method and rated with a reliability score. This methodology allows to conclude an indicative value of quantified benefits. The financial savings that are possible, due to the implementation of BIM, are determined at 17,6% over the complete life cycle of a building project.

The main findings of this research can be used as a starting point for future research of the added value of BIM. As this research was hampered by the lack of adequate data from infrastructure projects using BIM, the validation process might be re-considered and investigated in practice. The expectation for infrastructure projects is that this can be done within one to two years from now, as BIM is increasingly implemented in these projects nowadays.

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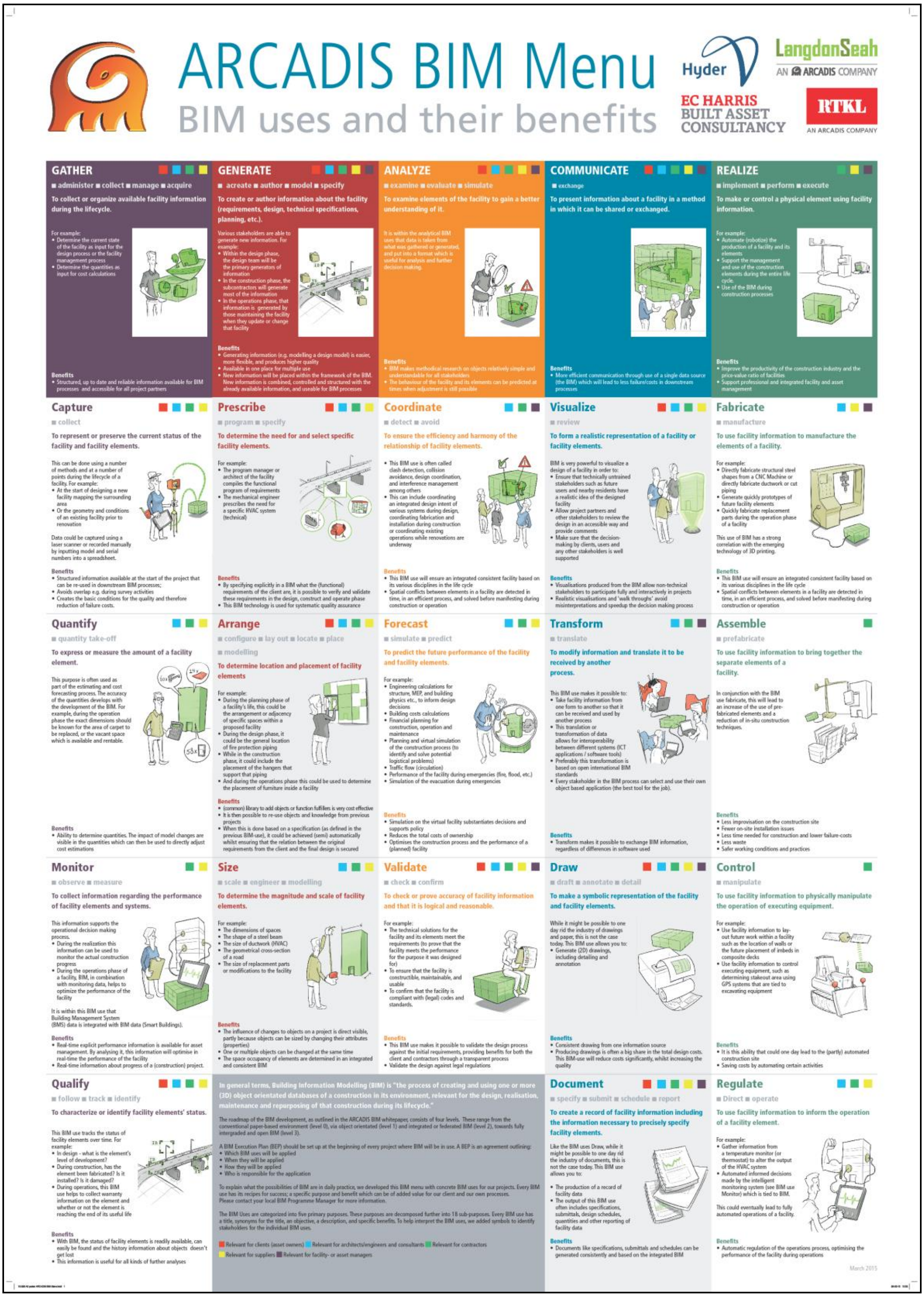
Appendices

I. BIM POSTER

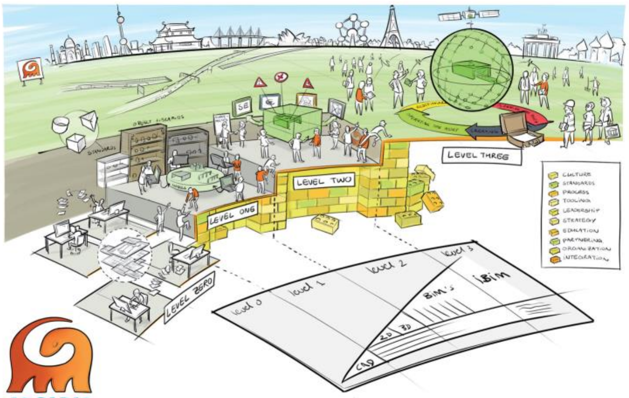

ARCADIS BIM Menu
BIM uses and their benefits
Hyder
LangdonSeah
AN ARCADIS COMPANY
EC HARRIS
BUILT ASSET
CONSULTANCY
RTKL
AN ARCADIS COMPANY
GATHER
GENERATE
ANALYZE
COMMUNICATE
REALIZE
Capture
Prescribe
Coordinate
Visualize
Fabricate
Quantify
Arrange
Forecast
Transform
Assemble
Monitor
Size
Validate
Draw
Control
Qualify
Document
Regulate

II. DESCRIPTION BIM LEVEL 1

BIM bij ARCADIS

BIM level 1

Beschrijving[1]



De *eerste stap* in de implementatie van BIM is het _werken met objecten_. Dit wordt vaak geassocieerd met het werken met 3D-objecten, die in een ontwerpprogramma in een virtuele omgeving worden geplaatst. 3D is echter geen uitgangspunt. Ook 2D-objecten zijn mogelijk en zelfs objecten zonder enkele geometrische beschrijving. **Kenmerkend voor dit level is de toepassing van eenduidige objecten waaraan informatie (intelligentie) is te koppelen**. Er is in dit level *geen sprake van integratie* tussen verschillende disciplines of aspecten. Dus nog *geen koppeling* van het 3D-model met bijvoorbeeld financiële calculatie of planningssoftware. Dit vindt plaats in Level 2.

Algemene kenmerken van BIM level 1

1. Objectgericht kunnen denken en objectgericht kunnen ontwerpen;
2. Ontwerpproces én vastleggen van objectinformatie gebeurt in de eigen werkomgeving (eigen computer);
3. Kunnen werken met objecten, waarvan zijn vastgelegd:
    a. Het generieke type (bv. kunstwerk i.p.v. viaduct);
    b. De relevante kenmerken (bv. geometrie, locatie, stelsel);
    c. De object-beschrijving;
    d. Het beheer en ‘onderhoud’ van de object(informatie) (bv.in een bibliotheek of in het ontwerp);
    e. Objectparameters (bv lengte, breedte, hoogte, objectrelaties) t.b.v. parametrisch[2] ontwerpen;
4. We wisselen monodisciplinaire (object)informatie met elkaar uit;
5. Data wordt eenmalig ingewonnen en meervoudig door meerdere disciplines gebruikt;
6. Alle projectbetrokkenen (ontwerpers) worden op traditionele wijze (projectteam) geïnformeerd bij nieuwe en/of gewijzigde informatie in de verschillende aspectmodellen;
7. Medewerkers hebben een gemeenschappelijke mindset en weten waarom ARCADIS BIM toepast.
    a. Motto - “BIM, driver for collaboration and work-sharing”;
    b. BIM is de sleutel tot hogere kwaliteit, lagere faalkosten en een betere oplossing voor de klant.

---

[1] Bron van de beschrijving is de “BIR kenniskaart 1”
[2] Parametrisch ontwerpen: expliciet definiëren van objectparameters en objectrelaties;

Aandachtsgebieden

Markt

- Acquisitiegesprek
  In acquisitiegesprekken komt het onderwerp "objecten"/"objectgerichtheid" aan bod; belangrijke vragen:
  - Welke objecten beheert de klant?
  - Werkt de klant object-georiënteerd?
  - Welke objectkenmerken zijn relevant?

- Offerte
  In de offerte worden de BIM-kansen en BIM-doelen benoemd; de situatie bij de klant wordt, wat betreft objecten, beschreven en er wordt aangegeven op welke wijze aansluiting wordt gezocht met, dan wel invulling kan worden gegeven aan, het beheersproces van de objecten dan wel de assets van de klant.

Competenties

- Integraal kunnen denken en ontwerpen gericht op de totale projectscope - weten wie binnen een project welke rol heeft en met welke objecten werkt;
- Objectgericht kunnen denken en ontwerpen, wat betekent dat je het ontwerp met objecten opbouwt;
- Bewust zijn van het feit dát je informatie van elkaar nodig hebt en wélke informatie, binnen een project.

