UNLEASHING THE POTENTIAL OF BIM

Analysis of interventions to overcome the barriers hindering the implementation of BIM within large

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Unleashing the potential of BIM

Analysis of interventions to overcome the barriers hindering the implementation of BIM within large engineering firms using game theory.

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Preface

This master thesis is written as final component of the master programme Construction Management and Engineering at the Eindhoven University of Technology.

In the last months I was allowed to work on my thesis at the department of 'Integraal Ontwerpen' at Movares on an interesting and relevant topic. The effectiveness of interventions to overcome barriers to the use of BIM within engineering firms. I was inspired to work on a project including both topics from the bachelor Psychology & Technology and the master Construction Management & Engineering. During my bachelor I mainly focused on the experience of the urban environment. In the master I became interested in how tools such as BIM are experienced by the user and whether they are actually used as is intended. The topic of this thesis is based on the latter and combines game theory and Building Information Modelling. Game theory can be used to analyse decision making in strategic situations between different parties. The topic has been discussed in both the bachelor and master. BIM was introduced during the master. Since BIM is usually used in collaboration among multiple stakeholders, game theory provided an interesting possibility to analyse the use of BIM.

Several challenges were faced during the composition of this thesis. From finding a suitable topic to understanding the details of game theory. This thesis would not have been possible without the help of many people. Firstly, I would like to thank my supervisors from the Eindhoven University of Technology. I am grateful for the help I received from Qi Han, to whom I could always reach out for questions and who provided me with valuable feedback. You have allowed me to find my own approach, challenged me and offered me useful feedback. Regarding the search for a suitable topic, I want to thank Bauke de Vries for helping me to find the right direction.

Secondly, in the time that I have been working on my thesis at Movares, I have met a lot of helpful and inspiring colleagues. They gave me the opportunity to do my research and helped me by providing their knowledge, expertise and time. Specifically, for the supervision from Movares, I want to address my thanks to Jan van Wolfswinkel. You have allowed me to get to know the company and helped me whenever necessary. I have been very happy to carry my thesis out at this company.

I am very grateful that, although Corona changed daily life in many ways, both Movares and the Eindhoven University of Technology made it possible to continue with my thesis in the same pace.

Finally, I want to thank my family and friends for their help and support.

Enjoy reading,

Merel Backx
Eindhoven, July 2020

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Summary

Building Information Modelling (BIM) has many advantages in collaboration, such as higher efficiency, reduction of costs and reduction of lead time (Siebelink, Adriaanse, & Voordijk, 2015). Moreover, provided that BIM is properly implemented on organizational level, it can contribute to more effective and efficient collaboration between organisations. This can bring such an advantage to the architecture, engineering, construction and operation (AECO) industry that it will result in a paradigm shift (Zheng, Lu, Chen, Chau, & Niu, 2017). However, several barriers are experienced in the implementation of BIM, such as inadequate knowledge and experience, new workflows and standards, and a shift in mindset (Kaner, Sacks, Kassian, & Quitt, 2008; Ku & Taiebat, 2011; Sebastian, 2011; Siebelink et al., 2015). Little studies have focussed on how these barriers differ per actor. The same holds for guidelines which can stimulate BIM implementation on the intra-firm level. Although, intra-firm BIM is a requirement for inter-firm BIM use, significantly more studies have focused on inter-firm BIM implementation.

The aim of this study is two folded. First, it aims to find interventions that can help to overcome the barriers experienced in intra-organizational BIM implementation. A second aim of this study is to analyse the effectiveness of these interventions by using game theory. To achieve these aims the following research question was used: *Which interventions are most effective in overcoming the barriers to the use of BIM experienced by actors significant in the BIM implementation process within large engineering firms?*

BIM is defined in this thesis as *(the creation of) a 3D model, where digital information is added to the model for collaboration throughout multiple stages of the building lifecycle* ("BIR Kenniskaart nr. 0 Wat is BIM?," 2015). The average level of BIM implementation in the Netherlands is fairly high and engineering firms are ahead of other sectors in the Dutch AECO industry. Therefore, it is not possible for engineering firms to learn from good practices from other sectors involved in BIM, such as contractors (Berlo, Dijkmans, Hendriks, Spekkink, & Pel, 2012; Kassem & Succar, 2017; Siebelink, 2017).

In order to understand which interventions are useful to stimulate the implementation of BIM within engineering firms, this study includes several methods. The results are based on data that is collected at a large engineering firm in the Netherlands (Movares). Figure 1 gives an overview of the different methods used and their order.

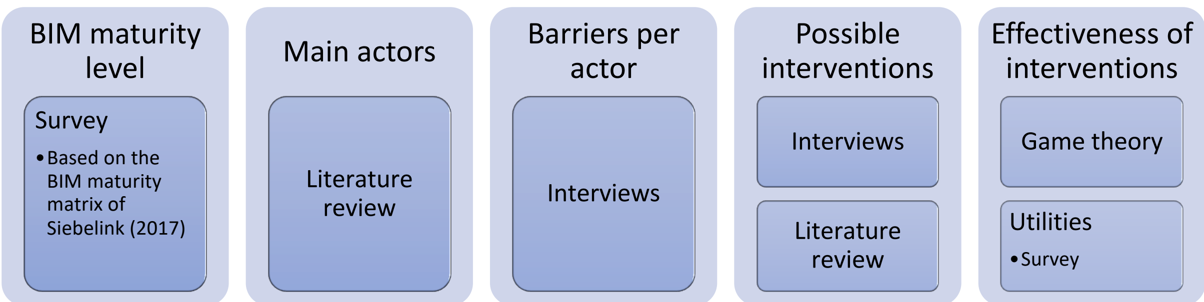


Figure 1. Overview of research methods.

First of all, the BIM maturity level was determined based on six categories: strategy, organizational structure, people and culture, BIM processes, ICT and data. An average score of 2.2 was found on a scale from zero to 5. This means that BIM is managed, BIM goals and

strategies are defined on project bases and the organizational structure is insufficiently aligned with BIM goals. Moreover, BIM processes are limitedly followed, adjusted and evaluated. It was also found that there are no significant differences between the categories or between the different disciplines that were taken into account. Therefore, all disciplines and categories were considered for the remainder of the study.

The most important actors were defined by a literature review. Three groups were found to be important for the implementation of BIM within organizations: BIM specific roles, non-technical users and technical users. These roles were narrowed down to fit the roles present at Movares. This resulted in three actors: BIM coordinators, project leaders and the disciplines: architecture, building, structural and MEP engineering. Ten semi-structured interviews were conducted with people in these roles to find the barriers per actor. The results are shown in Table 1.

Table 1

Overview of barriers.

Project leaders	**BIM coordinators**	**Disciplines**
Inefficiency of BIM Lack of BIM skills Lack of facilities	False BIM expectations Increased dependence on integrated cooperation Lack of BIM skills Lack of facilities Mindset not in favour of BIM	Lack of BIM skills Shortage of time Uneven distribution of work

Based on these barriers, four interventions were proposed: a *BIM feedback system*, aimed at overcoming the barrier lack of BIM skills, *creating a change in mindset in favour of BIM*, aimed at overcoming the mindset barrier, *linking wishes for BIM facilities with possibilities*, to overcome the barrier lack of facilities, and *BIM practice time*, to overcome the interlinked barriers lack of BIM skills and shortage of time. These were tested using an experimental game theory approach and a non-cooperative model. Game theory originates from mathematical sciences and can be described as a method to analyse the interaction between two or more people who try to maximize their own benefit on the principal of rationality. A game tree was used to represent the different scenarios with regard to the BIM process. The input for the extensive form model was obtained by a survey to find the utility for each game outcome for the four different interventions.

It was found that the interventions *BIM feedback system* and *BIM practice time* led to the highest average increase in utility. For the interventions *BIM feedback system*, *change in mindset in favour of BIM* and *BIM practice time*, the SPNE, a formal rule for predicting how a game will be played, was found for the outcome where all parties work according to BIM principles and standards. Finally, the outcome probabilities indicated that the intervention *BIM feedback system* is most likely to result in the scenario where every actor works according to BIM standards and principles. Hence, the intervention *BIM feedback system* was found to be most effective to overcome barriers experienced by significant actors in the BIM implementation process within large engineering firms.

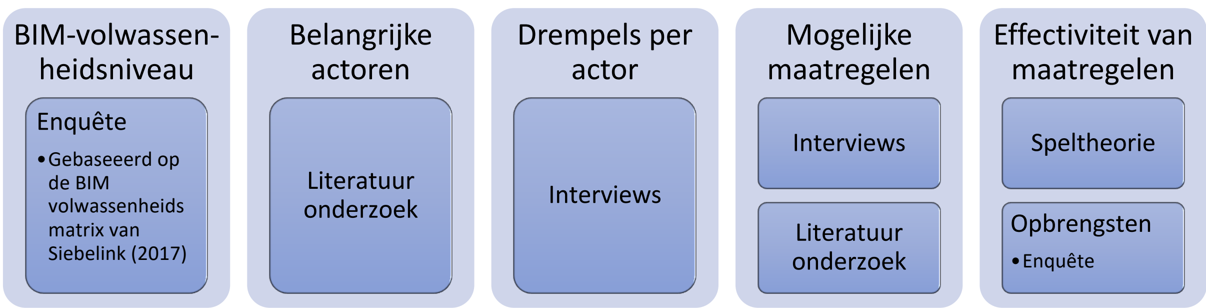
Samenvatting

Bouw Informatie Modellering (BIM) levert veel voordelen op voor samenwerking, zoals efficiëntie, verlaging van de kosten en verkorting van de doorlooptijd (Siebelink et al., 2015). Daarbij kan BIM, mits het voldoende geïmplementeerd is op organisatieniveau, bijdragen aan een meer efficiënte en effectieve samenwerking tussen organisaties. Dit kan een groot voordeel opleveren voor de bouwindustrie en uiteindelijk leiden tot een paradigma verschuiving (Zheng et al., 2017). Er zijn echter verschillende drempels die de implementatie van BIM hinderen, waaronder onvoldoende kennis en ervaring, nieuwe werkmethodes en standaarden, en een verschuiving in de manier van denken (Kaner et al., 2008; Ku & Taiebat, 2011; Sebastian, 2011; Siebelink et al., 2015). Weinig studies hebben beschreven hoe deze drempels verschillen tussen actoren. Hetzelfde geldt voor richtlijnen om BIM-gebruik te stimuleren binnen organisaties. Ondanks dat BIM-implementatie binnen een organisatie noodzakelijk is voor BIM-gebruik tussen bedrijven, zijn er aanzienlijk meer studies gedaan naar BIM-implementatie tussen bedrijven.

Dit onderzoek heeft twee doelen. Een eerste doel is het vinden van maatregelen die de drempels ervaren door verschillende actoren binnen een organisatie weg kunnen nemen. Een tweede doel is het analyseren van de effectiviteit van de maatregelen met behulp van speltheorie. Hierbij is de volgende onderzoeksvraag opgesteld: *Welke interventies kunnen het best worden toegepast om de drempels weg te nemen die ervaren worden door belangrijke actoren voor de implementatie van BIM binnen ingenieursbureaus?*

BIM wordt in deze thesis gedefinieerd als *(het opzetten van) een 3D model waar digitale informatie aan toegevoegd is, voor samenwerking gedurende meerdere fasen van de levenscyclus van het bouwwerk* ("BIR Kenniskaart nr. 0 Wat is BIM?," 2015). Het gemiddelde BIM-implementatie niveau in Nederland is hoog in vergelijking met andere landen. Daarbij zijn ingenieursbureaus in het algemeen verder met BIM dan met andere sectoren. Daarom zijn er voor ingenieursbureaus geen goede voorbeelden beschikbaar van hoe zij BIM-gebruik het beste kunnen stimuleren (Berlo et al., 2012; Kassem & Succar, 2017; Siebelink, 2017).

Om te begrijpen welke maatregelen de implementatie van BIM kunnen stimuleren binnen ingenieursbureaus zijn verschillende methoden gebruikt. De resultaten zijn verkregen op basis van data verzameld bij een groot ingenieurs- en adviesbureau in Nederland (Movares). Figuur 1 geeft een overzicht van de gebruikte onderzoeksmethoden en de volgorde.



Figuur 1. Overzicht van onderzoeksmethoden.

Als eerste is het BIM-volwassenheidsniveau bepaald op basis van zes categorieën: strategie, organisatiestructuur, mens en cultuur, BIM-processen, ICT en data. Op een schaal van nul tot vijf werd een gemiddelde score van 2,2 gevonden. Dit betekent dat BIM wordt gemanaged.

BIM-doelen en strategieën zijn gedefinieerd op projectbasis en de organisatiestructuur is nog niet voldoende afgestemd op BIM-doelen. Ook worden BIM-processen maar beperkt gevolgd, aangepast en geëvalueerd. De uitkomsten van de vragenlijst lieten ook zien dat de verschillen tussen de zes categorieën en de verschillende disciplines klein waren. Daarom zijn alle zes de categorieën en alle disciplines meegenomen in het vervolg van dit onderzoek.

Uit een literatuurstudie bleek dat er drie groepen actoren belangrijk zijn voor de BIM-implementatie op organisatieniveau: BIM specifieke actoren, niet-technische en technische gebruikers. Op basis van de rollen aanwezig binnen Movares zijn deze groepen gespecificeerd: BIM-coördinatoren, projectleiders en de disciplines: architectuur, bouwkunde, constructies en installaties. Met deze actoren zijn tien semigestructureerde interviews gehouden om de drempels per actor te vinden. De resultaten zijn weergeven in Tabel 1.

Tabel 1

Overzicht van de ervaren drempels.

Projectleiders	**BIM-coördinatoren**	**Disciplines**
Gebrek aan BIM-vaardigheden Gebrek aan faciliteiten Inefficiëntie van BIM	Gebrek aan BIM-vaardigheden Foutieve BIM-verwachtingen Gebrek aan faciliteiten Manier van denken niet ten gunste van BIM Toegenomen afhankelijkheid van integraal samenwerken	Gebrek aan BIM-vaardigheden Ongelijke werk verdeling Te weinig tijd

Op basis van deze drempels zijn vier maatregelen opgesteld: *BIM-feedback systeem*, gericht op het wegnemen van de drempel gebrek aan BIM-vaardigheden, *verandering van de manier van denken ten gunste van BIM*, om de gelijknamige drempel weg te nemen, *het linken van wensen voor BIM-faciliteiten aan mogelijkheden*, om de drempel gebrek aan faciliteiten weg te nemen, en *BIM-oefentijd*, om de samenhangende drempels gebrek aan BIM-vaardigheden en te weinig tijd weg te nemen. De effectiviteit van deze maatregelen is bepaald met behulp van een model op basis van niet-coöperatieve speltheorie. Speltheorie is afkomstig uit de wiskunde. Het is een methode die het mogelijk maakt om de interactie tussen twee of meer individuen te analyseren als wordt aangenomen dat zij hun eigen opbrengsten willen maximaliseren. Een spelboom is gebruikt om de verschillende situaties met betrekking tot het BIM-proces weer te geven. De input voor het model is verkregen met behulp van een vragenlijst om de opbrengsten voor de verschillende speluitkomsten in kaart te brengen voor de vier interventies.

Uit de uitkomsten kon worden opgemaakt dat de maatregelen *BIM-feedback systeem* en *BIM-oefentijd* tot de grootste gemiddelde stijging in opbrengsten leiden. De maatregelen *BIM-feedback systeem*, *verandering van de manier van denken ten gunste van BIM* en *BIM-oefentijd* werd het SPNE, een formele regel om te voorspellen hoe een spel gespeeld wordt, gevonden voor de uitkomst waarbij alle partijen volgens BIM-standaarden en protocollen werken. Op basis van de uitkomstkansen werd gevonden dat de kans dat alle partijen volgens BIM werken het grootst is bij de maatregel *BIM-feedback systeem.* Concluderend, is de maatregel BIM-feedback het meest effectief om de drempels te overwinnen die worden ervaren door belangrijke actoren gedurende het BIM-implementatieproces in grote ingenieursbureaus.

Abstract

BIM has many advantages in collaboration. However, several barriers are experienced in implementation. How these barriers differ per actor is a topic that has been little studied. The same holds for BIM implementation guidelines on the intra-firm level. Significantly more studies have focused on inter-firm BIM use, while intra-firm BIM implementation is a requirement for inter-firm BIM implementation. The aim of this study is two folded. First of all, it aims to find interventions that can help to overcome the barriers experienced in intra-organizational BIM implementation. A second aim of this study is to analyse the effectiveness of the interventions, in intra-organizational collaboration through BIM, using game theory. In order to find effective interventions, data was gathered in a large engineering firm. The study consists of five components. First of all, the BIM maturity level was determined based on the framework provided by (Siebelink, 2017). Thereafter, important actors were pinpointed for this subsector. Thirdly, barriers for each actor were clarified. These barriers were used to design interventions. Finally, these interventions were tested in a Game theoretic model. The results showed that BIM specific users, technical and non-technical users are all important for the BIM process within engineering companies. With a BIM maturity level of two, managed, as defined by Siebelink (2017), the lack of BIM skills was found as a barrier for all earlier defined actors. Besides the latter barrier, non-technical users also agreed on the barriers lack of facilities and inefficiency of BIM. BIM specific users agreed on the barriers false BIM expectations, lack of facilities, mindset not in favour of BIM and increased dependence on integrated cooperation. Finally, besides the barrier lack of BIM skills, the technical users agreed on the barriers uneven distribution of work and shortage of time. Four interventions were proposed, and all were found to be effective to stimulate BIM implementation. The intervention BIM feedback system was found to be most effective in overcoming barriers to BIM experienced by significant actors within large engineering companies.

Keywords: barriers, BIM, BIM maturity, interventions, intra-firm collaboration

List of Abbreviations

AECO	Architecture, Engineering, Construction and Operation
ASCE	American Society of Civil Engineering
BIM	Building Information Model, Building Information Modelling or Building Information Management
BDR	Bouw Digitaliserings Raad (Building Digitalization Council)
BIR	Bouw Informatie Raad (Building Information Council)
FIC	Facility Information Council
ID	Integrated Design
IDM	Information Delivery Manual
IPD	Integrated Project Delivery
LOD	Level of Detail
MEP	Mechanical, Electrical and Plumbing
NBIMS	National Building Information Modelling Standard
NBS	National Building Specification
NEVI	Nederlandse Vereniging voor Inkoopmanagement (Dutch Association for Purchase management)
NIBS	National Institute for Building Sciences
STB	Standaardtaakbeschrijving (Standard Task Description)

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1 Introduction

This chapter provides the problem definition in Section 1.1, the research question in Section 1.2 and the research approach in Section 1.3. Moreover, the motives for this thesis are described in Section 1.4. Finally, Section 1.5 presents a reading guide.

1.1 Problem definition

Although many information and communication technologies have been developed to deal with the increasing complexity of building projects, Building Information Modelling (BIM) is currently the most common one in the architecture, engineering, construction and operation (AECO) industry (Bryde, Broquetas, & Volm, 2013). One of the main advantages of BIM over other technologies is its ability to relate information between disciplines, stakeholders and project stages by providing one standard for information management. BIM also allows for a coherent, complete and true digital representation of a building (Grilo & Jardim-goncalves, 2010; Tarandi, 2015; Turk, 2016). Moreover, it has been shown that BIM is more effective than getting everyone to work on the same software platform and that BIM almost always results in a positive return on investment (Berlo & Krijnen, 2014; Neelamkavil & Ahamed, 2012).

Although BIM has many benefits for stakeholders and society, it is still in its infancy. This also holds for the Netherlands where BIM is used in almost sixty percent of building projects (Dekker, 2018; C. Sun, Jiang, Skibniewski, Man, & Shen, 2017). This is unfortunate since BIM encourages integration of stakeholders. Moreover, it contributes to an increased accuracy, productivity and quality and a decrease in project costs and project delivery time (Azhar, 2011; C. Sun et al., 2017). Besides these benefits BIM also supports collaboration. It helps the owner to understand the purpose of the project, it supports the projects' development, and it enables management during operation and deconstruction (Grilo & Jardim-goncalves, 2010).

BIM provides a collaboration platform for the stakeholders involved in the project lifecycle of a building. Many stakeholders are involved in this process including the client, project manager, architect, contractor, engineer, owner and designer (Ghaffarianhoseini et al., 2017; Linderoth, 2010; Travaglini, Radujkovic, & Mancini, 2014). BIM is both used within and between companies and mainly for inter-firm communication, intra-firm coordination and inter-firm coordination (Zheng et al., 2017). The perceived benefits of using BIM differ across stakeholders. This makes it difficult to understand what makes people want to work according to BIM standards. However, it is known that project success is highly dependent on stakeholders' satisfaction. Stakeholder management is therefore one of the most critical success factors in projects (Barlish & Sullivan, 2012; Travaglini et al., 2014).

In order to achieve the benefits of BIM, close collaboration between all stakeholders is necessary and this impacts their roles and responsibilities. Although a broad spectrum of stakeholders needs to be considered for successful implementation of BIM, it was chosen to only focus on intra-firm BIM implementation. Intra-firm BIM implementation is a requirement for inter-firm BIM implementation (Jernigan & Onuma, 2008). Moreover, most studies focus on BIM in an inter-firm context (e.g. Sun & Wang, 2015). It was chosen to focus on large engineering firms since these are, together with the client, most relevant for the intra-firm implementation of BIM (Fikkers, Nieuwenhuizen, Nijssen, & Schaap, 2012). Whereas the engineering firms are participating in many BIM related tasks, most benefits are present for the client (Zheng et al., 2017). Furthermore, engineering firms are ahead in the use of BIM compared to other sectors (Ghaffarianhoseini et al., 2017; Siebelink, 2017; Waterhouse, 2014). Hence, they cannot rely on proven practices from other sectors. It is thus interesting to understand how satisfaction within engineering companies can be increased.

To increase the satisfaction of actors within engineering firms, the difficulties regarding the implementation of BIM are of interest. These difficulties are described as barriers or burdens in scientific literature. This thesis refers to barriers. Barriers are defined as something that is blocking someone from doing something ("Cambridge University Press," 2019). These barriers can relate to the process, people or technology (Eriksson, 2014). Some examples of barriers to BIM include education costs, lack of legal regulations, BIM terminology, the shift from individual towards project-based costs and benefits, and enforcement and recognition by the owners (Barlish & Sullivan, 2012; Czmoch & Pękala, 2014; Lee & Eastman, 2008; Succar, 2009).

The following problem definition summarizes the information above:

> *BIM has proven to have many advantages over the traditional way of working. However, implementation of BIM is still in its infancy because of barriers that are experienced. Intra-firm BIM is a requirement for inter-firm BIM. Little is known about barriers on the intra-firm level and hence, it is not clear how to overcome these barriers. This is especially relevant for engineering firms which are ahead of other sectors in the AECO industry.*

Game theory is a suitable tool to analyse the strategic interaction between different actors. According to Turk (2016) game theory provides a good framework to study the implementation of BIM, since BIM behaves as a socio-technical system because it changes businesses, business models, institutions, workplaces, careers and education. Moreover, BIM is also changed by the environment in which it operates. However, the combination of BIM and game theory is not very common in literature. Therefore, it is interesting to study the barriers to BIM implementation from a game theoretic perspective.

1.2 Research questions

This research aims to provide interventions to stimulate the implementation of BIM by finding suitable implementation strategies in order to overcome the barriers with regard to BIM. The following research question is used:

> *Which interventions are most effective in overcoming the barriers to the use of BIM experienced by actors significant in the BIM implementation process within large engineering firms?*

In order to answer the research question, the following sub-questions have been formulated:

- 1.1 What is the current level of BIM implementation within large engineering firms?
- 1.2 What are significant actors for BIM implementation within large engineering firms?
- 1.3 What are the major barriers to implementation of BIM experienced by significant actors within large engineering firms?
- 1.4 Which interventions are effective to remove or lower these barriers within large engineering firms?

1.2.1 Research objectives and limitations

The purpose of this thesis is to uncover which interventions can best be used to take away the barriers to BIM that are experienced by actors within large engineering firms. This is done by using game theory. The aim of this thesis is to find how BIM can be made more attractive for actors in order to support the implementation of BIM.

The study has several limitations. First of all, it is not possible to include all involved actors in the game theory model because of the complexity of this model and the time constraints. Therefore, the focus is primarily on internal actors. Regarding the actors in general, both the ones using BIM themselves and parties that can demand the use of BIM are considered, such as clients or line-managers. Another limitation is caused by the assumptions that have to be made in order to use game models. This results in a simplified version of reality. Thirdly, this study uses data that is collected at one engineering firm in order to develop an in-depth understanding of the BIM process. Finally, a limitation is that this thesis focusses specifically on large Dutch engineering firms and the results may therefore not be as relevant for small or mid-sized Dutch engineering firms or engineering firms in other countries.

1.3 Research approach

This section shortly describes the research components. Table 1.1 provides an overview of the methods. The research model is presented in Figure 1.1.

First of all, a literature review was conducted to understand the topic, provide context, and to identify significant actors for BIM implementation in engineering firms. Secondly, the BIM maturity level was determined with a survey to understand the extent to which BIM was already implemented. Barriers to BIM were found by conducting interviews with significant actors as found in the literature review. Subsequently, interventions were designed according to the most common barriers. Finally, the effectiveness of the different interventions was tested using game theory. The utility for the game theoretic model was found by the use of a survey.

Table 1.1

Overview of research methods.

Outcome	Type of data	Research method
Current status of BIM use	Quantitative	Survey at Movares
Main actors	Qualitative	Literature review
Barrier(s) per actor	Qualitative	Interviews at Movares
Possible interventions	Qualitative	Literature review and interviews
Effectiveness of interventions	Qualitative	Game theory
Utilities	Quantitative	Survey at Movares

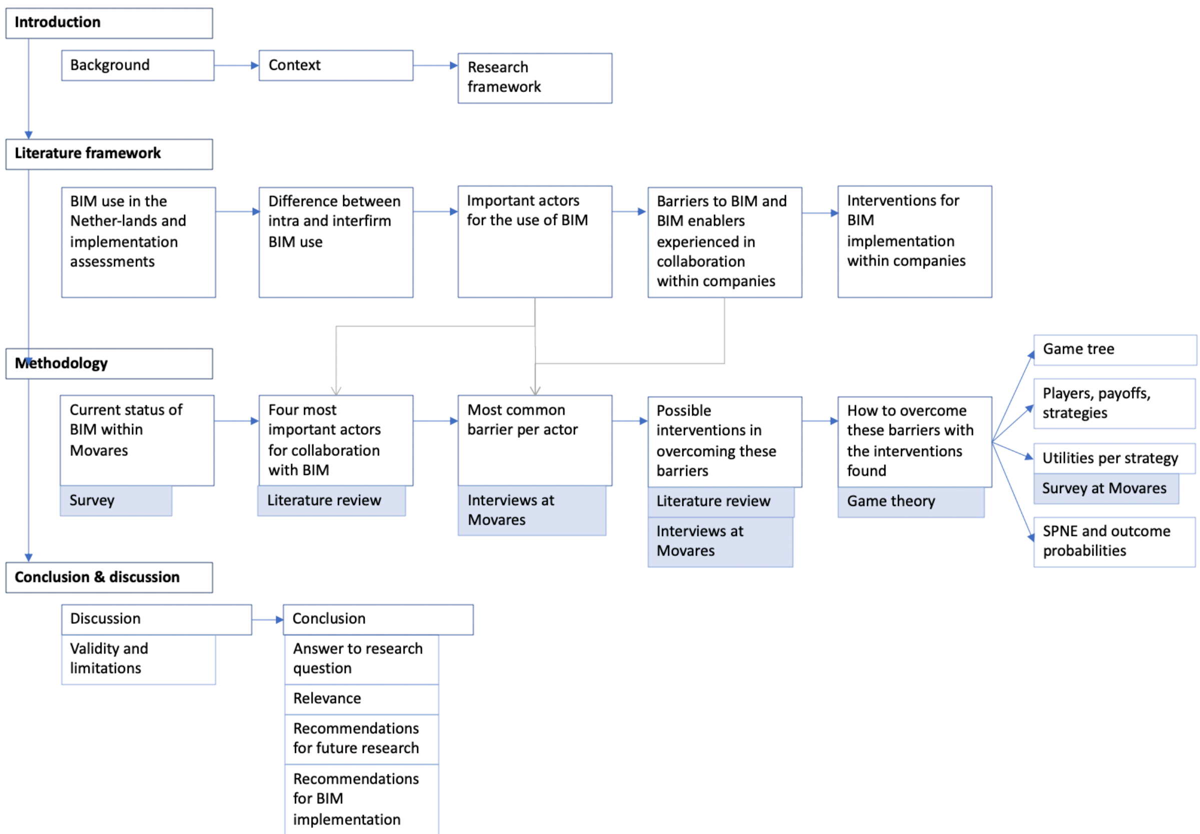

Figure 1.1. Research model.

1.4 Motives

This section describes both the scientific and personal relevance of the topic.

1.4.1 Scientific relevance

BIM has many benefits, but it is not yet widely implemented. Many firms are struggling with the implementation of BIM. Although general barriers to BIM are presented in literature, little is known about the barriers per actor. The same holds for BIM implementation guidelines on the intra-firm level. This is interesting since intra-firm BIM is a requirement for inter-organizational BIM (Hochscheid & Halin, 2019; Jernigan & Onuma, 2008). Proper implementation of BIM is dependent on three factors: people, process and technology (Eriksson, 2014). The people related barriers are often not included in studies (Barlish & Sullivan, 2012). When a significant number of individuals or organizations implements BIM, it becomes unavoidable for others. This contributes to the implementation of BIM. Game theory allows to analyse strategic interaction between individuals. Hence, it can help to understand when people choose to work according to BIM standards. The topic of BIM in combination with game theory is one that is little studied. Game theory is useful in the context of BIM, since it can help to clarify why specific actors respond to BIM in a certain way and how their reactions change in different scenarios. By modelling this, implementation strategies can be compared and tested and the most effective one can be chosen. Game theory can thus contribute to a more effective implementation of BIM. To summarize, this study has three main scientific contributions. First of all, it studies the barriers on actor level within organizations. Secondly, it proposes interventions to overcome barriers for Dutch engineering firms. Finally, it uses a game theoretic perspective to find suitable interventions to stimulate BIM implementation.

1.4.2 Personal relevance

For my thesis I wanted to combine both topics from my bachelor Psychology & Technology and my master Construction Management and Engineering. I am very interested in optimising processes for people. BIM is interesting since it allows for more effective collaboration in the AECO industry. However, in order to do so, people need to understand the technology and the project process has to be changed in order to efficiently incorporate BIM. Therefore, BIM is both relevant from a construction management perspective as well as from a psychological perspective. Game theory can help to understand people's behaviour and how this behaviour changes in different scenarios. Although game theory has not been discussed in much detail during my education, I was very interested in learning more about this method. The company was chosen based on their specialization in solving complex, societal issues regarding infrastructure, mobility, space, water and energy, and their desire to stimulate BIM implementation.