Kennisdeling/leren

De kennisdeling en het leren is gericht op het besef dat object-georiënteerd:

- denken nodig is om integraal kunnen ontwerpen;
- werken vereist dat ontwerpers elkaars informatiebehoefte kennen;
- ontwerpen nodig is om informatie te kunnen toevoegen aan het ontwerp;
- werken nodig is om (naderhand) informatie met elkaar te kunnen delen;

Kortom: weten wat objectgericht ontwerpen betekent voor je eigen werk én andermans werk; vormen hierin zijn: presentaties, e-learning, workshops, ed.

Processen/Informatiestromen

- Informatiestromen tussen disciplines zijn inzichtelijk en beschreven: wie heeft welke informatie waarvoor en wanneer nodig;
- De focus ligt op de eigen discipline en men maakt gebruik van traditionele uitwisseling van data;
- Het eigen proces is in detail beschreven en afhankelijkheden (binnen het eigen proces maar ook overdacht momenten met andere processen) worden benoemd, evenals de benodigde informatie.

Projecten (feitelijk de praktische toepassing)

- De BIM-doelen van het project zijn in het acquisitiegesprek en in de offerte meegenomen;
- De BIM-doelen zijn bekend in het project;
- Het project levert een bijdrage aan (de inrichting en/of vulling van) de beheerde objectenbibliotheek;
- In projecten ligt binnen de eigen discipline de focus op het objectgericht werken;
- Informatie-uitwisseling (traditioneel) vindt op vaste momenten plaats, afgestemd op elkaars informatiebehoefte.

Standaarden

Er zijn geen uitwisselingsstandaarden. Er wordt gewerkt met geldende CAD afspraken.

Voorbeelden

Voorbeelden van onderdelen van BIM level 1 die op dit moment al toegepast worden, zijn:

- De ontwerper werkt in zijn eigen ontwerp en beschikt over standaard objecten die hij kan hergebruiken in zijn nieuwe ontwerp; werkt bv. met objecten in Revit (bijv. een onderdoorgang) of Autocad (relaishuis).
- De eisen zijn vastgelegd in een objectenboom;
- De verschillende disciplines hebben met elkaar afgestemd hoe de processen lopen en wie welke (object)informatie beheert cq eigenaar is van welke informatie. Bij het uitwisselen is dat bekend en kan daar rekening mee worden gehouden.
- Een model wordt parametrisch gecreëerd en aangepast (onderdoorgang);
- Eenvoudige visualisaties worden gemaakt van een bouwwerk. Deze worden gebruikt om niet-technische betrokkenen mee te nemen in een ontwerp en de verschillende mogelijkheden.

Opgesteld: BIM Programmateam Mobiliteit

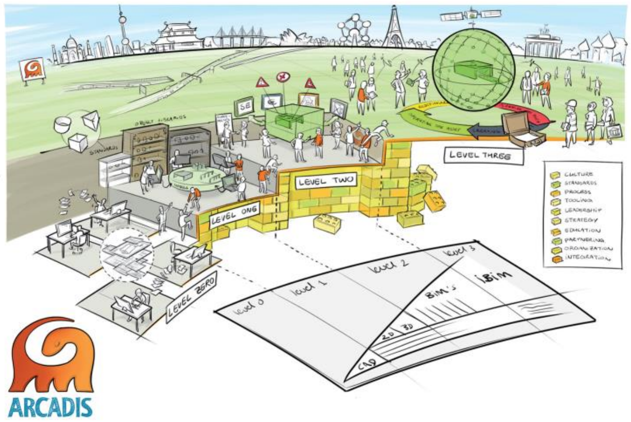
Amersfoort, december 2014 - definitief

III. DESCRIPTION BIM LEVEL 2

BIM bij ARCADIS

BIM level 2

Beschrijving[3]



In dit BIM-level is het mogelijk om de in level 1 opgebouwde objectmodellen, met elkaar te delen.
Er wordt samengewerkt op basis van een verzameling (een federatie) autonome databases: ieder heeft nog steeds zijn eigen model, maar deze **modellen worden gecombineerd in één viewmodel** om zodoende 'file based' samen te werken aan een project. Toepassingen zoals planning (4D) en kostencalculaties (5D) zijn aan het model te koppelen. Dit level wordt ook wel 'little BIM' genoemd. Als we BIM echter zien als 'samenwerken', dan staat 'level 2' gelijk aan BIM. De partijen die de informatie delen bevinden zich binnen één controleer- of beheerbare organisatie-eenheid.

Algemene kenmerken van BIM level 2[4]

1. Elke discipline heeft BIM-software waarin de informatie object georiënteerd is opgeslagen.
2. Informatie in BIM-software is zodanig opgeslagen dat deze uitgewisseld kan worden, onafhankelijk van de software.
3. Gedurende het (ontwerp)proces is het mogelijk monodisciplinaire ontwerpen te integreren.
4. Data kan door meerdere partijen (in)gelezen worden.
5. Uitwisseling tussen BIM-software vindt alleen binnen eigen projectorganisatie plaats. *(Uitwisseling met externe organisaties vindt plaats in Level 3)*
6. Er zijn BIM-rollen en bijbehorende verantwoordelijkheden gedefinieerd.

Aandachtsgebieden

Markt

- Acquisitiegesprek
  In het acquisitiegesprek worden "data-beschikbaarheid", "betrouwbaarheid" en "uitwisselbaarheid" benoemd. Belangrijke vragen:
  - Over welke data beschikt de klant?
  - Hoe is de betrouwbaarheid van de data?
  - Op welke wijze en in welke software wordt de data opgeslagen?
  - Hoe wordt de verrijkte data weer terug geleverd aan het systeem van de klant?

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[3] Bron van de beschrijving is de "BIR kenniskaart 1"

[4] Deze kenmerken zijn aanvullend op BIM-level 1

- Offerte
  In de offerte worden de BIM-kansen en BIM-doelen benoemd. De situatie bij de klant wordt, wat betreft integraal gebruik van de data, beschreven en er wordt aangegeven op welke wijze de verrijkte data moet worden gekoppeld aan de objecten-structuur (de assets) van de klant.

Competenties
- BIM-rollen en bijbehorende competenties en verantwoordelijkheden zijn opgesteld en bekend bij de medewerkers.
- Het trainingsaanbod maakt expliciet helder wat de relatie met BIM is.

Kennisdeling/leren
- Kennis en ervaring over koppeling van BIM-software wordt tussen projecten gedeeld.
- Kennis en ervaring over elkaars processen en informatiestromen wordt tussen disciplines gedeeld.

Processen/Informatiestromen
- Processen en informatiestromen zijn geregeld in BIM-software.
- Uitwisseling van informatie vindt dynamisch plaats in plaats van op aanvraag.
- Processen en informatiestromen zijn object georiënteerd.

Projecten (toepassing)
- Verschillende partijen binnen een project wisselen de informatie uit middels BIM-software.
- Het project gebruikt de beschikbare en/of ingewonnen data van de klant en verbindt deze in verrijkte toestand de eigen BIM-software.
- Binnen het project is een, voor iedereen, herkenbare objectenstructuur aanwezig.

Standaarden
De standaarden focussen zich op een gestandaardiseerd wijze van het uitwisselen van informatie. Op deze wijze is het voor alle BIM-software mogelijk om de informatie in te lezen en, wanneer nodig, te updaten. Belangrijke standaarden zijn[5]: VISI, GML, ETIM, IFC, CityGML, CB-NL en IMGeo.

Voorbeelden

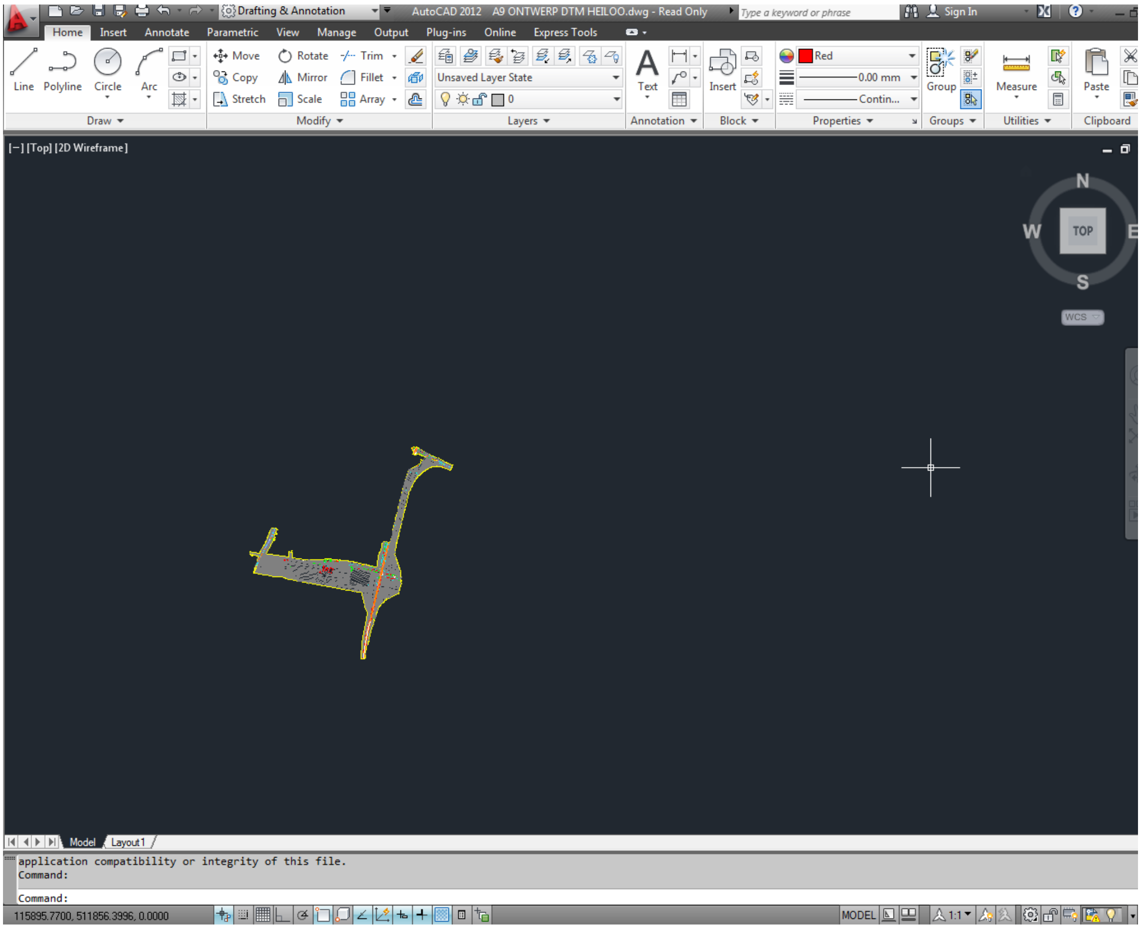
Voorbeelden van onderdelen van BIM level 2 die op dit moment al toegepast worden, zijn:
- Het ontwerp wordt geplaatst in een GIS-omgeving.
- Ontwerp van verschillende disciplines wordt in één datamodel gezet zodat een clashdetectie uitgevoerd kan worden.
- Basis- én project specifieke informatie wordt verzameld en ontsloten via een Dataroom.
- Eisen (in Relatics) zijn op te vragen vanuit Civil-3D.
- De planning wordt gekoppeld aan het ontwerp.
- Vanuit het ontwerp worden (automatisch) kengetallen gegenereerd ten behoeve van een kostenraming.
- Bouwlogistiek wordt gevisualiseerd (en gevalideerd) in de tijd in relatie tot het ontwerp.