1.5 Reading guide

Figure 1.2 gives an overview of the remaining chapters. Chapter two covers the definition of BIM in more detail, BIM implementation assessments, BIM in the Netherlands, the difference between intra- and interfirm BIM use, actors within engineering firms, BIM enablers and barriers, and interventions. Chapter three describes the different methods used in this study. It is explained how the BIM maturity level was determined (sub-question 1.1). Moreover, it is explained how significant actors were identified (sub-question 1.2) and how the barriers experienced by those actors were found (sub-question 1.3). This chapter also discusses how interventions were designed in order to overcome the barriers. Finally, this chapter elaborates on game theory as a concept and how it is used to test different interventions to answer sub-question 1.4. Chapter four presents the results of the different parts. Finally, a discussion is provided in chapter five and a conclusion is given in chapter six.

2. Literature review	**3. Method**	**4. Results**	**5. Discussion**	**6. Conclusion**
• Introduction to BIM	• Survey: BIM maturity level	• Current BIM maturity level	• Validity	• Answering research question
• BIM in different countries	• Literature review: important actors	• Significant actors	• Limitation	• Scientific and societal relevance
• BIM in the Netherlands	• Interviews: barriers	• Barriers for each actor		• Future research
• Intra- versus inter-firm BIM use	• Survey: utility of interventions	• Proposed interventions		• Recommendations for BIM implementation
• Actors	• Game theory: effectiveness of interventions	• Effectiveness of interventions		
• BIM barriers and enablers				
• Interventions				

Figure 1.2. Reading guide.

2 Literature review

This literature review includes an introduction on BIM (Section 2.1), different BIM assessments (Section 2.2), BIM use in the Netherlands (Section 2.3), and the difference between BIM in an intra- and inter-organizational context (Section 2.4). Moreover, relevant actors for BIM are discussed in Section 2.5 as well as barriers and enablers in Section 2.6 and 2.7. This chapter ends with Section 2.8 on interventions provided in literature.

2.1 BIM

This section describes the varying definitions of BIM and presents the different dimensions that a BIM model can have. Moreover, it provides the definition of BIM that is used in this thesis.

2.1.1 BIM defined

BIM is an abbreviation for different things. It can describe a product: Building Information Model, a process: Building Information Modelling or an information management system: Building Information Management ("BIR Kenniskaart nr. 0 Wat is BIM?," 2015).

So far, literature does not present one unilateral definition of BIM. Abbasnejad & Moud (2013) studied the basic challenges that are associated with BIM including its definition and interpretations. The variety and frequency of BIM definitions that were found by these authors illustrates the confusion in defining and quantifying BIM. Different organisations and individuals have their own BIM definition. Since these definitions vary, it is important to be precise when discussing BIM. Although these varying definitions can lead to difficulties in communication, the researchers do not propose one unique definition of BIM, but rather a definition in which key characteristics are included (Abbasnejad & Moud, 2013; Suermann & Issa, 2009). Several studies tried to provide a BIM definition that captures such key characteristics. Two examples are:

> *"A set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle."* (Succar, 2009, p. 357)
>
> *"An information model of a building (or building project) that comprises complete and sufficient information to support all lifecycle processes, and which can be interpreted directly by computer applications. It comprises information about the building itself as well as its components, and comprises information about properties such as function, shape, material and processes for the building life cycle."* (Sander Van Nederveen, Beheshti, & Gielingh, 2010, p. 16)

Because BIM definitions and standards vary per organization and individual, the National Building Information Modelling Standard (NBIMS), the Committee of the National Institute of Building Sciences (NIBS) and the Facility Information Council (FIC) provide standard definitions for building information exchanges. This standard forms the foundation for accurate and efficient communication that is needed in the construction industry (Nawari & Sgambelluri, 2010). The NBIMS defines BIM as:

> "*Building information Modelling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition."* ("What is a BIM?," 2019)

The NBIMS established three ways of categorizing BIM: BIM as a product, BIM as IT-enabled, open standards-based deliverable and a collaborative process, and BIM as a facility lifecycle management requirement (Eastman, Sacks, Lee, & Teicholz, 2018).

A similar way of categorizing is proposed by the Bouw Informatie Raad (BIR: Building Information Council), which is recently succeeded by the Bouw Digitatliserings Raad (BDR: Building Digitalization Council). The BIR was a cooperation between different branches in the construction and infrastructure sectors in the Netherlands. They provide three, equally important, definitions of BIM.

- Building Information Model: a digital representation of how a building is developed, realised or actually build. This definition highlights the digital model.
- Building Information Modelling: collaboration supported by information models. This definition highlights the process.
- Building Information Management: the structure, management and reuse of digital building information throughout the complete lifecycle of a building. This definition highlights the information ("BIR Kenniskaart nr. 0 Wat is BIM?," 2015).

Within the Dutch building industry, the definitions and standards of the BIR are most commonly used. The open standards provided by this organization are also supported by the Dutch government. Since this study focusses on large engineering firms in the Netherlands, a combination of the BIM definitions provided by the BIR is used in this thesis:

> *(The creation of) A 3D model, where digital information is added to the model for collaboration throughout multiple stages of the building lifecycle.*

2.1.2 BIM dimensions

A BIM can be described based on the number of dimensions that are present in the model. The number of dimensions indicates how many variables are included. Hence, for each successive dimension the conditions of the previous dimension have to be satisfied as well. These dimensions are indicated with a number, representing the number of dimensions, followed by 'D'. Above 7D, models are often indicated with nD.

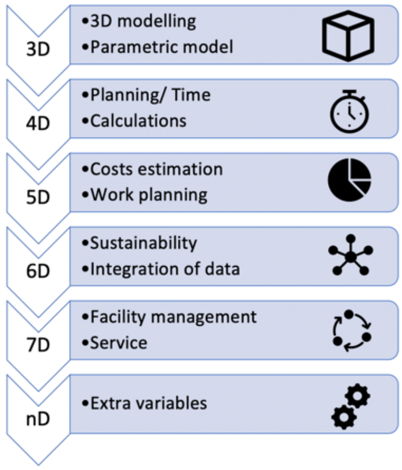

Figure 2.1. Dimensions of a BIM model (Czmoch & Pękala, 2014).

Different dimensions of BIM are specified in Figure 2.1. However, these dimensions do not have a unilateral definition. Especially the definitions of higher dimensions vary. For example Abbasnejad & Moud (2013) and Czmoch & Pękala (2014) define the third, fourth and fifth dimension very similar. However, the sixth dimension is defined in terms of sustainability, environmental protection and energy consumption by Czmoch & Pękala (2014), whereas Abbasnejad & Moud (2013) describe 6D in terms of lifecycle management and data capture. Interestingly, this later description is given to the 7D dimension by Czmoch & Pękala (2014).

A study conducted by Charef, Alaka, & Emmitt (2018) also indicated that there is no consensus on the sixth and seventh dimension. Their study across Europe towards the meaning of the dimensions indicated that the sixth and seventh dimension are associated with sustainability, facility management and safety. However, most participants refer to sustainability for 6D and facility management for 7D (Charef et al., 2018).

Concludingly, when communicating about BIM it has to be considered that definitions vary, and dimensions do not have the same meaning to every stakeholder.

2.2 BIM implementation assessments

BIM is defined in different ways and dimensions are given different meanings. In order to understand the extent to which BIM is implemented several assessments are available. This section presents a selection and discusses BIM maturity levels.

2.2.1 BIM implementation assessments

Many diverse methods and frameworks are presented in literature to measure the extent to which BIM is implemented by groups of various scales. Studies differ in the fields they address and the levels they define. It has to be noted that assessments are available for both BIM implementation and BIM adoption, which are two different things. Adoption refers to starting to use something new whereas implementation refers to the phase which occurs after an innovation is taken into use (Ahmed & Kassem, 2018). This study focusses on implementation assessments. Table 2.1 provides an overview of the assessments that are discussed in this section.

Table 2.1

BIM implementation assessments.

Implementation components considered	**Factors included**	**Notes**	**Authors**
BIM capability stages, BIM maturity stages, competencies, organizational scales and granularity levels	Technology sets, process sets and policy sets	Use of performance criteria	(Succar, Sher, & Williams, 2012)
BIM capability maturity	Technical and non-technical aspects		(Mom & Hsieh, 2012)
BIM capability and maturity model		Extent to which a mature BIM standard is implemented	(Nawari & Sgambelluri, 2010)
Organizational scale, granularity level, capability stages and BIM maturity		Emphasize accuracy and consistency and useful for all perspectives	(Succar, 2010)
How BIM is perceived and an evaluation of improvements on these aspects	Technology, model and human aspects		(Abdirad & Pishdad-Bozorgi, 2014)
BIM technology implementation	Process level, organizations, applications, tools, project teams and business models	Based on eighty key factors	(Tsai, Mom, & Hsieh, 2014)
The extent to which BIM is used and BIM maturity	People, resources and time, collaboration, work processes and procedures, BIM functions and BIM implementation	Quantitative and qualitative measure created by the Dutch building industry	(Fischer, 2013)
BIM maturity	Process, technology, organization, standards and human	Based on review of nine tools	(Wu, Xu, Mao, & Li, 2017)
BIM maturity	Strategy, organizational structure, people and culture, BIM processes, ICT and data	Based on three successive studies in a Dutch context	(Siebelink, 2017)

Succar, Sher, & Williams (2012) identify five complementary components specifically developed to enable the assessment of BIM: BIM capability stages, BIM maturity levels, BIM competencies, organizational scales and granularity levels. The framework is based on some guiding principles to be reliable, adoptable and usable. In order to satisfy these, several performance criteria are presented: accuracy, applicability, attainability, consistency, accumulation, flexibility, informativity, neutrality, specificity, universality and usability. Regarding BIM competencies, both technology sets, process sets, and policy sets are considered (Succar et al., 2012).

Most other sources only use one of these components for a BIM assessment model. For example, Mom & Hsieh (2012) present a BIM capability maturity model which can be used to define the BIM performance level of an organization. They include both technical and non-technical aspects. The performance is found by looking at the strategy in the business environment, the BIM unit and internal factors at the corporate level and by executing a BIM performance assessment based on this information. The NBIMS also proposes a combination of a capability and a maturity model, which can be used to measure the extent to which a mature BIM standard is implemented (Nawari & Sgambelluri, 2010).

BIM maturity and BIM capability are two different things. Succar (2010) defines capability as a minimum ability whereas a maturity denotes the extent of that ability in performing a task or delivering a BIM service or product. The paper defines BIM maturity as: “the quality, repeatability and degree of excellence within a BIM capability” (Succar, 2010, p. 5). The assessment consists of five steps. Firstly, the competency areas have to be isolated by selecting the organizational scale and the granularity level. In order to establish the BIM capability one of the following capability stages has to be established: object-based modelling, model-based collaboration and network-based integration. The next step is about assessing the BIM maturity and finally, a BIM capability and maturity report can be generated (Succar, 2010). The advantage of this assessment is that it is useful for all perspectives.

Abdirad & Pishdad-Bozorgi (2014) propose two other bases for assessing BIM implementation. Firstly, it can be measured how BIM is perceived based on technological aspects, model aspects and human aspects. Secondly, BIM can be assessed based on an evaluation of improvements on these aspects. The technological aspect consists of BIM tools, BIM platforms and BIM environments. Regarding the model aspect, the focus is on building realization, including physical correctness and performance requirements. Finally, the human aspect consists of human-human interactions and human-computer interactions. For the second assessment, Improvements can also be studied from the perspective of different project parties or different disciplines (Abdirad & Pishdad-Bozorgi, 2014; Deutsch, 2011; Eastman et al., 2018).

Interestingly, no metric has been developed for assessing individual-team BIM users. Moreover, no metric has been found to measure the impact of BIM in decision making stages and feasibility analysis (Abdirad & Pishdad-Bozorgi, 2014). A review of the American Society of Civil Engineering (ASCE) shows that most research has focused on BIM outcomes. An extensive gap exists in research on BIM input, including BIM tools, BIM users, and process assessment (Abdirad & Pishdad-Bozorgi, 2014). The assessment of BIM is thus far from unilateral. This makes it difficult to objectively determine the BIM maturity level and to compare BIM maturity levels of different units.

An example of a study that does include BIM input and process assessment is conducted by Tsai, Mom, & Hsieh (2014) who developed factors for the assessment of BIM technology implementation. The framework they proposed includes six levels to assess BIM technology including the process level, organizations, applications, tools, project teams and business models. In their paper they present eighty key factors for the assessment of BIM implementation at organizational level in the AEC industry. The factors were found by ranking 123 influencing factors. Support from top management, functionality and design validation were found to be most important, followed by the definition of project goals before forming teams and coordination and integration among the professions. Other important factors are the nature and state of organization, applications, tools, project teams and business models (Tsai et al., 2014).

Another study identifies the level of BIM implementation based on a quantitative and a qualitative measure. Both the extent to which BIM is used and the maturity level are necessary in order to assess the BIM implementation level. The BIM maturity level is here defined as the distance between the BIM ambition and realization. The following categories are suggested to find the BIM maturity level: people, resources and time, collaboration, work processes and procedures, BIM functions and BIM implementation (Fischer, 2013). This study does thus also focus on the process and BIM inputs by incorporating people, collaboration and BIM processes.

Similar categories as proposed by Fischer (2013) are defined by Wu and colleagues (2017) who reviewed nine different tools to measure BIM maturity. They came up with five different categories that are important to assess BIM implementation: process, technology, organization, standards and human. The process category assesses the establishment, management and documentation process of BIM-related works, interactions and deliveries. Within the technology category, the proficiencies of BIM functions and the qualities of relevant software, hardware and deliverables are evaluated. The organizational category focuses on organizational BIM planning, including strategies, objectives and leadership support. The human category addresses issues related to mentalities, capabilities and trainings of BIM staff. Finally, the standard category measures the implementation of standards, guidelines, specifications and contracts (Wu et al., 2017).

A Dutch study with similar categories is conducted by Siebelink (2017) who proposes a BIM maturity model based on six categories. The category strategy includes the BIM vision, goals, management support and BIM expertise. The category organisational structure includes tasks and responsibilities, and contractual aspects. The category people and culture includes personal motivation, the presence of a requesting actor, education, training, support, cooperation, openness and transparency. Regarding BIM processes both procedures and process change are included. The category ICT includes hardware, software and BIM facilities. Finally, the category, data includes the information and object structure, the object library and data exchange. The model was tested, and it was found to be accurate in describing how the different levels are executed in practice. The categories are established based on three successive studies in which the University of Twente, the BIR and the 'Nederlandse Vereniging voor Inkoopmanagement' (NEVI: Dutch association for Purchasing management) were involved (Siebelink, 2017; Siebelink et al., 2015).

All in all, many different tools exist to assess the BIM implementation level. However, BIM maturity is most commonly used in research to refer to the BIM implementation level.

2.2.2 BIM maturity levels

The examples above give an indication of the wide variety of BIM assessment tools that exist. However, literature most often refers to BIM maturity to clarify the implementation level. The BIM maturity can be expressed in levels. Besides the difference in measurement instruments there is also a difference in the names of levels. Table 2.2 gives an overview of several studies and the BIM maturity levels they address.

Table 2.2

Overview of maturity level names by different authors.

Country	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5	Author
United States	None	Basic	Inter-mediate	Advanced	Expert		(Succar, Sher, & Williams, 2013)
Taiwan		Initial	Managed	Standardized	Measured	Optimized	(Mom & Hsieh, 2012)
Australia		Initial/ Ad-Hoc	Defined	Managed	Integrated	Optimized	(Succar, 2010)
The Nether-lands	Not present	Initial	Managed	Defined	Quantitatively managed	Optimized	(Siebelink et al., 2015)
The Nether-lands	Document oriented	Object oriented	Merged	Integrated, lifecycle			("BIR Kenniskaart nr. 1: Nederlandse BIM Levels," 2014)

As can be seen, the number of levels included, and their description highly differs per study. Three studies discussed in the previous section that include BIM maturity are not included in Table 2.2. Nawari & Sgambelluri (2010) provide a scale from zero to ten without labels to assess the BIM maturity. Fischer (2013) and Wu and colleagues (2017) do not present an overview of the levels in their studies.

2.2.2.1 BIM maturity in the Netherlands

The general BIM maturity level of the Netherlands was found by Kassem & Succar (2017) who compared 21 countries on five different BIM implementation assessments. Countries were selected based on three criteria. The country needed to have active on-going discussions about national and international BIM policies, identifiable professionals had to be present and countries from all continents had to be included. The five measures included a comparison of countries on BIM areas of diffusion, the BIM maturity level, the diffusion dynamic driving BIM innovation in the respective country, policy actions and, finally, group responsibilities. It can be concluded that the Netherlands scored relatively high on all five measures compared to other countries. Regarding BIM maturity specifically, the Netherlands was found to have the fifth highest score. Interestingly, the United Kingdom, who scored highest on BIM maturity, scored only slightly more than half of the maximum score. It could thus be argued that the BIM maturity level in general is low (Kassem & Succar, 2017).

The BIM maturity levels within the Netherlands differ per sector. Berlo and colleagues (2012) analysed the BIM maturity level in the Netherlands for nine sectors in four different categories: organization and management, mentality and culture, information structure and information flow, and tools and applications. Their results show that construction engineers and MEP engineers score highest with regard to the BIM maturity level. The categories client, supplier and fitter-installer score lowest. The contractor, builder and architect have a score in the middle range. Interestingly, all sectors score similarly on the categories organization and management, mentality and culture and information structure and information flow. However, every sector is behind in the category of tools and applications.

The University of Twente executed three studies in order to create an accurate BIM maturity model commissioned by the BIR and the NEVI. The second study included a sector analysis based on surveys. The results of the survey were analysed based on a 6 point scale and reported by Siebelink (2017). Figure 2.2 shows these results. Similar to the study of Berlo and colleagues (2012), who measured the level based on an open scale, engineering firms score highest on BIM maturity according to the figure. Also, the score of the suppliers, architects and the MEP contractors are similar. However, the BIM maturity level of the client differs quite strongly. This is interesting since both studies used data from Dutch firms. This difference might be explained by the fact that the interest of clients in BIM has increased in the past years.

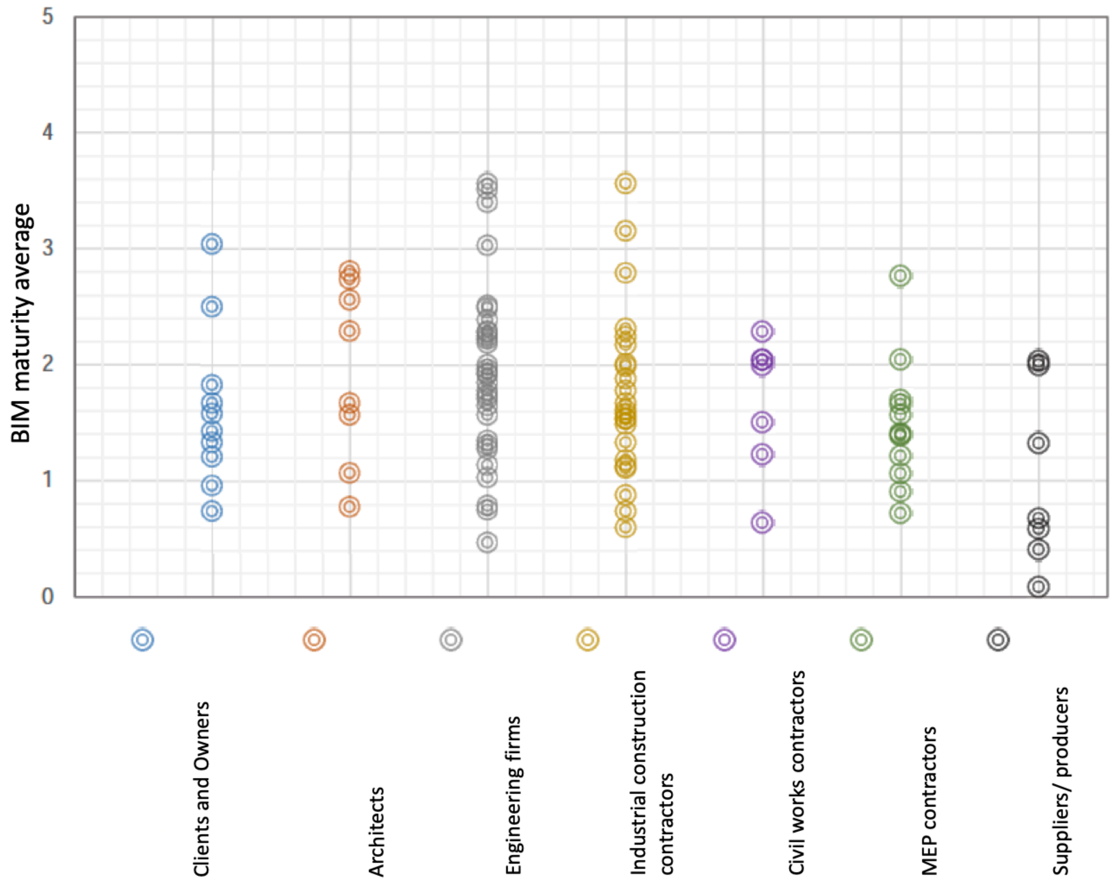

Figure 2.2. Average BIM maturity score per organization, arranged per subsector (figure adopted from Siebelink (2017).

Concludingly, there are many diverse methods to assess BIM implementation. BIM maturity levels are most often used to describe the BIM implementation level. However, these levels differ per study. Literature shows that there is a difference between countries in both the extent to which BIM is implemented. The Netherlands score relatively high on this in comparison with other countries. A distinction between sectors in the Netherlands indicated that especially engineering firms score high on BIM maturity.

2.3 BIM in the Netherlands

The previous section elaborated on the BIM maturity in the Netherlands. This section describes BIM developments present in the Netherlands. Several initiatives are present to stimulate BIM (Nederveen, Beheshti, & Willems, 2010).

2.3.1 BIM initiatives

DigiDealGo is the main platform for the national digitalisation programme for the building industry. This initiative is supported by the BDR and the BIM Loket. Both are an industry initiative and provide information on what BIM is, which national and international standards are available, which roles and competencies relate to BIM and contractual aspects. The BDR aims at supporting widespread implementation of BIM. The BIM Loket is the central location for information about open BIM standards. ("Open BIM-standaarden," n.d.; "The driving force behind BIM in the construction industry," n.d.).

2.3.2 Project stages in the Netherlands

Since this study is focused on Dutch engineering firms, the Dutch project stages are taken as a reference. These are described in the DNR Standaardtaakbeschrijving (STB: Standard Task Description). The latest version dates from 2014 and includes several stages as shown in Figure 2.3. An elaboration on all these stages is provided in Table 2.3.

Figure 2.3 includes the common level of detail (LOD) of each stage. The level of detail indicates the complexity of a building model. Dimensions, as described in 0 cannot be linked to specific project stages. They can be implemented in every project stage. However, some of the dimensions, for example sustainability and facility management are easier to implement when done so in an earlier project stage.

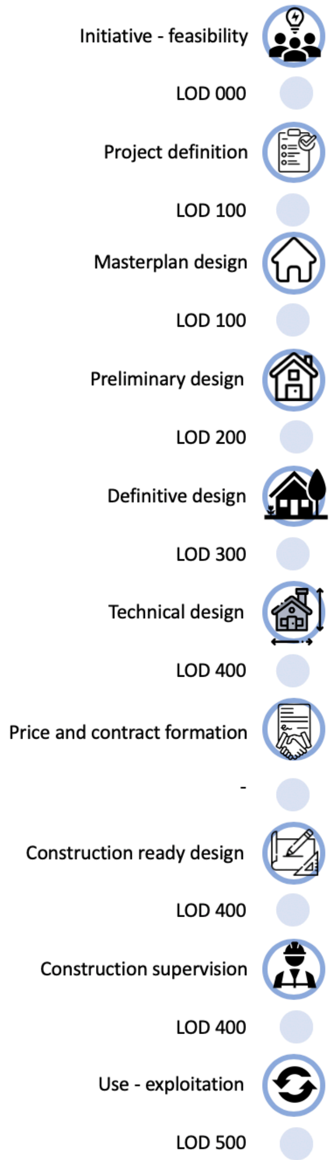

Figure 2.3. Overview of the project stages used in the Netherlands.

2.3.3 BIM activities in different project stages

The STB project stages described in Table 2.3, are, according to the BIM Loket, not yet aligned with BIM-processes and responsibilities, and therefore not useful ("BIR Kenniskaart nr. 4a: BIM juridisch , algemeen," 2014). However, since there is no generally accepted description on how to include BIM in building projects and processes, the STB project stages are also used for BIM projects. The Dutch association of 'Samenwerkende Architecten en Bouwtechnisch adviseurs' (Collaborating Architects and Engineering consultants) published a document in which BIM activities are linked to project stages and the activities that are present in all of these stages (Vereniging Samenwerkende Architecten en Bouwtechnisch adviseurs, 2017). The BIM activities that are relevant for specific project stages are presented in Table 2.4.

Table 2.3

Overview of Dutch project stages ("DNR-STB 2014 Toelichting," 2014).

Project stage	Aim
Stage 1: Initiative - feasibility	Finding and analysing the housing requirements or market request and studying the feasibility to meet this requirement or request.
Stage 2: Project definition	Find and record the ambitions, requirement, desires, expectations and conditions of the future user in order to start the design process.
Stage 3: Masterplan design	Development of a global design of the project. This should provide the shape and division of the building. (The master plan design is usually not necessary in projects. This stage is mainly useful for large, complex projects or projects which are strongly related to urban development.)
Stage 4: Preliminary design	Develop an overall representation of the building including the positioning, functional and spatial structure, facilities, architectonical shape and integration of construction and installation aspects.
Stage 5: Definitive design	Develop a detailed design of the building in order to represent the shape, internal and external structure, material use, detailing, construction and the type and capacity of installations. Moreover, an application for a building permit is send out.
Stage 6: Technical design	Develop the scope statement and elaborate and specify elements from previous stages. This is necessary to provide the final pricing. Moreover, partial designs are merged, and the technical specifications are determined.
Stage 7: Price and contract formation	Aims at selecting and contracting a party for executing the project. A party is chosen depending on the type of contract, possibly including design, financing, maintenance and exploitation.
Stage 8: Construction ready design	Aims at elaborating the design in such a way that it can be used for actual construction of the building. Detailed drawings are made in this phase.
Stage 9: Construction supervision	Aims at supervising and guiding the executive work. Moreover, the works after completion are checked and the report regarding completion is taken care of.
Stage 10: Use - exploitation	Supporting the client, owner or user with the use and exploitation or facility management of the building.

Table 2.4

BIM activities linked to project stages.

Project stage	BIM activities
Initiative - feasibility	No activities
Project definition	No activities
Masterplan design	Usually no BIM activities. In case BIM is used, this is usually limited to the 3D modelling of masses.
Preliminary design	Drafting a BIM protocol; Actualizing BIM management; 3D modelling of masses; Adding information to a 3D model; Providing insight into the monitoring of the specification of requirements; 3D modelling of the building; Testing the building based on the regulations; Embellishing parts of the model to create 3D impressions; 3D coordination of the integration of partial designs; Embellishing 2D views of the model, including floor plans, facades and sections; Extracting overall quantities from the model to make an estimation of the construction costs.
Definitive design	Updating the BIM protocol; Actualizing BIM management; 3D modelling of masses; 3D modelling of the building model; Refining the dynamic test for building regulations of the model; Embellishing parts of model to create 3D impressions; Elaborate overall principle details; Monitor specification of requirements; 3D coordination and integration of partial designs; Embellishing 2D views of the model, including floor plans, facades and sections; Extracting overall quantities from the model to make an estimation of the construction costs.
Technical design	Updating the BIM protocol; Actualizing BIM management; 3D modelling of the technical model; Develop technical drawings for the details of the building model; Monitoring the specification of requirements; Executing a complete test for building regulations within the model; 3D coordination and integration of partial designs; Embellishing 2D views of the model, including all technical detail drawings; Extracting exact quantities from the model to make an estimation of the construction costs.
Price and contract formation	Updating the BIM protocol; Actualizing BIM management.
Construction ready design	Updating the BIM protocol; Actualizing BIM management; 3D modelling of the construction ready design; Develop technical details; Monitoring the specification of requirements; 3D coordination and integration of partial designs; Embellishing 2D views of the model, including all construction plans.
Contract supervision	Updating the BIM protocol; Actualizing BIM management; Documentation of findings related to building completion, the current status and possible work on parts in the building model.
Use - exploitation	Updating the BIM protocol; Actualizing BIM management; Updating the building model; Adding all non-geometric information to the building model that is relevant during use.

Eastman and colleagues (2018) give an interesting insight in the use of BIM over different project stages in different countries. The study compared 27 case studies on the project life cycles that were supported by BIM. The case studies included projects from Europe, North America, Asia and the Middle East and focused on the benefits experienced by different organizations. The results show that BIM was most often used in the stage of price and contract formation. In the stages of masterplan, preliminary, definitive, technical and construction ready design and construction supervision BIM was slightly less often present but still in more than half of the cases. Regarding the stages of initiative – feasibility and use – exploitation, BIM was used in only a few cases. This makes sense since BIM becomes more interesting when the building model becomes more relevant and more complex.

The BIM applications that employees at Dutch engineering firms most frequently use are found by Siebelink and colleagues (2015). The results were found by conducting interviews with employees from multiple engineering firms and show that the most frequent used BIM applications include: 3D modelling, generating of 2D drawings from 3D models, 3D coordination including clash detection and intersection management, visualisation of the 3D model, exchanging data with other parties, generating quantities of a 3D model and constructive analysis using 3D models.

2.3.4 Information exchange using BIM

Three documents can be used in order to successfully exchange information between BIM actors and project stages: Information Delivery Manual (IDM), protocols and an implementation plan. The IDM supports the business requirement, the software solution and the business process. To support the business requirement an exchange requirement must be present. In this requirement the set of information, contained within the Industry Foundation Class (IFC) that needs to be exchanged to support a particular business requirement in the relevant project stages, must be established. An IDM supports the software solution by providing the technical content required by solution providers to support an exchange requirement. Finally, the business process is supported by a process map that connects the exchange requirements to the business process (Wix & Karlshøj, 2010).The protocol is a standard part of the contract agreed by the commissioning party and the contractor(s) and it focuses on capturing project specific contractual provisions for BIM. The national BIM protocol includes conditions on BIM models, the ownership of models, BIM processes, tasks, responsibilities and liabilities, and sample texts for contractual requirements. The implementation plan can be used to capture mutual BIM working agreements for a successful and efficient project. It is a document in which project partners agree on how they will cooperate in a BIM-supported project within the frameworks set by the protocol. The national BIM implementation plan can be used to support project specific BIM Implementation plans ("BIM Loket: Using open BIM standards to build a stronger industry," 2016). These three documents support proper contractual and cooperation agreements between different actors in different project stages.

All in all, BIM is relevant for many different project stages. With regard to engineering firms, BIM is most often used in the design stages. Several BIM developments and initiatives are present in the Netherlands and although the project stages are not yet aligned with BIM use, attempts are made to integrate BIM as smoothly as possible in the existing project stages. This is done by both industry initiatives and the government.