Opgesteld: BIM Programmateam Mobiliteit

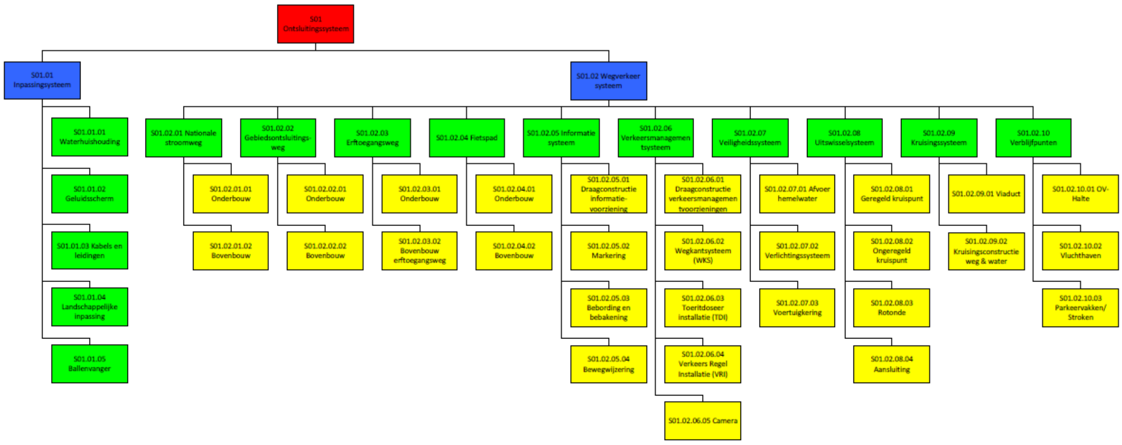
Amersfoort, maart 2015 - definitief

[5] Bron is de :"BIR kenniskaart 2"