2.4 Intra- versus interfirm BIM use

BIM can be implemented within an organization, also called intra-firm or little BIM, or between multiple organizations, also called inter-firm or big BIM. Intra-firm BIM is a prerequisite for inter-firms BIM, which focusses on the optimisation and efficiency of processes (Jernigan & Onuma, 2008). Another way of indicating the BIM level is the granular organizational scale. The macro level refers to markets and industries, meso refers to projects and their teams and micro refers to organizations (Hochscheid & Halin, 2019).

Graaff & Simons (2014) conducted a study in order to find the current and desired cultural values for both little and big BIM. Cultural values are relevant for the diffusion of BIM. Both organisational and personal values were considered for little and big BIM. Organisational values were divided into current and desired values. For both intra-firm BIM and inter-firm BIM the ten most important personal values, current values and desired values were listed. Regarding little BIM, collaboration was found to be the most important for all three values. Interestingly, involvement and enthusiasm score high on both personal values and desired values but are not included in the top ten for current values, where cost reduction and results are included instead. For big BIM collaboration was also found to be the most important for all three value categories. Enthusiasm as well as trust are present for the most important personal and desired values, but not for the current values. According to their results, users of little BIM have similar desired values for collaboration, information sharing and teamwork as the current values of big BIM users (Graaff & Simons, 2014).

A study reviewing 52 cases showed that BIM is mainly used for inter-firm communication, intra-firm coordination, and inter-firm coordination. The first two practices focus on a specific aim with BIM, whereas the third includes lifecycle BIM. However, from the 52 cases, only six implemented lifecycle BIM. BIM can help project managers to move from intra-firm processes to inter-firm cooperation. The study also showed that inter-firm cooperation and management activities can be enhanced using BIM. This leads to a decrease in uncertainties in schedules and budgets, which leads to cost savings. On the other hand, an increase in costs is experienced within firms, because the use of BIM requires firms to manage projects interdependently and collaboratively. This results in new costs and more expensive managerial issues (Zheng et al., 2017).

Both inter-firm BIM and intra-firm BIM has benefits and disadvantages. Intra-firm BIM implementation is the basis for effective inter-firm BIM use. Therefore, it is important that intra-organizational BIM use is optimised in order to properly facilitate BIM use between different organizations.

2.5 Actors

BIM is present within the domain of AECO and many different actors are involved in the construction process. Examples of actors are an architect, client, contractor, constructor, planner, installation technician, aesthetics committee, and the municipality. The client and the advisors, including engineering firms, installers and architectural firms, are most important for inter-firm BIM implementation (Fikkers et al., 2012). As described before, a distinction can be made between the actors involved in intra-firm BIM and inter-firm BIM. With regard to inter-firm BIM, many different organizations are involved, whereas for intra-firm BIM only one organization is considered. Hence, in general, intra-firm BIM involves less actors. It depends on the type of project and the size of an organization which actors are included.

Most literature focusses on actors involved in a project context or on inter-organizational level. Very little literature describes actors involved in intra-organizational BIM processes. Moreover, few studies have been done on actors significant for the BIM process in engineering firms. The first section describes BIM actor roles. The second section presents actor roles in an intra-organizational context

2.5.1 Changing BIM actor roles

Over the years, specific BIM actor roles have been defined to smoothen the use of BIM. The BIR defined several roles. These include BIM manager, BIM director, BIM coordinator, BIM aspect advisor and BIM modeler. The focus of the BIM director is on the implementation of BIM, guidance of project organization, collaboration and contracting. The BIM coordinator tests the building model, coordinates and generates information for production. Generating information for production is also done by BIM aspect advisors. BIM aspect advisors are specialists in specific disciplines. They are also involved in calculating and analysing. The BIM modeler elaborates the design, works with object libraries and generates data. Finally, the BIM manager is responsible for the strategy and the market position. Moreover, implementation and guidance should be done by the BIM-manager ("BIR Kenniskaart nr. 3: BIM-rollen en -competencies," 2015).

Despite these standard task descriptions, the execution of the roles differs. For example, the size of an organization influences the roles that are present, but also the tasks and responsibilities that are included in certain roles. For small organizations, multiple roles are sometimes executed by the same person. Moreover, differences exist in the interpretation of the different roles between different organization.

Besides specific BIM roles, other actors are also involved in the BIM process. The study of Papadonikolaki & Van Oel (2016) gives two interesting insights with regard to BIM users. By conducting in-depth semi-structured interviews, data was collected on inter-firm level in the Netherlands. Based on BIM-based cases, nine actors were included: architects, structural engineers, MEP engineers, contractors, sub-contractors, suppliers, clients and multi-actors. According to the study, the implementation of BIM induces project-based, intra-firm as well as inter-firm changes. On inter-firm level they analysed how changing roles due to BIM are perceived by the actors themselves and by other actors. Roles were analysed based on soft competences and hard skills. For soft competences, no domain expertise or a BIM-related technical nature is required. Hard skills require a BIM-related technical nature and domain expertise. The results showed that the perception of own soft competencies and hard skills related to BIM do not align with the expectations of other actors. Especially the competences and skills of the structural engineer and the supplier are very different. Moreover, the perceived and expected hard skills of the sub-contractor are very diverse. This is supported by Fikkers and colleagues (2012) who state that job descriptions need to be changed to include different responsibilities when BIM is implemented.

What can be concluded from this is that BIM tasks related to specific actor roles are not yet clearly defined nor clear to the actors themselves. This may hinder the implementation of BIM. Moreover, standard task descriptions for specifically defined BIM roles are present, but those are not applicable to every organization to the same extent.

2.5.2 BIM actors on organisational level

Little literature is available about BIM actors relevant for intra-organizational BIM. An example of a study that did focus on the organisational level is conducted by Bosdriesz (2018). The study distinguishes intra-organizational actors for a group level and a user level. On the group level both the relevant firm and departments involved in the building process should be included. With regard to the user level both non-technical users and technical users should be included. Non-technical users are stakeholders that should be able to work with the data available in the BIM model, but who do not need to understand all the complexities from BIM. Technical users are the experts who create the model and add the initial data in the model. They are also responsible for including object information.

Fikkers, Nieuwenhuizen, Nijssen, & Schaap (2012), who conducted a study in cooperation with the BIR, provide more specific actors that are relevant for intra-organizational BIM. On intra-firm level they specify the following roles as being important for BIM implementation: BIM coordinator, someone responsible for the specifications, planning and modellers, and the modellers themselves. Management is not directly involved in the BIM process. However, management needs to translate the implementation of BIM to a practical plan. Moreover, management needs to mobilise employees to execute the plan. People who arrange the technical and organizational change, by implementing new technology and software, creating new job descriptions are also important for the implementation and by monitoring change.

Papadonikolaki & Van Oel (2016) did an interesting finding with regard to a typical combination of complementary BIM functions on intra-firm level. This combination consists of a BIM modeler, BIM knowledgeable project manager, and a BIM-enthusiast project leader. The BIM functions present do differ based on the firm size (Papadonikolaki & Van Oel, 2016).

In conclusion, the BIM process includes many different actors and the actors involved differ between organizations and projects. Because of this difference, it is not unilateral which actors are most important for the implementation of BIM. However, this literature review showed that three important groups of actors can be distinguished. First of all, specific BIM actor roles are typically present in BIM projects. Moreover, both non-technical users as well as the technical users should be included. The answer to sub-question 1.2 *'What are important actors for using BIM in collaboration within a firm?'* does thus not point out three specific actor roles, but rather three actor groups that are of interest for the implementation of BIM.

2.6 Barriers to BIM

This section elaborates on intra-firm barriers and barriers for engineering firms. Moreover, Table 2.5 gives an overview of the barriers per project stage.

Literature distinguishes barriers in different categories. For example, Eriksson (2014) suggests a distinction between people, process and technology related barriers to BIM. People related barriers are often not considered whereas these are very important. Barlish & Sullivan (2012) support this by stating that the real challenges are user related. People have to agree on common IT platforms, share their BIM models and share all relevant information. This may not be done in order to protect ownership of the BIM models and intellectual property rights. This makes collaboration more difficult. Something else that has to be taken into account is that barriers experienced in current and future areas in BIM use differ. Only the barrier lack of skilled personnel was found in both areas (Czmoch & Pękala, 2014; Ku & Taiebat, 2011).

2.6.1 Barriers for engineering firms

Siebelink and colleagues (2015) describe barriers on sector level for the Dutch industry. Based on interviews with employees from nine engineering firms they found that engineering companies have five barriers that hinder the implementation of BIM. First of all, the knowledge and experience regarding BIM is inadequate and this hinders the speed of implementation and expansion of BIM applications. Although some early adopters are already advocating BIM, great effort is required to motivate the majority of the organisation for the implementation of BIM. Thirdly, not all partners are able to work with BIM, this hinders further implementation. Moreover, accessibility of the model by different project partners cannot be arranged properly, either because not all parties are familiar with BIM or because firms do not want to share all information. This limits the integrated collaboration. Finally, there is a lack of mutual trust, openness and transparency between project partners. When all sectors are analysed together, the main barriers found are the same as the first three barriers presented for engineering firms. However, other barriers found differ per sector.

Kaner and colleagues (2008) identified four main obstacles for implementation of BIM specifically for precast concrete design within structural engineering firms. Firstly, the lack of adequate interoperability between different BIM software tools is seen as a barrier. Moreover, new workflows and standards have to be developed that better exploit and are suited for BIM tools. Thirdly, there is a shortage of skilled BIM personnel in structural engineering. Finally, the high initial investments are identified as an obstacle. These are needed for training, software purchases and for the setup of templates and custom object libraries. Although less prevalent, the difference in approach between a 2D CAD programme and BIM and the departure of employees who received training in BIM were also found as barriers. Moreover, the shift in mindset and the change in contractual relationships due to BIM may also form a barrier for engineering companies (Sebastian, 2011).

Although Graaff & Simons (2014) did not describe barriers specifically for engineering firms, their study is interesting since they describe barriers on the intra-organizational level for different actors: BIM users, project managers and decision makers. For the study, a survey was distributed which was completed by 985 participants. In 254 cases participants indicated that they worked with intra-organizational BIM. BIM users and project managers indicated the lack of other organisations working with BIM and the capacity of the organisation most often as barriers. Other barriers that were often mentioned include the availability and quality of ICT facilities, legal aspects around BIM, education and training, a lack of BIM projects within the organisation, time allocation and data exchange based on open standards. Decision makers indicated consecutively legal aspects around BIM, efficiency and strategy. Interestingly, a significant number of decision makers indicated that they experienced no barriers, whereas this was not indicated by any of the BIM users or project managers.

Based on the studies discussed above, the lack of BIM skills of employees, standards and issues with the integration of software are important barriers that hinder the implementation of BIM in engineering firms. This is also supported by the study of Bosdriesz (2018), who identified barriers experienced in practice by actors from a construction firm. Moreover, the barriers experienced differ per actor.

2.6.2 Barriers related to project stages

Unfortunately, no studies have focused on the barriers to BIM for engineering firms in specific project stages. However, several studies link general barriers to project stages. Table 2.5 provides an overview.

All in all, barriers are often user related and differ per actor role. Specifically, for engineering firms, the interoperability of software, the lack of skilled personnel and the lack of clear standards are experienced as barrier. Regarding project stages, barriers are mainly experienced in the initiative – feasibility stage and the design stages.

Table 2.5

Overview of barriers to BIM per project stage (Czmoch & Pękala, 2014; Lee & Eastman, 2008; Sacks & Barak, 2008; Succar, 2009; Zheng et al., 2017).

Project stage	**Barriers**						
Initiative – feasibility	Enforcement and recognition by owners/ Not all partners work with BIM	Distribution of benefits and costs	Inadequate knowledge/ lack of skilled personnel	Lack of data on ROI/ effectiveness	Lack of trust, openness and transparency	Lack of company investment	Time constraints
Project definition	No barriers were found for this stage						
Master plan design	Costs for technology, organizational processes and training	Accuracy of BIM	Increased workload for structural engineers	Lack of collaborative work processes and standards	Availability and quality of ICT facilities	Shift of mindset	Costs for training
Preliminary design	Costs for technology, organizational processes and training	Accuracy of BIM	Increased workload for structural engineers	Lack of collaborative work processes and standards	Availability and quality of ICT facilities	Shift of mindset	Costs for training
Definitive design	Costs for technology, organizational processes and training	Lack of collaborative work processes and standards	Availability and quality of ICT facilities	Shift of mindset	Costs for training		
Technical design	Costs for technology, organizational processes and training	Lack of collaborative work processes and standards	Availability and quality of ICT facilities	Shift of mindset	Costs for training		
Price and contract information	Legal barriers	Accessibility of models/ Interoperability	Contract related barriers	Overall understanding of BIM	Costs for training		
Construction ready design	Costs for technology, organizational processes and training	Lack of collaborative work processes and standards	Availability and quality of ICT facilities	Shift of mindset			
Construction supervision	Extra costs since model needs to be repurposed or reproduced	Shift of mindset					
Use - exploitation	No barriers were found for this stage						

2.7 BIM enablers

Although the benefits per stakeholder differ, some clear benefits of BIM in general have been described in literature. For example Leicht & Messner (2008) studied the benefits of BIM throughout the complete construction process and found that the main benefits relate to planning and transparency of the process. Ghaffarianhoseini and colleagues (2017) describe six main benefits of the use of BIM in construction processes in their paper: technical, knowledge management, standardization, diversity management, integration, economic, building life cycle assessment and decision support benefits. Based on case studies, Eastman and colleagues (2018) found that the benefit regarding time savings is most often present in projects. Other benefits that are often experienced are cost reduction, enhanced design quality, better end-user requirements capture, and rework reduction were present in at least six out of eleven projects (Eastman et al., 2018).

Finally, investment in the use of BIM almost always gives a positive return on projects due to, amongst others, better communication between parties, improved project process outcomes, improved productivity, positive impact on marketing, reduced cycle time and lower project costs. Moreover, value is added to the project along the complete lifecycle and the experience and knowledge gained from projects where BIM is used are beneficial for future projects (Neelamkavil & Ahamed, 2012).

However, almost every project in the AECO industry consists of different actor networks. This makes it difficult for organizations to benefit from BIM, since benefits with BIM are experienced in temporary coalitions of actors and difficulties in the transfer and diffusion of ICT are often experienced. The challenge for permanent organizations is therefore to transfer and routinize benefits achieved with BIM in one project network and transfer these to another project network (Linderoth, 2010).

2.7.1 Enablers for engineering firms

Where the previous sub-section described benefits of BIM in general the benefits of BIM for engineering firms are elaborated on below.

Kaner, Sacks, Kassian, & Quitt (2008) studied the benefits of BIM from the perspective of mid-sized engineering firms. They found that the use of BIM results in an improvement of productivity and improves the engineering design quality. BIM is also useful since it is very beneficial in projects linked to sustainability. The AECO industry, which has been criticized for its control and management of carbon emissions and environmental sustainability, is becoming more and more important. In case sustainable building methods are demanded, greater independency and earlier involvement and cooperation between de different stakeholders are required. Moreover, a large amount of information needs to be stored in order to facilitate sustainable design and life cycle management. This can be facilitated by BIM (Barlish & Sullivan, 2012; Wong & Zhou, 2015).

Specifically for engineering firms in the Netherlands, several main enablers for the use of BIM are specified by Siebelink and colleagues (2015). Firstly, higher efficiency, reduction of costs and a reduction of lead time were found to be important enablers. Moreover, BIM can be used to strengthen the competitive position and to distinguish the firm from other organisations. Two other enablers are the opportunity to be at the forefront of technical developments and the possibility to facilitate projects with a higher complexity and higher quality.

2.7.2 BIM enablers in different project stages

Similar as for the barriers no studies have focused on BIM enablers in different project stages specifically for engineering firms. However, literature linking BIM enablers in general to project stages is present. Table 2.6 provides an overview.