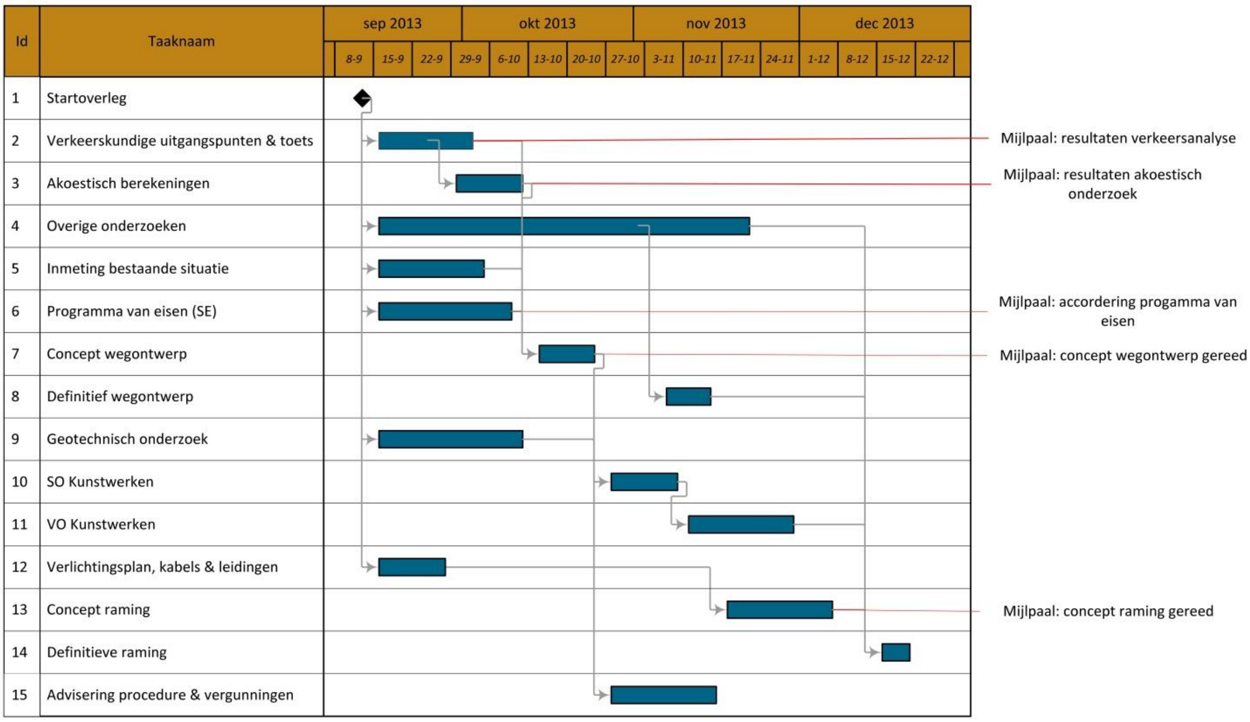
IV. A9 HEILOO: 1.1 CAPTURE



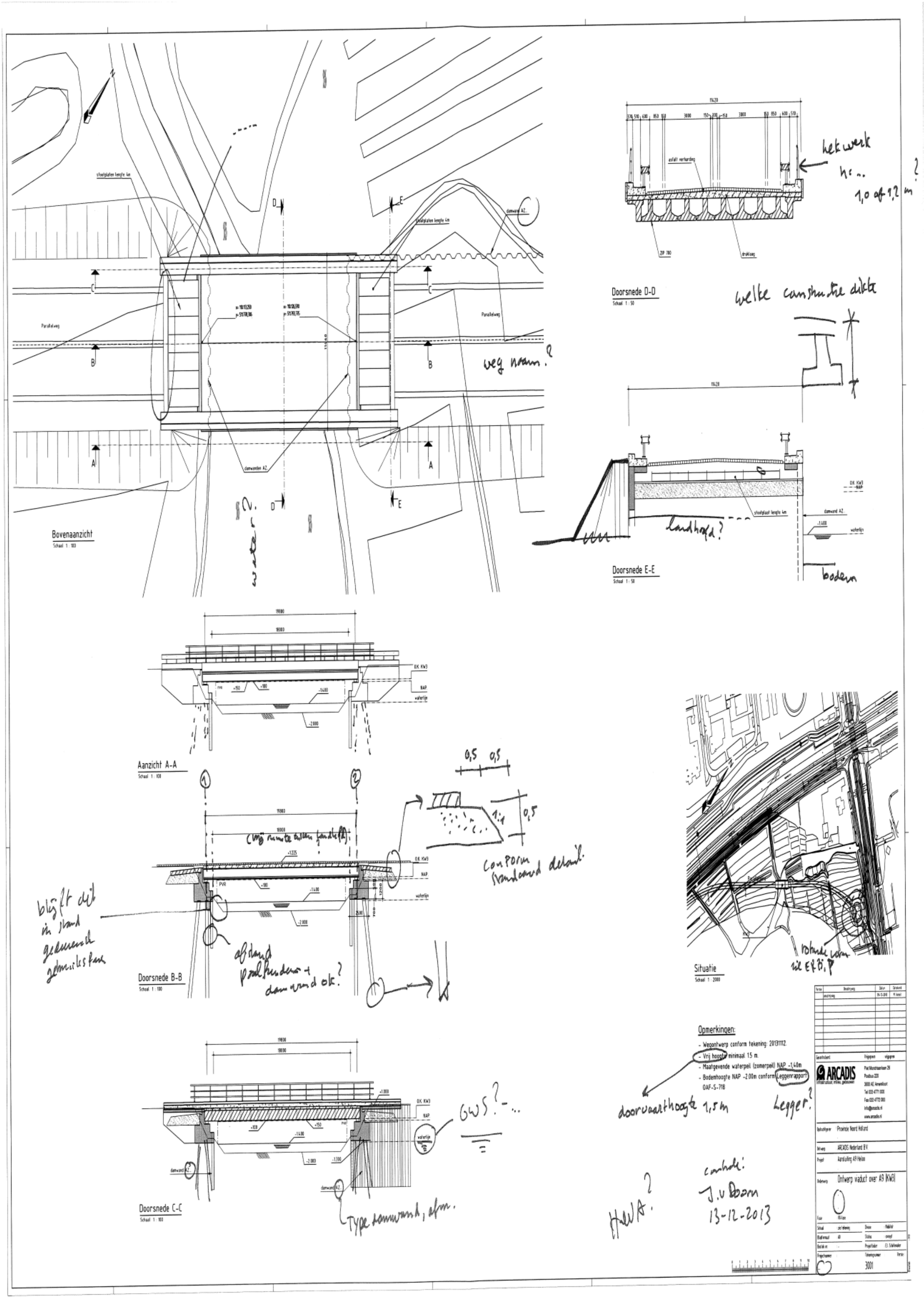
V. A9 HEILOO: 2.1 PRESCRIBE



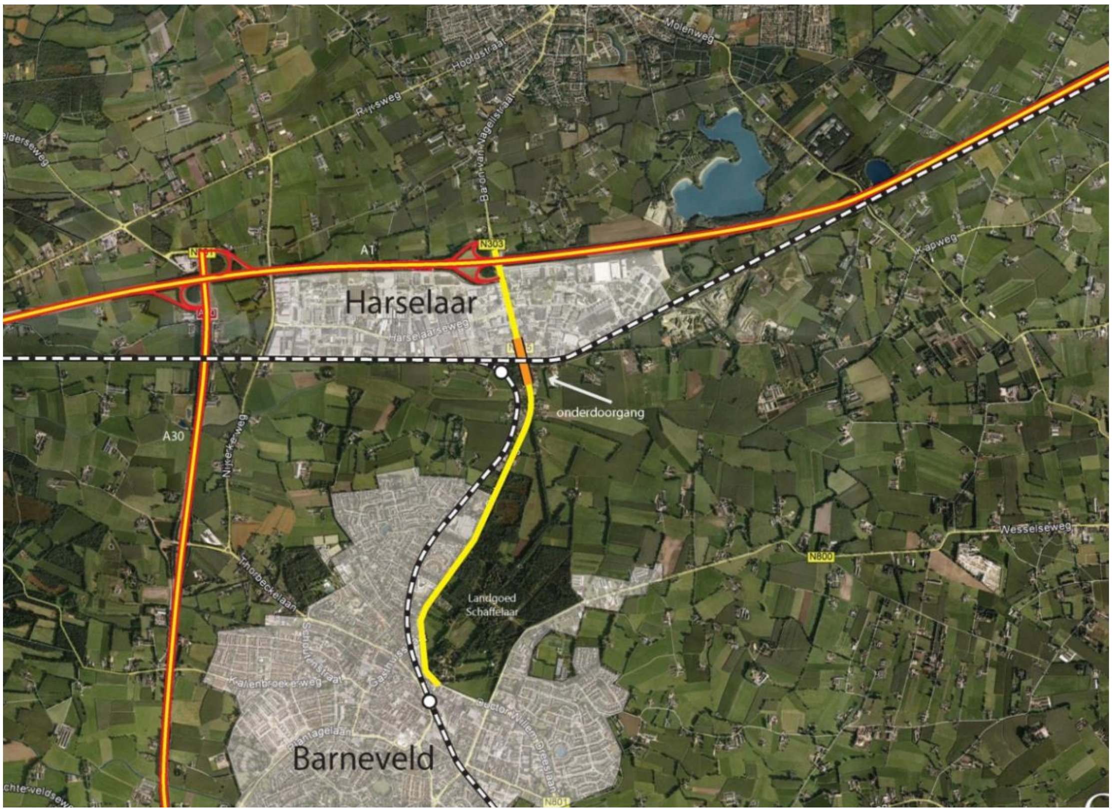
VI. A9 HEILOO: 3.2 FORECAST



VII. A9 HEILOO: 4.3 DRAW



VIII. BARNEVELD ONDERDOORGANG HARSELAAR: 1.1 CAPTURE



IX. BARNEVELD ONDERDOORGANG HARSELAAR: 2.1 PRESCRIBE

55	Geleiden, IC-station	Bovenl. Eis	Bron	Eisinitiator
BOH.F.027	Een mogelijk toekomstig IC-station Barneveld Noord aan de spoorlijn Amersfoort – Apeldoorn mag niet onmogelijk worden gemaakt.	BOH.F.019	SRS onderdoorgang Harselaar	ProRail
Verificatiemethode	Documentcontrole			

56	Faciliteren infra, afwikkelen verkeer verkeersdek	Bovenl. Eis	Bron	Eisinitiator
BOH.F.028	BOH dient ten noorden van de spoorbaan, parallel aan de spoorbaan te zijn voorzien van een verkeersdek	BOH.F.001	VO+ Rapport + tekening	Gemeente Barneveld, ProRail
Verificatiemethode	Documentcontrole			
Onderl. Eisen	BOH.F.029			

57	Aafwikkelen verkeer verkeersdek, dwarsprofiel	Bovenl. Eis	Bron	Eisinitiator
BOH.F.029	Het dwarsprofiel van het fietspad dient minimaal 2750mm breed en afschot van 2,5% van de spoorbaan af te bezitten.	BOH.F.028	VO+ Rapport + tekening	Gemeente Barneveld
Verificatiemethode	Documentcontrole			
Onderl. Eisen	BOH.F.030, BOH.F.031, BOH.F.032			

58	Dwarsprofiel, schrikstrook	Bovenl. Eis	Bron	Eisinitiator
BOH.F.030	Het fietspad dient aan de noordzijde van het fietspad te zijn voorzien van een schrikstrook met een minimale breedte van 500mm en afschot van 1:100 richting het fietspad.	BOH.F.029	VO+ Rapport + tekening	Gemeente Barneveld
Verificatiemethode	Documentcontrole			

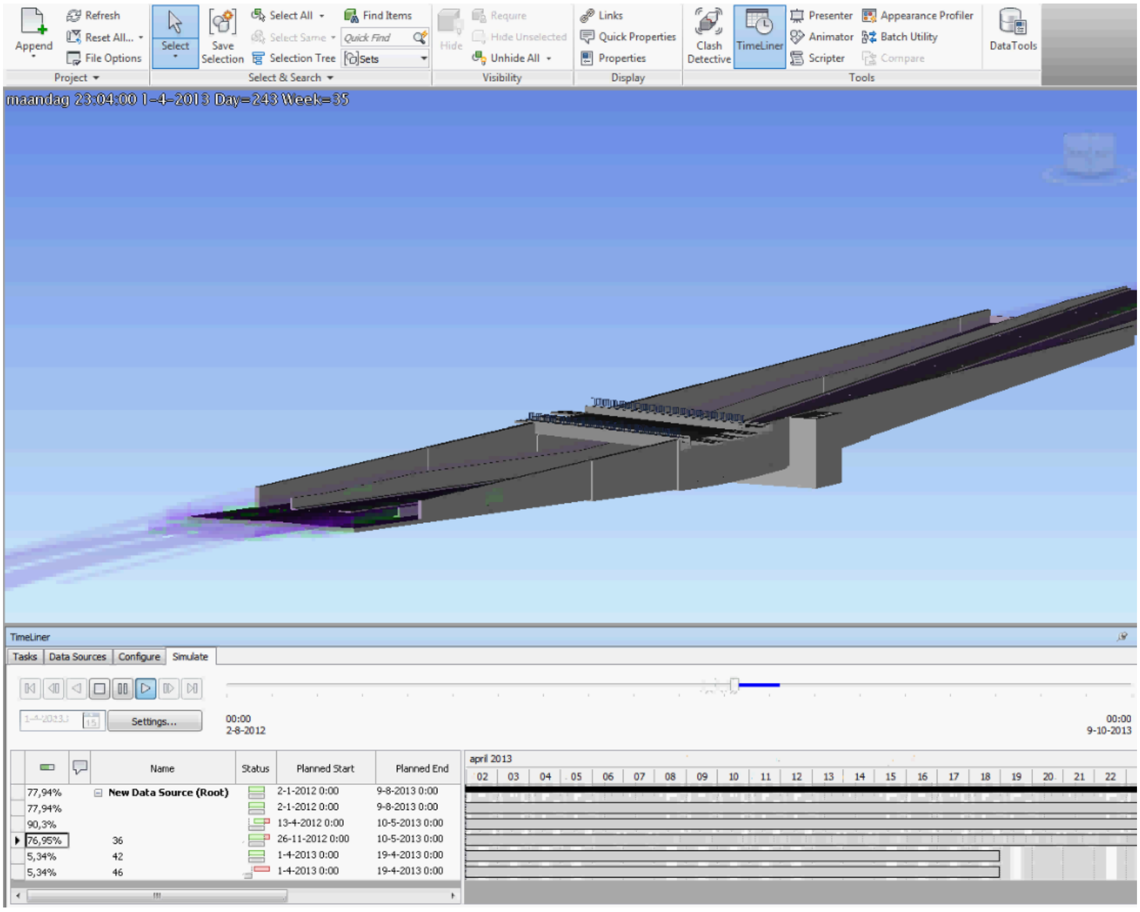
59	Dwarsprofiel, voetpad	Bovenl. Eis	Bron	Eisinitiator
BOH.F.031	Het fietspad dient aan de zuidzijde van het fietspad te zijn voorzien van een voetpad met een minimale breedte van 2250mm en afschot van 2% richting het fietspad	BOH.F.029	VO+ Rapport + tekening	Gemeente Barneveld
Verificatiemethode	Documentcontrole			

60	Dwarsprofiel, hoogteverschil t.o.v. fietspad	Bovenl. Eis	Bron	Eisinitiator
BOH.F.032	Het voetpad en de schrikstrook dienen over de gehele lengte 50mm hoger dan het naastgelegen fietspad te liggen.	BOH.F.029	VO+ Rapport + tekening	Gemeente Barneveld
Toelichting	Gemeten op de overgang van het fietspad naar vrije zone en schrikstrook			
Verificatiemethode	Documentcontrole			

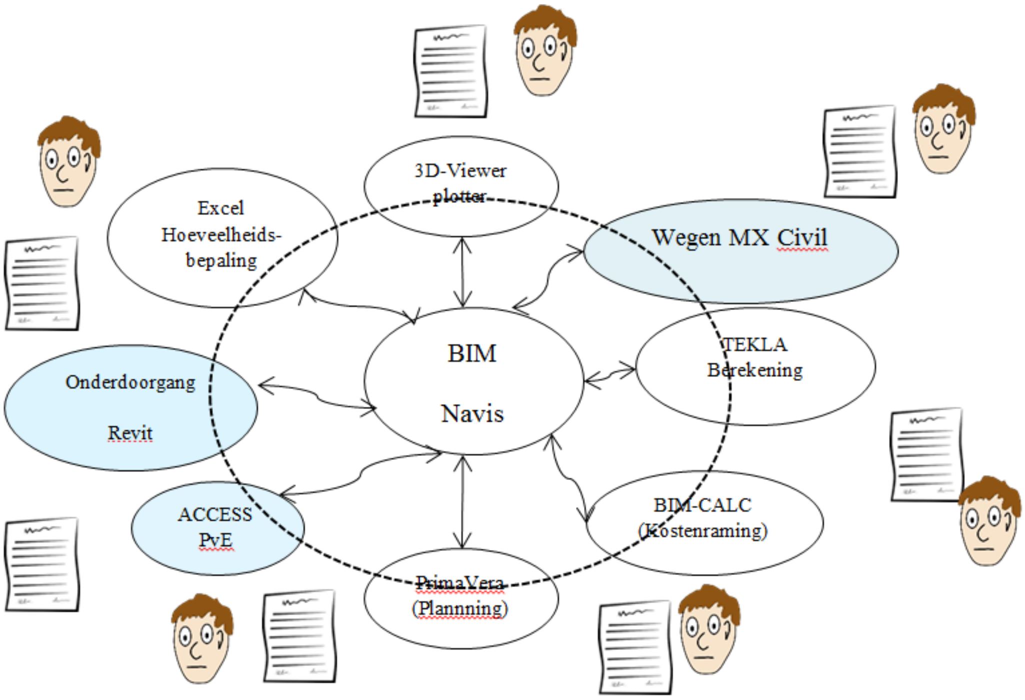
61	Afwikkelen verkeer in odg., isoleren verkeer van omgeving	Bovenl. Eis	Bron	Eisinitiator
BOH.F.033	BOH dient het wegverkeer en fietsverkeer te isoleren voor verstorende effecten vanuit de omgeving	BOH.F.001	VO+ Rapport + tekening	Gemeente Barneveld, ProRail
Verificatiemethode	In een vervolgfase			
Onderl. Eisen	BOH.F.034, BOH.F.035, BOH.F.038			

X. BARNEVELD ONDERDOORGANG HARSELAAR: 4.1 VISUALIZE

XI. BARNEVELD ONDERDOORGANG HARSELAAR: 4.1 VISUALIZE (1)



XII. BARNEVELD ONDERDOORGANG HARSELAAR: 4.2 TRANSFORM



XIII. OMBOUW AMSTELVEENLIJN: 1.1 CAPTURE

XIV. OMBOUW AMSTELVEENLIJN: 2.1 PRESCRIBE

Klanteisen Ontwerpatelier 1 (05-06-2014) **Code**	**Eistekst**	**Eistitel**	**stakeholder**	**Toelichting**
0043	Wens: De halte dient uitgevoerd te zijn als een middenperron	Tramsysteem, Halte, Middenperron	Dienst Metro (Gemeente Amsterdam)	Alleen zijperron als middenperron niet kan.
0044	De toegankelijkheid voor minder validen dient te zijn geborgd door minimale breedte van 1,90m (2,20m is de aanbeveling).	Tramsysteem, Halte, Toegankelijkheid	Dienst Metro (Gemeente Amsterdam)	Minimale afmetingen moeten nog worden vastgesteld.
0046	De halte dient een minimale lengte te hebben van 65 meter.	Tramsysteem, Halte, Lengte	Dienst Metro (Gemeente Amsterdam)	Minimale lengte is 65/70 meter, exacte maat moet nog worden vastgesteld.
0047	De halte dient een minimale breedte te hebben van 6,00 meter.	Tramsysteem, Halte, Breedte	Dienst Metro (Gemeente Amsterdam)	Uitgaande van een middenperron.
0048	Het baanvak bij de halte dient horizontaal te zijn ingepast.	Tramsysteem, Halte, Baanvak horizontaal	Dienst Metro (Gemeente Amsterdam)	Er dient nog te worden vastgesteld wat is exacte eis is (0,0%)
0052	En gelijkvloerse overstap over spoor bij toepassing zijperrons wordt niet uitgesloten.	Tramsysteem, Halte, Cross-platform spoor	Dienst Metro (Gemeente Amsterdam)	
0054	Tijdens de ombouw dient de overlast naar de omgeving zoveel mogelijk te worden beperkt.	Tramsysteem, Realisatie, Overlast omgeving	Dienst Metro (Gemeente Amsterdam)	
0058	Tijdens de ombouw dient de geluidshinder tot een minimum beperkt te zijn.	Tramsysteem, Realisatie, Geluidshinder	Dienst Metro (Gemeente Amsterdam)	Met name de geluidscontouren van de Beneluxbaan zijn een belangrijk aandachtspunt, aangezien deze al aan de bovengrens van de maximaal toelaatbare geluidsdruk zitten.

XV. OMBOUW AMSTELVEENLIJN: 4.1 VISUALIZE

XVI. OMBOUW AMSTELVEENLIJN: 4.3 DRAW

XVII. DATABASE BIM USES PER LEVEL PER PROJECT

	1.1 Capture	2.1 Prescribe	3.1 Coordinate	4.1 Visualize	5.1 Fabricate
BIM level 1 (41)	12%	24%	24%	20%	0%
BIM level 2 (10)	20%	50%	70%	90%	10%
Difference	8%	26%	46%	70%	10%
	1.2 Quantify	2.2 Arrange	3.2 Forecast	4.2 Transform	5.2 Assemble
BIM level 1 (41)	10%	22%	0%	7%	0%
BIM level 2 (10)	40%	70%	20%	30%	20%
Difference	30%	48%	20%	23%	20%
	1.3 Monitor	2.3 Size	3.3 Validate	4.3 Draw	5.4 Regulate
BIM level 1 (41)	5%	83%	20%	83%	0%
BIM level 2 (10)	0%	90%	20%	80%	10%
Difference	-5%	7%	0%	-3%	10%
				4.4 Document	
BIM level 1 (41)				17%	
BIM level 2 (10)				20%	
Difference				3%	

Project	**BIM Level**	**BIM Field**
Amstel Kwartier	BIM Level 2	2. Generate
	BIM Level 2	2.2 Arrange
	BIM Level 2	2.3 Size
	BIM Level 2	3.1 Coordinate
	BIM Level 2	4.1 Visualize
	BIM Level 2	4.3 Draw
Amsterdam CS	BIM Level 1	1.1 Capture
	BIM Level 1	2.2 Arrange
	BIM Level 1	2.3 Size
	BIM Level 1	3.1 Coordinate
	BIM Level 1	4.1 Visualize
	BIM Level 1	4.3 Draw
Amsterdam Oost Tunnel	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4.3 Draw
Amsterdam Zuid Station	BIM Level 1	2. Generate
	BIM Level 1	2.1 Prescribe
	BIM Level 1	2.3 Size
	BIM Level 1	4.1 Visualize
	BIM Level 1	4.3 Draw
ASML	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4. Communicate
	BIM Level 1	4.3 Draw