Concludingly, BIM enablers for engineering firms differ from general BIM enablers. BIM enablers for engineering firms include higher productivity and the possibility to distinguish the firm from other organizations. Regarding BIM enablers in different project stages, it can be stated that most benefits are experienced in the construction and use and exploitation stage. In general, most enablers apply to the initiative – feasibility stage, the price and contract formation stage and the early design stages. Finally, because of changing actor networks, it is difficult to routinize the benefits

Table 2.6

Overview of BIM enablers per project stage (Azhar, 2011; Bryde et al., 2013; Kaner et al., 2008; Manning & Messner, 2008; Sacks & Barak, 2008; Zheng et al., 2017).

Project stage	**Enablers**				
Initiative – feasibility	Reduction of costs	Reduction of lead time	Higher efficiency	To be at the forefront of technical developments	Facilitate projects with higher complexity and quality	
Project definition	No barriers were found for this stage					
Master plan design	Use model in meetings and make notes directly onto it/ Increased communication and increased confidence	Allows for virtual design approach	Better decision support, rapid and accurate updating of changes	Productivity increase, less drafting staff needed, less extensive checking, design integrity, decreased costs	Allows for accurate geometrical representation/ Rapid visualization	Reduction of man-hours
Preliminary design	Allows for virtual design approach	Better decision support, rapid and accurate updating of changes	Allows for accurate geometrical representation/ Rapid visualization	Productivity increase, less drafting staff needed, less extensive checking, design integrity, decreased costs	Reduction of man-hours	Increased communication and increased confidence
Definitive design	Better design	Allows for accurate geometrical representation				
Technical design	Better design	Allows for accurate geometrical representation				
Price and contract information	Faster and more Effective processes	Elimination of Unbudgeted change	Reduction of time to Generate cost estimation	Cost saving through Clash detection	Reduction in project time	Planning and transparency of the process
Construction ready design	Better design	Allows for accurate geometrical representation				
Construction supervision	Diminished reworks	Easier to produce construction documents	'As built' BIM can be developed			
Use - exploitation	Better production quality	Useful for facility management	Cost reduction and control through the lifecycle	Better end-user requirements capture	Facilitates sustainable design	

2.8 Intra-organizational interventions

Little studies have payed attention to guidelines for the implementation of BIM on organizational level. What is already known is that change needs to be managed in firms who implement BIM. Moreover, these firms need to review their business process strategy. Thirdly, in order to provide accurate guidelines, factors that affect implementation have to be considered (Hochscheid & Halin, 2019).

Proper implementation of BIM can help to move project management from the intra-firm level to inter-organizational cooperation. This can bring such an advantage to the AECO industry that it will result in a paradigm shift (Zheng et al., 2017). Therefore, it is useful to find solutions that can help to reduce the barriers that are experienced in intra-firm collaboration using BIM.

Unfortunately, little studies have focused on implementation guidelines for BIM on the intra-firm level (Hochscheid & Halin, 2019). However, literature is available for this level of analysis with regard to change management, BIM implementation frameworks and on how to overcome barriers. Each of these topics is elaborated on below. An overview of different interventions that can be deducted from these scientific sources and the factors that are considered by each of them can be found in Table 2.7.

2.8.1 Organizational change and innovation diffusion

Several factors affect organizational change including the internal and external context, characteristics of innovation and change characteristics. However, these factors are rarely included in literature about the factors influencing the BIM adoption and implementation process (Hochscheid & Halin, 2019). Gardner & Ash (2003) present a framework for managing change regarding the implementation of information systems in organisations. According to them it is necessary to know the dynamics of change between people, technology and change agents and between information systems and strategy in order to realise the benefits of ICT.

Within an organization, different departments, units or individuals adopt new technologies at different moments in time. The factors that affect implementation of such a technology change over time and differ among potential adopters. The factors depend on perceived innovation characteristics, adopter characteristics, and the internal and external environment characteristics. This includes internal motivation and the actor network. In general, it is important that the idea or vision of BIM is broad enough to be interpreted by a wide variety of actors as a solution to problems relevant for those actors. Moreover, the organizational structure is relevant, since a more horizontal structure leads to more integration of BIM in the supply chain. Regarding the change of factors over time it should be considered that later adopters are more concerned with the scalability of the system, with the implementation period and with the value of having the new technology, while these are not important for early adopters. The total costs of investment are important for both early and later adopters. The compatibility of the system with the current situation becomes less important over time. Therefore, this is less important for later adopters compared to early adopters (Linderoth, 2010; Papadonikolaki & Wamelink, 2017; Waarts, van Everdingen, & van Hillegersberg, 2002). What is important to note here is that this literature focusses on ICT implementation in organizations in general. It is therefore not clear what the effects would be in engineering firms. Moreover, only part of the literature focusses specifically on BIM.

2.8.2 BIM implementation frameworks

Only one study was found regarding BIM implementation frameworks for an intra-organizational context. Hochscheid & Halin (2019) studied the implementation of BIM within firms. They suggest a four phase BIM implementation plan for the organizational level. First of all, in the diagnosis phase, observations have to be done and presented in an understandable way. Secondly, in the planning phase, a planning is made and BIM tools, collaboration tools and the type of training is selected. Next, the execution phase includes the preparation of BIM implementation by purchasing materials and developing internal standards and a test on BIM use in a chosen pilot project. Lastly, the anchoring phase consists of stabilization by using BIM on other projects and developing an incentive policy to keep trained staff and develop new processes. The framework was developed based on case studies of BIM implementation in design firms and change management literature. Finally, the study suggests five different components that are relevant for the interactions during intra-firm BIM implementation: technology, individual skills/roles, structure, management processes and strategy.

2.8.3 Overcoming barriers

Regarding literature on overcoming barriers, three interesting studies were found. The study of Kekana, Aigbavboa, & Thwala (2015) investigated barriers to BIM and how to overcome these barriers in the African construction industry by the use of a survey. The barriers that were found to be most important in hindering full implementation of BIM are a lack of skills, education and knowledge of BIM. These were also found studies that were performed in other countries as described in 0. In order to find ways of overcoming barriers, possible ways were presented in the survey and respondents were asked to rate the usefulness of each way. Educational and skill development initiatives were rated highest. Moreover, increasing the availability of BIM technology to all organisations and establishing feasible ways of moving away from common practice into using BIM on all construction projects were also rated high. These were followed by creating awareness of BIM benefits among all stakeholders and undertaking pilot projects to validate and demonstrate BIM outcomes.

Similarly, the study of Olawumi, Chan, Wong, & Chan (2018) focussed on overcoming barriers experienced in construction projects. Moreover, this study found that the major barriers relate to education and knowledge. However, this study also indicated attitude and market, and organization and project related issues as major barriers. According to a two-round Delphi survey based on 38 barriers it was found that barriers related to education and knowledge could be overcome by increasing the capacity of employees on developments in the industry and by creating opportunities for skill and capacity development programs where actors can learn and share experiences. Secondly, the barriers related to attitude and market can be overcome by positively embracing changes and developments and by proactively adopting BIM principles and projects. Organizational and project related issues could be overcome by government subsidies for technology investment in construction firms. Moreover, organizations and project teams should develop effective strategies for the implementation of BIM.

Ibrahim (2006) studied specifically how BIM barriers should be overcome in large design firms. The major obstacles hindering BIM implementation were found to be project management and training related. Regarding project management the barriers can be overcome by clarifying the added value, overcoming bad experience memories and explaining the full potential. Moreover, dealing with multi-disciplined design environments, clarifying the benefits, choosing the right time to start and risk management should all be considered by project management for proper implementation of BIM. Secondly, regarding training, the mindset of conventional CAD users has to be changed, training should be aligned with levels of personnel and a training plan should be set up to give everyone the right amount of training. Unfortunately, this paper does not indicate on which countries the findings are based.

Concludingly, the workflow has to be changed in a suitable way for the new technology and differences between individuals have to be taken into account. In order to overcome the existing barriers and facilitate further implementation of BIM, several possibilities are presented in literature. These relate to education and skill development, factors considered by management and the availability of technology. Table 2.7 presents an overview of all interventions discussed in this section.

Table 2.7

Overview of possible interventions.

Input from	Study	Interventions	factors considered
Change management	(Gardner & Ash, 2003)	Create awareness of the dynamics of change between people, technology and change agents and between information systems and strategy	People, technology, change agents, information system, strategy
Change management	(Waarts et al., 2002)	Consider difference in reasons for implementation based on time of implementation	Perceived innovation characteristics, adopter characteristics, internal environment and external environment characteristics
Innovation diffusion	(Linderoth, 2010)	Convince actors of benefits, a broad vision and communicate solutions to problems relevant for all actors	Characteristics of potential adopters and characteristics of innovation
Intra-organizational networks	(Papadonikolaki & Wamelink, 2017)	Create internal motivation, define a clear BIM vision, create a horizontal organizational structure	Internal motivation, intra-firm structure, BIM vision, intra-firm BIM functions
Implementation framework	(Jung & Joo, 2011)	Use four step implementation guidelines based on diagnosis, planning, execution and anchoring	Technology, user skills/ roles, structure, management processes and strategy
Implementation framework	(Hochscheid & Halin, 2019)	Differentiate between project, organization and industry perspective	Property, relation, standards, utilization, BIM perspective and construction business functions
Overcoming barriers	(Kekana et al., 2015)	Educational and skill development, increasing the availability of BIM, change in common practice, creating awareness of benefits and pilot projects to demonstrate benefits	Several barriers as input
Overcoming barriers	(Ibrahim, 2006)	Adapt current workflow and trainings in favour of new technology	Project management and training
Overcoming barriers	(Olawumi et al., 2018)	Increasing capacity, learning and sharing experiences, skill development, proactively adopting BIM, subsidies and effective strategies	Education and knowledge, attitude and market, and organizational and project issues

2.9 Summary and implications

This literature framework presented several topics that are relevant for this thesis. First of all, the BIM definition used in this thesis was provided. Moreover, different assessment tools and maturity levels were discussed. Based on this part, a BIM maturity measurement tool was selected that was used to determine the BIM maturity level. More about this is described in Section 3.2, which describes the method in detail. Regarding BIM use in the Netherlands, the Dutch project stages were discussed and linked to BIM activities. The differences between intra- and inter-organizational BIM use was presented. The literature framework also partly answered sub-question 1.2 with regard to the most important actors for BIM implementation within organizations. Section 3.3 discusses this in more detail. On top of that, BIM barriers and enablers were discussed. The barriers served as a starting point for the interviews to find the barriers per actor. The enablers were used as input for the survey to find the utility for the Game theoretic model. More on this is discussed in Section 3.4. Finally, intra-organizational interventions are discussed based on the topics of change management and innovation diffusion, implementation frameworks and overcoming barriers. This information is used to design interventions as described in 3.5. Finally, Section 3.6 describes how game theory was applied.

3 Methodology

This chapter starts with an introduction. Section 3.2 elaborates on how the BIM maturity level was determined. Section 3.3 describes how significant actors were identified. Thirdly, Section 3.4 describes how the interviews were used to find the barriers and Section 3.5 elaborates on the design of interventions. Finally, Section 3.6 explains game theory and Section 3.7 elaborates on how the utility was found.

3.1 Introduction

This study uses several methods in order to find out how the barriers to BIM can be overcome in large engineering companies. Figure 3.1 provides an overview of the methods. The data was gathered within one department of a large engineering company in the Netherlands (Movares). Appendix A gives an introduction to the company.

By focussing on one department, in-depth insights and an enhanced understanding could be obtained. It was chosen to focus on the department of Integrated Design (ID) within a large engineering company, because this department focusses on buildings, whereas most other departments are involved in other types of projects (e.g. energy or infrastructure related projects). These departments have very different ways of working and different processes. Moreover, the department of ID is ahead of the other departments regarding the use of BIM. Two factors are important in this. First of all, the current BIM standards are more applicable to building projects compared to infrastructure projects. A good example of this is the availability of object libraries. Moreover, the manager of the department of ID is very progressive in the application of BIM. Because of these differences between different departments, it is not possible to find a single solution that is useful for every department. Therefore, it was decided to collect data only from the department of ID to provide suitable interventions for overcoming the barriers experienced regarding BIM in building projects. An elaboration on the department as well as an overview of the BIM process at the department can be found in Appendix A.

Methodology					
3.2 Survey	3.3 Literature review	3.4 Interviews	3.5 Literature review and interviews	3.6 Game theory	3.7 Survey
BIM maturity level	Important actors for BIM implementation in engineering firms	Barriers experienced by different actors and suggested measures Game tree validation	Designing possible interventions	Relevance, game elements and designing games	Estimation of players preferences and utility as input for game theory model

Figure 3.1. Overview of the methodological components.

3.2 Survey: Current BIM maturity level

A multiple-choice survey was used to define the current level of BIM maturity at the department of ID and to answer sub-question 1.1. A survey is a common used method to determine the BIM maturity level (e.g. Fischer, 2013). This current level is relevant, since it shows what is already known, done and present at this department regarding the implementation of BIM. For this study the BIM maturity definition of Succar (2010, p. 5) was used as presented in Section 2.2.1.

3.2.1 Participants

The survey was distributed among all employees of the department of ID. This includes people with many different roles and functions. Out of 68 employees, 35 participated. Outsourced employees that were employed by the department were not taken into account in this study, since they do not have any knowledge of the BIM process at the department.

3.2.2 Materials

An online multiple-choice survey was distributed using Google forms. A Dutch survey was used, since the company operates in Dutch. An English version of the survey can be found in Appendix B. The survey consisted of seven sections: a general section, a section on strategy, organizational structure, people and culture, BIM processes, ICT (infrastructure) and data (structure).

An existing study was used to base the questions on, and as a reference for the BIM maturity levels. Although many studies exist that present a framework for BIM implementation assessment, as was discussed in 2.2.1 , the framework of Siebelink (2017) was found to be most suitable. The BIM maturity levels of this study were chosen as a baseline based on three criteria. First of all, since Movares is an engineering firm located in the Netherlands and BIM maturity levels differ per country as described in Section 2.2.2, a Dutch study was chosen. Moreover, the study needed to allow for analysis on organisational level and needed to be suitable for engineering firms. Many existing measures fail to recognize and measure BIM maturity on different organizational scales and it is important for those metrics to be accurate for specific sectors (Liang, Lu, Rowlinson, & Zhang, 2016; Succar, 2010). Secondly, literature indicates that BIM is not only about technology or the business process, but the human aspect is at least as important (Deutsch, 2011; Liu, Nederveen, & Hertogh, 2017). Therefore, a model was chosen that also incorporates this component. Thirdly, most studies do not report on how they obtained the criteria for the different levels (Liang et al., 2016). The study used, consists of three parts. In each of those studies, the categories and sub-categories and the criteria for the different levels in the matrix were revised. The most recent matrix is used in this study. Figure 3.2 shows which categories and sub-categories are included in this BIM maturity model. The BIM maturity levels are defined below. Moreover, a translation of the BIM maturity matrix proposed by Siebelink (2017) can be found in Appendix B.1.

3.2.2.1 Maturity levels

The model provides six BIM maturity levels: Level 0 – Not present, Level 1 – Initial, Level 2 – Managed, Level 3 – Defined, Level 4 – Quantitatively managed and Level 5 – Optimised (Siebelink, 2017). The characteristics of the different levels are shown in Table 3.1.

Table 3.1

Overview of BIM maturity levels.