	BIM Level 1	4.4 Document
BBV RN 2015 Oostelijk Eiland	BIM Level 0	3.3 Validate
Bocholt School	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4.3 Draw
Cister detailengineering en realisatie	BIM Level 1	1.3 Monitor
	BIM Level 1	2.1 Prescribe
	BIM Level 1	2.2 Arrange
	BIM Level 1	2.3 Size
	BIM Level 1	3.1 Coordinate
	BIM Level 1	3.3 Validate
	BIM Level 1	4.2 Transform
	BIM Level 1	4.3 Draw
	BIM Level 1	4.4 Document
Cremerplein	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4.3 Draw
Dienstgebouwen Coen Tunnel	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4.3 Draw
DOSS Nijmegen-Den Bosch	BIM Level 1	1.2 Quantify
	BIM Level 1	2.1 Prescribe
	BIM Level 1	2.2 Arrange
	BIM Level 1	3.1 Coordinate
	BIM Level 1	3.3 Validate
	BIM Level 1	4.3 Draw
	BIM Level 1	4.4 Document
Driebergen Zeist	BIM Level 1	2. Generate
	BIM Level 1	2.1 Prescribe
	BIM Level 1	2.3 Size
	BIM Level 1	4.1 Visualize
	BIM Level 1	4.3 Draw
DriebergenZeist	BIM Level 1	1.1 Capture
	BIM Level 1	1.2 Quantify
	BIM Level 1	2.2 Arrange
	BIM Level 1	2.3 Size
	BIM Level 1	3.1 Coordinate
	BIM Level 1	3.3 Validate
	BIM Level 1	4.2 Transform
	BIM Level 1	4.3 Draw
	BIM Level 1	4.4 Document
Eempolis	BIM Level 1	2. Generate
Elasstic	BIM Level 2	1. Gather
	BIM Level 2	2. Generate

	BIM Level 2	2.2 Arrange
	BIM Level 2	2.3 Size
	BIM Level 2	3. Analyse
	BIM Level 2	3.1 Coordinate
	BIM Level 2	3.2 Forecast
	BIM Level 2	4. Communicate
	BIM Level 2	4.1 Visualize
	BIM Level 2	4.2 Transform
	BIM Level 2	5.4 Regulate
Elektrificatie Zwolle-Kampen	BIM Level 1	1.1 Capture
	BIM Level 1	1.2 Quantify
	BIM Level 1	2.1 Prescribe
	BIM Level 1	2.2 Arrange
	BIM Level 1	2.3 Size
	BIM Level 1	3.1 Coordinate
	BIM Level 1	3.3 Validate
	BIM Level 1	4.1 Visualize
	BIM Level 1	4.3 Draw
	BIM Level 1	4.4 Document
EPO	BIM Level 1	2.1 Prescribe
	BIM Level 1	3. Analyse
	BIM Level 1	3.3 Validate
Fietsenstalilngen CS	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4.3 Draw
Frederik Kazerne	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4. Communicate
	BIM Level 1	4.3 Draw
Friesland Campina	BIM Level 1	1.1 Capture
	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4.3 Draw
	BIM Level 1	5. Realize
Frisia	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4.3 Draw
FWN Leiden	BIM Level 2	2.2 Arrange
	BIM Level 2	2.3 Size
	BIM Level 2	3.1 Coordinate
	BIM Level 2	4.1 Visualize
	BIM Level 2	4.3 Draw
Geluidswal Haarrijn	BIM Level 2	1.2 Quantify
	BIM Level 2	2. Generate

	BIM Level 2	2.3 Size
	BIM Level 2	3.2 Forecast
	BIM Level 2	3.3 Validate
	BIM Level 2	4. Communicate
	BIM Level 2	4.1 Visualize
	BIM Level 2	4.2 Transform
	BIM Level 2	5.2 Assemble
Grotiustoren	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4.3 Draw
Hogeschool Zuyd	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4.3 Draw
Houthavens	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4. Communicate
	BIM Level 1	4.3 Draw
Kavel 3 ODE	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4.3 Draw
Klimhal	BIM Level 2	2. Generate
	BIM Level 2	2.3 Size
	BIM Level 2	4.3 Draw
	BIM Level 2	5.1 Fabricate
	BIM Level 2	5.2 Assemble
Knooppunt Gouwe	BIM Level 1	2.1 Prescribe
Kringloopwinkel Houten	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4.3 Draw
Makado	BIM Level 1	1. Gather
	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4.3 Draw
Meteren-Boxtel	BIM Level 2	1.1 Capture
	BIM Level 2	1.2 Quantify
	BIM Level 2	2.1 Prescribe
	BIM Level 2	2.2 Arrange
	BIM Level 2	3.1 Coordinate
	BIM Level 2	4.1 Visualize
	BIM Level 2	4.2 Transform
	BIM Level 2	4.3 Draw
	BIM Level 2	4.4 Document
NVLU	BIM Level 2	1.2 Quantify
	BIM Level 2	2. Generate

	BIM Level 2	2.1 Prescribe
	BIM Level 2	2.2 Arrange
	BIM Level 2	2.3 Size
	BIM Level 2	3.1 Coordinate
	BIM Level 2	4.1 Visualize
	BIM Level 2	4.3 Draw
Parnassusweg Tijdelijke Parkeergarage	BIM Level 1	2.1 Prescribe
Provinciehuis Dreef Haarlem	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4.3 Draw
Prysmian Delft	BIM Level 1	1. Gather
	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4. Communicate
	BIM Level 1	4.3 Draw
Rechtbank Zwolle	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4.3 Draw
Royal Cosun/Hurks	BIM Level 1	3.3 Validate
RUG (RijksUniversiteit Groningen)	BIM Level 2	1. Gather
	BIM Level 2	2. Generate
	BIM Level 2	2.1 Prescribe
	BIM Level 2	2.2 Arrange
	BIM Level 2	2.3 Size
	BIM Level 2	3.1 Coordinate
	BIM Level 2	4.1 Visualize
	BIM Level 2	4.3 Draw
Serdijn	BIM Level 1	2. Generate
	BIM Level 1	2.2 Arrange
	BIM Level 1	2.3 Size
	BIM Level 1	4.1 Visualize
	BIM Level 1	4.3 Draw
Shell	BIM Level 1	2. Generate
	BIM Level 1	2.2 Arrange
	BIM Level 1	2.3 Size
	BIM Level 1	3. Analyse
	BIM Level 1	3.1 Coordinate
	BIM Level 1	4.3 Draw
Station Eindhoven	BIM Level 1	2. Generate
	BIM Level 1	2.2 Arrange
	BIM Level 1	2.3 Size
	BIM Level 1	3.1 Coordinate
	BIM Level 1	4.1 Visualize

	BIM Level 1	4.3 Draw
Stationsoverkapping Noorderpark Amsterdam	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4.3 Draw
Theater Maaspoort Venlo	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4.3 Draw
Uitvoeringsbegeleiding RRN perceel 1	BIM Level 0	3.3 Validate
UMC Radboud	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4.3 Draw
Valkenburg	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	3.1 Coordinate
	BIM Level 1	4. Communicate
	BIM Level 1	4.1 Visualize
	BIM Level 1	4.3 Draw
	BIM Level 1	5. Realize
Valleilijn - engineering Robuustheid	BIM Level 1	1.1 Capture
	BIM Level 1	1.2 Quantify
	BIM Level 1	2.1 Prescribe
	BIM Level 1	2.3 Size
	BIM Level 1	3.1 Coordinate
	BIM Level 1	3.3 Validate
	BIM Level 1	4.4 Document
Van Gogh museum	BIM Level 1	2. Generate
	BIM Level 1	2.3 Size
	BIM Level 1	4.3 Draw
Verizon	BIM Level 1	4.1 Visualize
Vervangen TPRB door PRL - Achterhoek	BIM Level 1	1.3 Monitor
	BIM Level 1	2.1 Prescribe
	BIM Level 1	2.2 Arrange
	BIM Level 1	2.3 Size
	BIM Level 1	3.1 Coordinate
	BIM Level 1	3.3 Validate
	BIM Level 1	4.2 Transform
	BIM Level 1	4.3 Draw
	BIM Level 1	4.4 Document
Vervoersknoop BleiZo	BIM Level 2	1.1 Capture
	BIM Level 2	1.2 Quantify
	BIM Level 2	2.1 Prescribe
	BIM Level 2	2.2 Arrange
	BIM Level 2	2.3 Size

	BIM Level 2	3.1 Coordinate
	BIM Level 2	3.3 Validate
	BIM Level 2	4.1 Visualize
	BIM Level 2	4.3 Draw
	BIM Level 2	4.4 Document
Vonk & vlam	BIM Level 2	2. Generate
	BIM Level 2	2.1 Prescribe
	BIM Level 2	2.3 Size
	BIM Level 2	3. Analyse
	BIM Level 2	4. Communicate
	BIM Level 2	4.1 Visualize
	BIM Level 2	4.3 Draw

XVIII. BIM SAVINGS AND RETURN ON INVESTMENT

Stage	Statistic	Mid-Point Savings	Source	Reference Project	Reliability (1-5)	Reliability comment
A. Design	Up to 10% savings of contract value from clash detections	10%	Building Information Modelling (BIM): Leading BIM development in Hong Kong - EC Harris, Foreign Commonwealth Office, Ryder, Arup & Laing O' Rourke (2015) (Bim & Kong, 2015)	Case study: A study of 32 major projects, Stanford University Centre for Integrated Facilities Engineering	4	14 out of 32 projects used 3D/4D models for design checking, i.e. clash detection (= 43%)
A. Design	Project cost savings of 15 - 20%	17,5%	BIM Building Information Modelling - EC Harris Centre of Excellence (ASIA). From National Construction Law and Contracts Survey Report (NBS) (2012) ("BIM Introduction - Nov 2014," n.d.)	Survey findings: in the UK construction industry	3	More than 20 industry bodies More than 1000 clients
A. Design	The data sample available shows reductions of 8 - 18% on design fees in the three main disciplines	13%	How can Building Information Modelling (BIM) support the new rules of measurement (NRM1) - (Wu, Ginige, Wood, & Jong, 2014)	Case study: Measured benefits	5	Measured benefits 6 Case studies
A. Design	The project has demonstrated cost savings of between 4 and 11% are achievable	7,5%	Building Information Modelling: BIM Trial - Recommendations - (Conradie, 2009)	BIM trial project	2	Comparison with a previous tendered project
A. Design	The project achieved savings of 18% in cost drawing production (independently audited by the client' s project quantity surveyor)	18%	Investing in BIM competence: BuildingSMART: a guide to collaborative working for project owners and building professionals - (Dinesen & Thompson, 2010)	Case study: Endeavour House, Stansted	3	Achieved savings of a single project