Characteristics	Level 0 – Not present	Level 1 – Initial	Level 2 – Managed	Level 3 – Defined	Level 4 – Quantitatively managed	Level 5 - Optimised
Defined BIM processes, goals and strategies	None	None or limited and lack of defined good practices.	Project based and goals are defined for basic external processes.	BIM goals based on strategy, clear overview of performance and progress, and application of good practices.	Quality programmes to verify progress and results of BIM projects, measurable goals.	Continuous improvement of processes.
Organisational structure	Not supporting BIM	Not supporting BIM.	Insufficiently aligned with BIM goals.	Focussed on collaboration.	Trust in BIM and BIM to strengthen competitive position.	Openness and transparency to promote intensive BIM based collaboration.
BIM collaboration	None	Cooperation is not aligned with other parties.	Importance is seen.	Achieve and coordinate common goals.	Part of the strategy.	Intensive collaboration, mutual trust and financial dependency.
Success of BIM projects		Unpredictable and depending on capabilities and competences of project team.	BIM processes are limitedly followed, adjusted and evaluated.	Trust in, and motivation for common BIM goals.	BIM processes are objectively mastered and satisfaction of project partners.	Insight in and exchange of performance metrics to foresee problems.

3.2.3 Procedure

The multiple-choice survey was sent out to all employees of the department of ID by the researcher and participants had two weeks to complete the survey. After one week a reminder was sent by the researcher. Moreover, the invitation and a link to the online survey were two times included in the weekly, online newsletter of the department.

The survey consists of seven sections. The first section included six questions regarding personal characteristics. The next six sections were based on the categories of the existing BIM maturity model. Questions were created based on the sub-categories of the BIM maturity model. Every question had six answer options that were based on the descriptions of the maturity levels of each sub-category. In case that level descriptions were very elaborate, multiple questions were created for that subcategory. This was only applicable for the category strategy.

The second section covered the strategy, which represented the vision and goals for BIM, how these were supported by management and how the implementation of BIM was supported by experts and BIM-teams. One question was present for the first subcategory. For the final two sub-categories, two questions were asked for each sub-category. The remainder five section covered the sub-categories as shown in Figure 3.2. One question was present for each sub-category. Finally, at the end of the survey, participants could leave a comment.

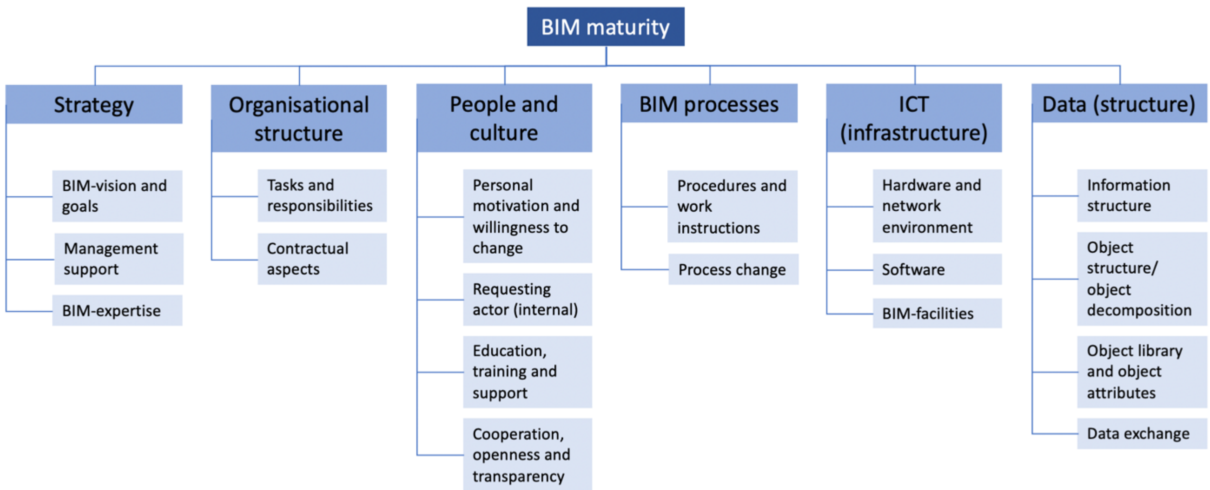

Figure 3.2. (Sub-)Categories relevant to measure the BIM maturity level (Siebelink, 2017)

The results were analysed. First, results were checked on irregularities. One participant answered with the option ‘I don’t know’ to all questions in the six sections relevant for the maturity level. Based on a comment it became clear that this participant was outsourced by the department. This case was therefore left out of the results. None of the other cases showed irregularities, so all other cases were taken into account during analysis.

Results were qualitatively analysed both on departmental level as well as per discipline. For the latter six categories, for each question a score between zero and five could be obtained. This corresponds with the BIM maturity level, where zero indicates the lowest level and five the highest. The BIM maturity level was first defined for each subcategory and these scores were used to calculate the score for each category by giving each subcategory equal weight.

3.3 Identifying important actors

3.3.1 Materials

In order to identify the most important actors for BIM implementation in engineering firms, a literature review was conducted as presented in Section 2.5. Both relevant BIM actors within engineering firms as well as intra-organizational actors in general were considered.

3.3.2 Procedure

Since literature described important actor groups for BIM implementation, the actor groups were specified to a role at the department. This was done with the help of a project leader and a BIM specialist.

3.4 Interviews: Barriers, suggestions for interventions and game tree validation

Semi-structured interviews were conducted with three main objectives. First of all, the interviews were used to find the barriers experienced by these actors. Secondly, participants were asked to come up with possible measures for the barriers they described. Finally, these interviews were used to validate the game tree. Interviews were used to answer sub-question 1.3 and are appropriate in this part of the research since it includes 'how' and 'why' questions about events over which the researcher has no control (Linderoth, 2010). For each actor group at least three interviews were conducted. This was done to gain more insight in which barriers are experienced by the different actor groups, how those could possibly be solved and to understand the BIM process.

3.4.1 Participants

In total, ten people from the department of ID participated in the interviews. Three project leaders, three BIM coordinators and one person from every discipline, including an architect, building engineer, structural engineer and MEP engineer. Participants were selected from the department based on their role. It needs to be noted here that roles are not clearly defined within the organisation and some people have multiple roles. This is especially applicable for the role of BIM coordinator. For this group BIM specialists were interviewed that perform tasks that a BIM coordinator could perform according to the BIR ("BIR Kenniskaart nr. 3: BIM-rollen en -competencies," 2015). Someone from the department was asked to recommend people in order to prevent having only people with a positive or negative opinion about BIM. The interview request was sent out by mail.

3.4.2 Materials

The interviews were conducted through Microsoft Teams. A mobile phone was used to record the interviews. The list of questions used for the interviews can be found in Appendix C.1.

3.4.3 Procedure

Semi-structured interviews were conducted to leave the possibility open to add questions during the interview if this was necessary to clarify things. Interview questions were based on the information that was needed for the remainder of this research. The interviews were conducted within a time frame of two weeks. All interviews were conducted in Dutch by the researcher. Each interview started with a short introduction of the research. Thereafter, the participants were asked for permission to record the interview and the informed consent form was discussed. This form was sent to the interviewee by e-mail after the interview took place.

The interview consisted of four sections. A general section about participant characteristics, a section about the barriers, a section on measures to take away the barriers and a section to verify the game tree. Many people within the department had multiple roles. In case participants indicated to have multiple roles, they were asked to focus on the role for which they were approached for the interview for the remaining questions. Participants were also asked to their definition of BIM. In case the participants definition of BIM did not align with the definition used in this thesis, the participant was given this definition and asked to answer the remaining questions according to this definition. With regard to the barriers, each participant was first asked to the most recent BIM project he or she was involved in that included the preliminary design project stage or the definitive design project stage. With regard to this project, several questions were asked including which burdens or barriers were experienced related to BIM and how this influenced the project. Thereafter, it was asked whether the participant experienced any other barriers in other BIM projects and which barrier was most strongly present for them. In the measures part, the participant was asked how the barriers discussed in the previous part could be overcome. The participant was also asked about the level of organisation with the most influence in the BIM implementation process and how the current measures were experienced. Finally, the participant was asked what needed to be done in order to implement BIM properly. With regard to the verification of the process, the participant was asked whether the groups included in the process were a good representation of the involved actors in the BIM process. All interviews lasted between forty and sixty minutes.

Interviews were transcribed using oTranscribe. Transcribing was done by word. All interviews were anonymised. Participants were indicated with 'Pn'. Were n is representing the number of the interview. The interviewer is indicated with 'In'. After all interviews were conducted, the interviews were coded in Nvivo. Coding was done by the use of top and sub-nodes. Top nodes were based on the questions that were asked during the interviews. Sub-nodes were based on the answers that were given. The top- and sub-nodes that were used can be found in Appendix C.3. The main barriers for each actor group were identified based on the barriers that were mentioned by each participant from that actor group. Useful measures were identified based on the main barriers found per group and possible measures that were mentioned. Moreover, the game tree was updated based on participants comments.

3.5 Designing possible interventions

3.5.1 Materials

Based on the results presented in Section 4.3 on the most commonly experienced barriers by the different actor groups, the measures they suggested, and the literature review in Section 2.8, several interventions were selected. Literature about BIM and literature about the implementation of communication technologies in general was considered.

3.5.2 Procedure

Interventions were selected in three steps. First of all, the most prevalent barrier per actor group was chosen. Secondly, the measures that were suggested for this barrier during the interviews were compared on similarities between participants and finally, the interventions found in the interviews were complemented with findings from literature. Since little literature was available on interventions, the suggested measures were considered first.

3.6 Game theory: Effectiveness of interventions

3.6.1 Introduction to game theory

Game theory is used to analyse the effectiveness of interventions and answer sub-question 1.4. Game theory can be used to test different models of strategic behaviour (Bresnahan & Reiss, 1991). It includes mathematical models that can simulate rational decision making between two or more individuals who try to maximize their own benefit. However, the benefits for each player are influenced by the choices of the other player (Barough, Shoubi, & Skardi, 2012; Ho, Hsu, & Lin, 2011). In this context a game is a model of interaction that helps to understand how players choose their strategies. This can be either prescriptive, leading to a recommendation on how players should play, or descriptive, providing a prediction how players will play (Canetti & Rosen, 2009). In this study, the goal is to give a prediction.

Game theory is an appropriate approach for solving different problems in management processes and construction engineering (Kapliński & Tamošaitiene, 2010). Project managers need to motivate involved parties and employees to use BIM to obtain a more efficient and effective way of working. Moreover, project managers may need to negotiate with people in order to achieve their goals. Game theory can be used to analyse knowledge and strategies used in this process. Hence, it can help to understand how different actors involved in a process interact and contribute to success for teamwork projects (Bočková, Sláviková, & Gabrhel, 2015). According to the writers of the article, "it is in these negotiations that game theory can play an essential tool for project management" (Bočková, Sláviková, & Gabrhel, 2015, p. 712).

To clarify game theory, the prisoner's dilemma is used as an example. This example gives a good insight in the usefulness of game theory in collaboration. In this game two people, called players in game theory, are arrested because they are suspected of committing a crime. However, there is no evidence. They are imprisoned separately and not able to communicate with each other. Thereafter, an offer is made to both suspects. In case both of them do not confess, they both get a fine. In case one of them confesses, the one that confesses is free to go and the other suspect gets ten years. In case both of them confess, they both get five years of prison. What is interesting in this situation is what the best move is for a player: confess or not confess. Game theory can help to answer this question.

What this dilemma shows is that it would be best for both players if they would both not confess. However, each suspect only considers his own payoff and they are not able to communicate with each other. Consequently, it is best for both players to confess, since this is the best option regardless of what the other player chooses.

Table 3.2

Payoffs for players in the prisoner's dilemma.

	Player 1: Confesses	**Player 1: Not confess**
Player 2: Confesses	Player 1: 5 years Player 2: 5 years	Player 1: 10 years Player 2: 0 years
Player 2: Not confess	Player 1: 0 years Player 2: 10 years	Player 1: Fine Player 2: Fine

3.6.2 Relevance of game theory

Limited studies have combined BIM and game theory so far. Nevertheless, game theory can be very helpful in understanding the implementation of BIM. An example of a study that included both BIM and game theory is performed by Turk (2016). According to the paper, game theory is the proper theoretical tool to study factors that discourage or encourage the use of BIM. Game theory provides a good framework to study the implementation of BIM, since BIM behaves as a socio-technical system in that it changes business models, businesses, institutions, workplaces, education and careers. Moreover, it is also changed by the environment in which it operates (Turk, 2016). Game theory has been used in several papers in combination with Integrated Project Delivery (IPD) which is a similar technology as BIM (e.g. Teng et al., 2017). The goal of IPD is to increase team efficiencies and increase communication while working towards a common goal (Glick & Guggemos, 2009). Most of these studies focus on cooperative game theory in an inter-organizational context. Cooperative game theory is useful in determining fair profit or cost savings since it assumes collective payoffs and the formation of groups called coalitions. However, with regard to BIM in the intra-organizational context, non-cooperative game theory is also interesting since it assumes that people pursue their own interests instead of forming coalitions in the BIM process.

Game theory is relevant for this study since whether or not BIM is used in an effective way depends on multiple parties. Consequently, the decision to use BIM or not of one party is affecting the outcome for others, since the use of BIM is far more beneficial if it is used by all actors. The purpose of game theory in this study is to test the usefulness of different interventions to stimulate the use of BIM within the department of ID. Game theory provides a way to model scenarios with the different interventions and can therefore help to find the effectiveness of each intervention. This method saves time and investment costs in case an intervention is found not to be effective.

3.6.3 Game tree

Games in extensive form can be represented with a game tree (Peck, 2010). A game tree represents all positions in a game and all possible moves. However, there is no convention on how to draw a game tree (Glumac, Han, Schaefer, & van der Krabben, 2015). Figure 3.3 provides an example of a game tree drawn downwards, starting with the root on top. The tree consists of nodes and lines. The first node represents the current state of the game, while two successor nodes represent the possible moves of the decision maker. Lines connect the nodes. A node is called a decision node in case a player performs an action. An action can be determined either by nature, indicated by a circle, or by a player, indicated with a square. Triangles indicate terminal nodes, which are nodes without a successor. At these nodes, every player receives a payoff.

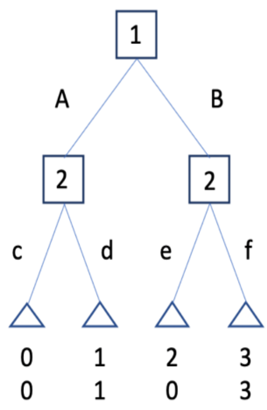

Figure 3.3. Example of a game tree.

3.6.4 Game elements: players, payoffs and strategies

A game theoretical model is an abstract representation of a real-life situation in which several basic assumptions are made. The main assumption is that decision-makers are rational. Moreover, it is assumed that they have perfect recall and reason strategically by taking into account their knowledge and expectations of another decision-makers behaviour. Within game theory, three main concepts are present: players, payoffs and strategies. A player, p, is a decision maker that is assumed to make decisions as a single decision body. The strategy (S_p) represents a plan of all possible actions (A_n) that a player might choose in any situation presented in the game. It is assumed that a player always aims for utility maximization. Although each player selects his own strategy, the payoff each player receives also depends on the strategy of other players. The set of strategies that results for each player is denoted as a strategy profile ($S_n = s_n,....,s_n$). In case that only two players are involved, a strategy profile is a pair of strategies with one strategy per player. The third element is the payoff. The payoff of a player is denoted as U_n ($s_n,...,s_n$). The payoff represents a number for each possible outcome and is based on the complete set of strategic actions by all players in the game. (Glumac et al., 2015).

The outcome of the game is defined as “the conjunction of chosen strategies and related payoffs” (Glumac et al., 2015, p. 68). The outcome is different from the payoff. The outcome is the decision that the players make collectively. The payoff is the value that each player receives for that outcome. Since different players have different valuation systems for the different outcomes, they have different preferences. Accordingly, conflicts can arise. When all game elements are known the outcome probabilities can be calculated.