A. Design	During design, improvements in the range of 8 - 18% were realised on the design fee, with significant contributions made by improved understanding and spatial coordination, clash detection and construction planning	13%	Investing in BIM competence: BuildingSMART: a guide to collaborative working for project owners and building professionals - (Dinesen & Thompson, 2010)	Survey findings: Mix of people in different firms in the industry who have experience of BIM	2	Nine respondents took part in the survey
A. Design	10 - 15% savings in the first costs	12,5%	Framework & Case Studies Comparing Implementations & Impacts of 3D/4D Modeling Across Projects - (Gao & Fisher, 2008)	Case Study: Helsinki University of Technology Auditorium-600, Helsinki	3	Achieved savings of a single project
					22	
B. Design and Construction	It was also estimated that BIM resulted in savings from 3 - 7.5% associated with improved coordination and fewer conflicts	5,3%	Return on investment analysis of building information modeling in construction - (Giel, Issa, & Olbina, 2010)From Holness, P.E. (2008)	Estimation By the Construction Industry Institute	1	Estimation by the Construction Industry Institute
B. Design and Construction	The sample is consistent and shows figures of 8 - 10% of construction cost	9%	How can Building Information Modelling (BIM) support the new rules of measurement (NRM1) - (Wu et al., 2014)	Case study: Measured benefits	5	Measured benefits 6 Case studies

B. Design and Construction	When totaled in dollar value and percentages computed investments in both design and construction resulted in a savings of 2%	2%	How to measure the benefits of BIM - a case study approach - (Barlish & Sullivan, 2012)	Case study: Testing metrics against case studies. Non-BIM versus BIM projects	3	Three BIM case studies at the same company
B. Design and Construction	The marketing benefits of the model, which allowed virtual walkthroughs, complemented savings around 9% which could be realised in the construction phase	9%	Investing in BIM competence: BuildingSMART: a guide to collaborative working for project owners and building professionals - (Dinesen & Thompson, 2010)	Case Study: Festival Place, Basingstoke Benefits of modelling for complex retail project	3	Achieved savings of a single project

B. Design and Construction	The evidence in favour of BIM is stacking up. Six short case studies where BIM or a common data environment was used are presented: an office building at Stansted, for example, made a saving of over 9% of project costs through data sharing and collaborative working. The interviews bear this out: measured savings in the range of 10–15% were achieved in projects monitored by one respondent. The savings achieved through the use of a single model environment on Heathrow's Terminal 5 were massive, although the figures have not been formally disclosed.	9%	Investing in BIM competence: BuildingSMART: a guide to collaborative working for project owners and building professionals - (Dinesen & Thompson, 2010)	Case study: Endeavour House, Stansted Repeat project offers opportunity for improvement	3	Achieved savings of a single project

B. Design and Construction	On the hard benefits of BIM, we believe that the potential savings across a project may be as much as 20 - 30%	25%	Investing in BIM competence: BuildingSMART: a guide to collaborative working for project owners and building professionals - (Dinesen & Thompson, 2010)	Focus interviews	2	Nine respondents took part in the survey
B. Design and Construction	The benefits of BIM could lead to savings of 10 to 20 % in CAPEX (Capital Expenditure)	15%	University of Ulster - Introduction to BIM - Dec 2012	Estimation	1	
B. Design and Construction	The delivery of the Level 2 BIM programme has enabled us to help secure 20% savings on CAPEX as recorded by Cabinet Office case studies against the 09/10 benchmarks9, during a period of focused and sustained departmental savings and create widespread awareness of the need and techniques required to deliver a digital construction economy.	20%	Digital Built Britain: Level 3 Building Information Modelling - Strategic Plan - (HM Government, 2015)	Various sources	2	Cabinet Office case studies

					20	
C. Construction	In 2006, it was estimated that BIM resulted in the potential savings in construction costs ranging from 15 - 40%	27,5%	Return on investment analysis of building information modeling in construction - (Giel et al., 2010) From Holness, P.E. (2006)	Estimation By the Construction Industry Institute	1	Estimated by the Construction Industry Institute
C. Construction	The sample is consistent and shows figures of 8 - 10% of construction cost	9%	How can Building Information Modelling (BIM) support the new rules of measurement (NRM1) - (Wu et al., 2014)	Case study: Measured benefits	5	Measured benefits 6 Case studies
C. Construction	Case 2 shows 5% savings of contractor costs	5%	How to measure the benefits of BIM - a case study approach - (Barlish & Sullivan, 2012)	Case study: Testing metrics against case studies. Non-BIM versus BIM projects	3	Three BIM case studies at the same company
C. Construction	Savings of 8 - 10% of the overall construction cost were achieved at pre-construction and construction	9%	Investing in BIM competence: BuildingSMART: a guide to collaborative working for project owners and building professionals - (Dinesen & Thompson, 2010)	Survey findings: Mix of people in different firms in the industry who have experience of BIM	2	Nine respondents took part in the survey
C. Construction	The project achieved cost savings of 9.8% of project cost (independently audited by the client's project quantity surveyor)	9,8%	Investing in BIM competence: BuildingSMART: a guide to collaborative working for project owners and building professionals - (Dinesen & Thompson, 2010)	Case study: Endeavour House, Stansted Repeat project offers opportunity for improvement	3	Achieved savings of a single project
C. Construction	Enthusiasts suggest that the adoption of IPD can cut construction costst by 20 -	25%	Building Information Modelling for commercial office buildings - (British Council for Offices, 2013)	Estimation	1	Estimation

	30%					
C. Construction	Estimated 9% savings in CAPEX construction cost	9%	Investing in BIM competence: BuildingSMART: a guide to collaborative working for project owners and building professionals - (Dinesen & Thompson, 2010)	Case Study: Festival Place, Basingstoke Benefits of modelling for complex retail project	3	Achieved savings of a single project
C. Construction	Measured savings of 10 – 15%	12,5%	Investing in BIM competence BuildingSMART: a guide to collaborative working for project owners and building professionals (Dinesen & Thompson, 2010)	Summary findings	2	Nine respondents took part in the survey
					20	
D. Operation	You could get your project delivered 18% cheaper across the 15 year life span	18%	Building Information Modelling (BIM): Leading BIM development in Hong Kong - EC Harris, Foreign Commonwealth Office, Ryder, Arup & Laing O' Rourke (2015) (Bim & Kong, 2015)	Case study: A study of 32 major projects, Stanford University Centre for Integrated Facilities Engineering	1	Estimated cost impact based upon various project experience
D. Operation	Our migration to Digital Built Britain must answer these questions, but also help the industry to maintain the significant productivity improvements - including more savings of up to 33% of whole life costs starting with the circa 20% reduction in capital costs that	13%	Digital Built Britain: Level 3 Building Information Modelling - Strategic Plan - (HM Government, 2015)	Measurement benefits: Projects registred during 2011-2012	-	-

	have been achieved using BIM at Level 225. (Assume 13% target is attributed to operation with 20% being CAPEX)					
D. Operation	At company 1, calculated returns were: change orders saw a savings of 42% of standard costs	42%	How to measure the benefits of BIM - a case study approach - (Barlish & Sullivan, 2012)	Case study: Testing metrics against case studies. Non-BIM versus BIM projects	3	Three BIM case studies at the same company
D. Operation	A responde nt said that savings in the range of 10 - 15% had been anticipate d and in fact achievabl e	12,5%	Investing in BIM competence: BuildingSMART: a guide to collaborative working for project owners and building professionals - (Dinesen & Thompson, 2010)	Survey findings: Mix of people in different firms in the industry who have experience of BIM	2	Nine respondents took part in the survey
D. Operation	The value of the COBie approach had been estimated at between 0.5% and 0.25% of total project cost, with ongoing savings during FM, as the	0,4%	Investing in BIM competence: BuildingSMART: a guide to collaborative working for project owners and building professionals - (Dinesen & Thompson, 2010)	Focus interviews	2	Nine respondents took part in the survey

	costs of accessing and altering O&M information drop sharply with COBie					
D. Operation	This effort is reported to have reduced the cost of commisioning and handover by 25 - 30%	27,5%	Building Information Modelling for commercial office buildings - (British Council for Offices, 2013)	Case study: The Place at London Bridge Quarter	3	Achieved savings of a single project
D. Operation	And a 5 - 25% potential savings in the life-cycle cost	15%	Framework & Case Studies Comparing Implementations & Impacts of 3D/4D Modeling Across Projects - (Gao & Fisher, 2008)	Case Study: Helsinki University of Technology Auditorium-600, Helsinki	3	Achieved savings of a single project
D. Operation	10% estimated cost savings via BIM	10%	CEDR S3 Inventory: Draft results, 14 Octobre 2014 Helsinki meeting - CEDR (2014). From DTU Byg Rapport SR (2009)	Estimation	1	Estimation
D. Operation	Reduction of cost of FM/ Operation by 20%	20%	CEDR S3 Inventory: Draft results, 14 Octobre 2014 Helsinki meeting - CEDR (2014). From DTU Byg Rapport SR (2009)	-	-	-
D. Operation	45% saving in drafting hours during FM - CAD versus BIM (assume labour component makes up 10% of OPEX Costs)	4,5%	Building Operating Management's National Facilities Management & Technology March 2013 - Lifecycle BIM at FAA: Case Study	Proof of concept project - existing tower building in USA	-	-

D. Operation	60% saving in service hours for operation and maintenance - remotely diagnosable issues and on-site service (assume labour component makes up 10% of OPEX Costs)	6%	Building Operating Management's National Facilities Management & Technology March 2013 - Lifecycle BIM at FAA: Case Study	Proof of concept project - existing tower building in USA	-	-
D. Operation	The benefits of BIM could lead to savings 15 to 30% in OPEX (Operating Expenditure)	22,5%	University of Ulster - Introduction to BIM - Dec 2012	Estimation	1	Estimation
D. Operation	Reduced energy use through better equipment use	3%	BIM for Facility Managers Michael Schley, IFMA Fellow CEO and Founder, FM:Systems Paul Teicholz, Ph.D. Founder and former Director, Center for Integrated Facility Engineering at Stanford University Angela Lewis, Ph.D. P.E., LEED AP Project Manager, Facility Engineering Associates	Based on 2009 IFMA Maintenance cost survey data: 400,000 GSF office HQ with useful life of 25 years	3	Approximately 1445 surveys were returned during a six-month time period

D. Operation	Total FM savings of US$0.17/ GSF/yr Translating this to a recent EC Harris whole life cost study, the life cycle cost saving could be in the range of 20 to 30%	25%	BIM for Facility Managers Michael Schley, IFMA Fellow CEO and Founder, FM:Systems Paul Teicholz, Ph.D. Founder and former Director, Center for Integrated Facility Engineering at Stanford University Angela Lewis, Ph.D. P.E., LEED AP Project Manager, Facility Engineering Associates	Based on 2009 IFMA Maintenance cost survey data: 400,000 GSF office HQ with useful life of 25 years	3	Approximately 1445 surveys were returned during a six-month time period
D. Operation	According to the AMCA, the vast majority of Australia's major contractors, subcontractors and suppliers embrace BIM, which it says has the capacity to cut facilities management costs by 30 percent	30%	Facilities Management Magazine - Australia http://www.fmmagazine.com.au/news/bim-can-cut-fm-costs-by-30-percent/	Speaking at the BIM-MEPAUS Construction Innovation 2013 Forum, Sumit Oberoi, executive director of the Air Conditioning and Mechanical Contractors' Association (AMCA)	1	Estimation by AMCA
					23	
E. Return on Investment	15% of BIM users report an ROI of 50% or more	>50%	The business value of BIM: Getting Building Information Modeling to the Bottom Line (Young Jr. et al., 2009)	Survey findings: Surveying thousands of AEC participants in North America from the full spectrum of roles and disciplines	2	Supported by a small share of respondents (15%)

E. Return on Investment	9% of users, who formally measure ROI, see returns above 100%	>100%	The business value of BIM: Getting Building Information Modeling to the Bottom Line (Young Jr. et al., 2009)	Survey findings: Surveying thousands of AEC participants in North America from the full spectrum of roles and disciplines	2	Supported by a small share of respondents (9%)
E. Return on Investment	Most constructi on managers , who do experienc e positive ROI, see returns below 10%	<10%	The business value of BIM: Getting Building Information Modeling to the Bottom Line (Young Jr. et al., 2009)	Survey findings: Surveying thousands of AEC participants in North America from the full spectrum of roles and disciplines	2	Surveying thousands of AEC participants in North America from the full spectrum of roles and disciplines
E. Return on Investment	Annual ROI = 4.14%	4,14%	Building Information Modeling & Facilities Management - (Feeney, n.d.)	Based on assumed projections for a national and internationall y trading company	1	Based on assumptions
E. Return on Investment	In the two case studies presented , the ROI of BIM varies from 16 - 1654% (16.2, 36.7, 1653.9, 299.9)	835,1%	Return on investment analysis of building information modeling in construction - (Giel et al., 2010)	Two case studies: on two similar projects. One BIM-assisted and the other without BIM	0	Incomparable case studies ROI depends strongly on the scale and complexity of a project
E. Return on Investment	The ROI values for several projects Holder has undertake n in BIM range anywhere from 140 - 39900%	20020%	Return on investment analysis of building information modeling in construction - (Giel et al., 2010)	Measuremen t ROI: Since 2006, the company has measured over 30 BIM-assisted projects	0	Unreliable tracking of construction clashes in NavisWorks in uncomparble projects

E. Return on Investment	The largest percentage of firms estimate the ROI on their BIM investments to be between 10 - 25%	17,5%	The Business Value of BIM for Construction in Major Global Markets: How contractors around the world are driving innovation with Building Information Modeling - (McGraw Hill, 2014)	Survey findings: Data collected exclusively from construction companies that use BIM	3	Contractors in nine of the world's top construction markets using BIM
E. Return on Investment	According the PENG model; case studies, meetings, interviews and previous studies showed the use of BIM on ROI is 735%	735%	The Impact of BIM/VDC on ROI: Developing a Financial Model for Savings and ROI Calculation of Construction Projects (Salih, 2012)	Case study: ALFA project	0	Assumptions are made over calculations in the PENG model
E. Return on Investment	The overall ROI was 335% based on the assumption that none of the design errors would be found in the traditional process.	335%	D3 City project- Economic impact of BIM-assisted design validation - (Lee, Park, & Won, 2012)	Case study: 709 individual design errors found during the BIM validation in the D3 city project in Seoul	0	Unrealistic assumption that none of the design errors would be found in the traditional process
E. Return on Investment	However, since this assumption is unrealistic, the overall ROI was 64%	64%	D3 City project- Economic impact of BIM-assisted design validation - (Lee et al., 2012)	Case study: 709 individual design errors found during the BIM validation in the D3 city project in Seoul	1	Single case based on the avoidance costs of rework due to design errors
E. Return on Investment	The Monte Carlo method was used to calculate the ROI. This value is similar to that from the second static	63%	D3 City project- Economic impact of BIM-assisted design validation - (Lee et al., 2012)	Monte Carlo simulation	1	Single case based on the avoidance costs of rework due to design errors

	value approach, 63%					
E. Return on Investment	When all these approaches were considered the BIM ROI was expected to be 22 - 335%	178,5%	D3 City project- Economic impact of BIM-assisted design validation - (Lee et al., 2012)	Case study: 709 individual design errors found during the BIM validation in the D3 city project in Seoul Monte Carlo simulation	0	Unrealistic assumption that none of the design errors would be found in the traditional process
E. Return on Investment	When such extreme cases are excluded, the ROI is expected to be between 22 and 97%	59,5%	D3 City project- Economic impact of BIM-assisted design validation - (Lee et al., 2012)	Case study: 709 individual design errors found during the BIM validation in the D3 city project in Seoul Monte Carlo simulation	1	Single case based on the avoidance costs of rework due to design errors
E. Return on Investment	Skanska are starting to quantify savings and saying (as at 2010) that their return on investment in BIM is in excess of 2:1 (50%)	50%	Investing in BIM competence: BuildingSMART: a guide to collaborative working for project owners and building professionals - (Dinesen & Thompson, 2010)	Interview feedback from Contractor	2	Achieved savings of a single project by a single contractor
E. Return on Investment	ROI circa 40% and payback within 2 years	40%	Focus interviews	Focus interviews: Designers in Hong Kong	-	-

E. Return on Investment	ROI Analysis of BIM FM Integration - 64% (payback period 1.57years)	64%	BIM for Facility Managers Michael Schley, IFMA Fellow CEO and Founder, FM:Systems Paul Teicholz, Ph.D. Founder and former Director, Center for Integrated Facility Engineering at Stanford University Angela Lewis, Ph.D. P.E., LEED AP Project Manager, Facility Engineering Associates	Based on 2009 IFMA Maintenance cost survey data: 400,000 GSF office HQ with useful life of 25 years	3	Approximately 1445 surveys were returned during a six-month time period
					18	

XIX. RELIABILITY RULES

Reliability Rules	
Based on	**Score**
Assumptions	0
Estimations	1
Surveys	2
>1000 respondents	*3*
Case studies	3
>10 cases	*4*
all cases	5

XX. CONTRIBUTION OF BIM USES TO SAVINGS

	BIM uses						
	1.1 Capture	3.1 Coordinate	3.2 Forecast	4.1 Visualize	4.3 Draw	4.4 Document	5.2 Assemble
Design	0,0%	5,1%	2,8%	0,3%	3,3%	1,1%	0,0%
Design and Construction	0,1%	1,8%	1,4%	3,6%	0,8%	0,8%	0,1%
Construction	0,3%	2,4%	1,0%	0,3%	2,4%	1,4%	0,3%
Operation	5,3%	0,0%	3,8%	5,3%	3,8%	5,3%	5,3%
Total contribution	4,3%	0,5%	3,3%	4,6%	3,4%	4,5%	4,3%