3.6.4.1 Defining the game elements

Players were selected as described in Section 3.3. The payoffs need to be known in order to define the equilibriums. In this study the payoffs are expressed in utilities. The utility represents the subjective welfare. More specific, for this study it represents the increase in subjective welfare in case of different interventions. A survey is used to find the utilities. The payoffs can be used to estimate preferences and predictions of the game outcomes. By defining the payoffs, it can be deducted which strategy is chosen by different players. Hence it allows to understand which strategy profile is selected by each player.

Game theory allows for a prediction of the game. This is done by selecting one or more strategy profiles that reflect the most rational behaviour of players. The strategy profile that reflects the best strategy, if there is one, for every player in the game is called an equilibrium and indicated with $s^*=(s^*_1,...s^*_n)$. Equilibrium strategies are chosen by players in order to maximize their individual payoffs. To find these equilibriums, players most preferred strategies need to be known. The most preferred strategies can be defined with the help of solution concepts, these are rules that define an equilibrium based on the payoff functions and the possible strategy profiles. A solution concept is indicated with F: {S1,...Sn, U1,...Un} → s* (Glumac et al., 2015). This study uses the solution concept SPNE as described in Section 3.6.5.1.

3.6.5 Designing games for BIM implementation

Game theory originates from classical economic models which assume rational behaviour by individuals in interactive decision making. Classical game theory has three principal assumptions: strategic thinking of players, players optimise their strategy based on assumptions about other players' strategies, and all players adjust their decision until they are in equilibrium. It has been largely criticised for the assumption of complete rational decision making. Experimental game theory does not hold this assumption and emerged because of a need for empirical information about principles of strategic behavior. Experimental game theory includes, besides modelling the outcome of the game, experimental testing. This study is based on the latter type of game theory (Bonau, 2017; Glumac et al., 2015).

An experiment usually consists of three phases: a description of the game environment, assumptions underlying the game and an estimation of the preferences of players. A description of the game environment is given based on five steps, as proposed in Glumac and colleagues (2015). First of all, a game class is selected. This could be cooperative or non-cooperative and conflict or common interest. Secondly, a game form is selected by choosing either the strategic or extensive form. Thereafter, a game solution concept is selected. Fourthly, the institutional-economic context of the game is described and finally, the game conditions are designed within the game set environment. Finally, an estimation of players' preferences is made by using a survey to find the utilities. An elaboration of each step is given below.

3.6.5.1 Description of the game environment

Game class

First of all, the game class was selected. A game is cooperative when groups of players have already agreed to cooperate and aim for joint profits. A non-cooperative game is characterised by opposing interests of players. In this study, a non-cooperative game was chosen. Although a cooperative game may seem more realistic at first sight, since employees of the department are working together, a non-cooperative game better suits the current BIM process. In the BIM process of the department, different parties are involved with different levels of authority. Cooperative game theory assumes competition between groups of players due to the possibility of external enforcement and collective payoffs. However, there is not one party that has authority over all parties involved and that can enforce cooperation. Moreover, payoffs differ per player. This can be illustrated with the following example. In case the disciplines are under high time pressure and decide not to work according to BIM standards to finish the project in time, even if the client demands this and a BIM protocol is present, the client would send the final model back because it is not according to the agreement. In that case the model needs to be updated and this is often done by a BIM coordinator instead of someone from the disciplines. Hence, the disciplines do not receive any extra work and non-cooperative game theory better fits the situation in this study.

Another distinction is made between conflict and common interest in game theory. In conflict games the interests of several decision makers partly coincide or are completely opposed. In a conflict game, each player chooses an option in his own interest, which is not necessarily in line with other players' interests. In a common interest game, players have a common goal. Glumac and colleagues (2015) give the example of a traffic jam to explain a common interest game. Interactions could be seen as the pattern of a traffic jam resulting in an overall poor outcome that everyone wants to avoid. For the department of ID, a common interest game is most realistic compared to a conflict game. Every employee makes an effort in order to satisfy the client as well as possible. For example, if a project is under time pressure, the project team works extra hours and others help them in order to complete the project in time.

Game form

Secondly, the game form was chosen. The main difference between the strategic and extensive form is the moment of acting. In the strategic game, players act simultaneously, whereas in the extensive form, players act sequentially. In the extensive form players are aware of the moves of players that choose an action before them. An extensive form allows for multiple rounds of decisions with different payoffs (Myerson, 1991). The extensive form suits the current BIM process best, because different project parties depend on decisions made by players in previous time sequences. For example, only after it is clear to the project leader what the client wants, he or she starts forming the project team. Moreover, multiple phases are present between the order of the client and the delivery of the product and it is a very time-consuming process. This makes it unlikely that every party decides simultaneously whether to work according to BIM. Games in extensive form can be presented in a game tree.

Solution concept

In order to predict how a game will be played, a formal rule is used called solution concept. For non-cooperative game theory, this solution concept is the Nash equilibrium. In extensive games, the Nash equilibrium can be found by backward induction. In this case the Nash equilibrium is referred to as Sub game Perfect Nash Equilibrium (SPNE). A SPNE results from playing Nash Equilibria in every period of the game. The SPNE can be found by a backward induction process. This can be done in two ways. One way is based on the payoffs based on the utilities only. This is useful to find a SPNE in case of pure strategies. The second way is useful for mixed strategies. In the latter case the SPNE is based on the expected utilities. The expected utility can be found by multiplying the utility with the probability of an outcome. The optimal play for any player is to maximize the payoff for himself. This payoff is not depending on other players' payoff but is depending on actions of players later on. The SPNE can be found by starting at the end branches of the decision tree, in this case the bottom of the tree. Each player will choose the action with the highest payoff (Manea, 2016; Ratliff, 1997).

To illustrate the game tree, the example presented in Figure 3.3 is used. Player two can choose between a payoff of 0 and 1 in case player 1 chooses *a* and a payoff of 0 and 3 in case player 1 chooses *b*. Player 2 wants to maximize his payoff and therefore chooses actions *d* or *f*. Player 1 wants to maximize his own payoff based on the choice that player 1 is going to make and hence chooses action *b*. What has to be noted here, is that sometimes, multiple actions lead to the maximal payoff. In that case the action selected by backward induction is not unique. The procedure of backward induction results in a strategy profile by defining every action in a game tree and describing the strategy for every player. For extensive form games it is possible that the SPNE and the strategy profile obtained by backward induction are equivalent.

Institutional-economic context of the game

The BIM project process at the department has several phases. Projects can be performed according to BIM principles or in the traditional way (2D drawings). In case BIM principles are applied, it varies per project to what extent BIM standards are used. This depends on the wishes of the client, the experience of involved employees, the availability of a BIM coordinator and the time available. Depending on the type of project, several roles are fulfilled by different people. In smaller projects, one person usually has multiple roles. Other departments and external parties may also be involved. However, these are left out of the Game theoretic model, because this study focusses specifically on the BIM process at the department of ID.

The games presented in this thesis address issues in the BIM process with regard to collaboration. Since almost every project is different, the game model is generalized in order to be useful for projects with different characteristics. The decisions made by players influence the decisions made by other players, in this case whether BIM principles are applied and the extent to which they are applied. Finally, as mentioned before, this study only focusses on the Netherlands, since the BIM process differs per country. One of the differences is the level of governmental influence (Kivits & Furneaux, 2013).

Setting a game condition state

For the descriptive part of the game three relevant aspects were chosen. The aspects represent the change in the willingness to work according to BIM principles. The aspects were selected based on three criteria. First of all, the aspects needed to be proven BIM enablers. The literature study in 0 was used for this. Secondly, the aspects had to be relevant for all players. Finally, players needed to have insight in possible changes in these aspects under different circumstances.

The following aspects were selected:

- Design quality: the extent to which the quality of the 3D model and the information included in this model are influenced by different measures in different situations.
- Internal and external communication: the extent to which the communication within the department, within the organisation and with parties outside the organisation is influenced by different measures in different situations.
- Lead time: the extent to which the duration of the project is influenced by different measures in different situations.

3.6.5.2 Game assumptions

Perfect information is assumed. This means that it is assumed that all players are perfectly informed of all the events that have previously occurred when making a decision. This includes the information at the start of the game. Moreover, complete information is assumed. This requires all players to know the payoffs of all other players. Although, it may be difficult to estimate the exact payoffs for every individual colleague, people are able to make an estimation of the payoff per role. Moreover, it is assumed that information available to players is certain. This indicates that players know the payoff of playing a specific strategy when considering other players strategies. A non-zero-sum game is assumed since the total gain or loss in utility for all participants can be more or less than zero. Finally, a non-symmetric game is assumed, since strategy sets for players are not identical.

3.7 Estimation of players' preferences

The utilities for each end branch need to be known as input for the game theoretic model. A survey was used to estimate the utilities and preferences of participants. This method is useful to collect information on attitudes and behaviour (Pfleeger & Kitchenham, 2001). The survey consisted of questions to find the utility for each end branch of the game tree under different interventions. This was done by using the aspects presented in 3.6.5.1. For each aspect it was asked to what extent this aspect would improve under the presented measure for the given scenario. Each scenario represented a game outcome. The questionnaire presented four measures in total. These were based on the proposed interventions discussed in 4.4.

3.7.1 Participants

The survey was distributed among all employees of the department of ID. Out of 68 people, 24 completed the survey. Again, outsourced employees were not taken into account. Moreover, in order to find the utility of the client, the survey was also sent to several managers working for Movares outside of the department. These managers were selected based on their knowledge of the department and their awareness of the decision-making criteria of the client.

3.7.2 Materials

An online survey was used that was created in Google forms. The survey was distributed in Dutch, since the company operates in Dutch. Appendix D.1 includes an example of how the questions in the survey were presented. The survey consisted of five sections: a general section and one section for each proposed measure. Each question for the measures had to be answered for the three aspects on a scale from zero to ten. This scale was chosen to allow for more differentiation between the different scenarios and the different measures. A positive scale was chosen, since it was assumed that the chosen aspects would not lead to an impairment of the BIM process.

3.7.3 Procedure

The survey was sent out to all employees by the researcher and participants had three weeks to complete the survey. A reminder was sent twice. This was done seven and fourteen days after the initial invitation was sent. Moreover, the invitation and the link to the survey were included twice in the weekly online newsletter of the department. Participants in the role of client and BIM coordinator were also approached individually either by phone or e-mail, since a higher response rate was necessary for these groups.

The survey consisted of five sections. The first section included questions about general personal characteristics. Moreover, this section included a question about the importance of each of the three aspects with regard to the BIM process. The next four sections all presented a different measure. Each of these sections started with an introduction of the measure accompanied by a figure explaining it. Thereafter, fourteen scenarios were presented based on the game tree presented in Figure 4.3. One scenario was presented for each game outcome. An example of such a scenario is: client does not request BIM – project leader does not work according to BIM – project leader does not assign a BIM coordinator – no protocol is present – disciplines do not work according to BIM. It is asked to what extent each aspect would improve under the given scenario considering the presented measure.

Participants could rate each aspect on a scale from zero to ten, which represented no improvement, to ten, which represented a great improvement. This results in the same fourteen questions per measure, each consisting of three sub questions. An example can be found in Appendix D.1.

The analysis of the results started with checking for irregularities. Two cases were left out, since they indicated the exact same score for every situation. In order to calculate the utilities, several steps were taken. The utility consists of three aspects for each participant: the design quality, internal and external communication and lead time. Participants indicated the importance of each aspect. This indicated importance is used to distribute 100% over all three variables. This is done for each participant separately. Thereafter, the utility is calculated based on this importance for each participant separately for each end branch. After that, the average of the utilities of all participants were calculated for each player. This was done for each end branch of the game tree under each intervention. The formulas used for this can be found in Appendix D.2.

3.7.3.1 Testing interventions with game theory

Game theory is useful for predicting the effectiveness of the proposed interventions because it allows to compare players strategies under different circumstances. Several different interventions were compared in separate models. The analysis with game theory serves two goals. Firstly, it is used to find out what intervention(s) is most effective with regard to optimising the implementation of BIM. Secondly, it contributes to an understanding of the benefits of game theory in analysing collaboration through BIM.

The utilities were found by using the survey. These utilities together with the game tree can be used to find the outcome probabilities. The expected utilities can be calculated by using the utilities and the probabilities. These expected utilities need to be known to calculate the solution of the game. By using backward induction, the SPNE solution of the models can be found.

Usually, probabilities in a game theoretic model are calculated by putting an extensive game in strategic form. By doing this, the expected utilities can be set equal and if the utilities are known, the probabilities can be calculated. Although this method is most often used and rather simple in games of two players, it is complex to apply this method to games of four players (e.g. Manea, 2019; Ratliff, 1997). Therefore, a binominal probit model is used to calculate the probabilities as proposed by Glumac (2012). This latter study also combines this method with game theory. Although this model is proposed in combination with discrete choice modelling, it is also useful in the context of this study. Discrete choice modelling is based on the theory of choice behaviour, also called random utility theory. This theory assumes that any discrete choice model can be expressed by a utility value that consists of a systematic and a random component. Because there is a random component, utilities are inherently stochastic.

Based on the utilities, the probability that an individual will choose a certain alternative can be predicted. The choice probabilities (p_i) were calculated for outcomes (O_j) based on the utilities that were obtained with the survey. A binominal probit model has a random utility function where the error terms are independently and identically distributed according to the normal distribution. The normal distribution is a continuous probability distribution with a parameter for the expected value μ and standard deviation σ. In case μ = 0 and σ = 1^2, this is called the normal density function (Adan, Lefeber, Pogromsky, & Reniers, 2019; Glumac, 2012).

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}}\, e^{-(\frac{(x-\mu)}{2\sigma})^2}\ , (\mu = 0, \sigma = 1^2)$$

$$\emptyset(\eta_{AB}) = \frac{1}{\sqrt{2\pi}}\, e^{-\frac{1}{2}x^2}$$

The normal density function describes a function. The integral over this whole area is equal to one. The probabilities of the part-worth utilities can be calculated by the area that is created by the difference in utilities.

$$\mathrm{N}_{\mu,\sigma} = \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}x^2}\, dx = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} e^{-y^2}\, dy = 1$$

The probabilities can therefore be calculated based on the normal density function and the difference between part-worth utilities. For example, the probability p_{D1} for intervention *W* was calculated with the formula:

$$p_{D_1} = \int_{-\infty}^{U_D(O_1)\, -\, U_D\,(O_2)} \emptyset\,(\eta_{W1}) d\eta_{WD12}$$

In case a player has two possible actions, the part-worth probabilities of two outcomes together equal one. Therefore, the probability p_{D2} for intervention *W* was calculated with the formula:

$$p_{D_2} = 1 - p_{D_1}$$

If this is done for all part-worth probabilities, the outcome probabilities can be calculated by the following formula:

$$p_1 = p_{C_1} * p_{P_1} * p_{P'_1} * p_{B_1} * p_{D_1}$$

An overview of all formulas used can be found in Appendix E.

4 Results

The previous chapter describes the methods that were used in this study in order to find out how barriers to BIM within large engineering companies can be overcome. This chapter elaborates on the results. At the end of each section it is explained which implications were deducted from the results and how these have been used in the next step. Figure 4.1 gives an overview of the results. The results on the current BIM maturity level of the department are discussed in Section 4.1. The most important actors were found through a literature review as presented in Section 2.5 and specified with the help of two experts from the department. Section 4.2 describes these actors. Section 4.3 presents the barriers experienced by the three actors. The proposed interventions are presented in Section 4.4. Finally, the results on the effectiveness of these interventions is discussed in Section 4.5.

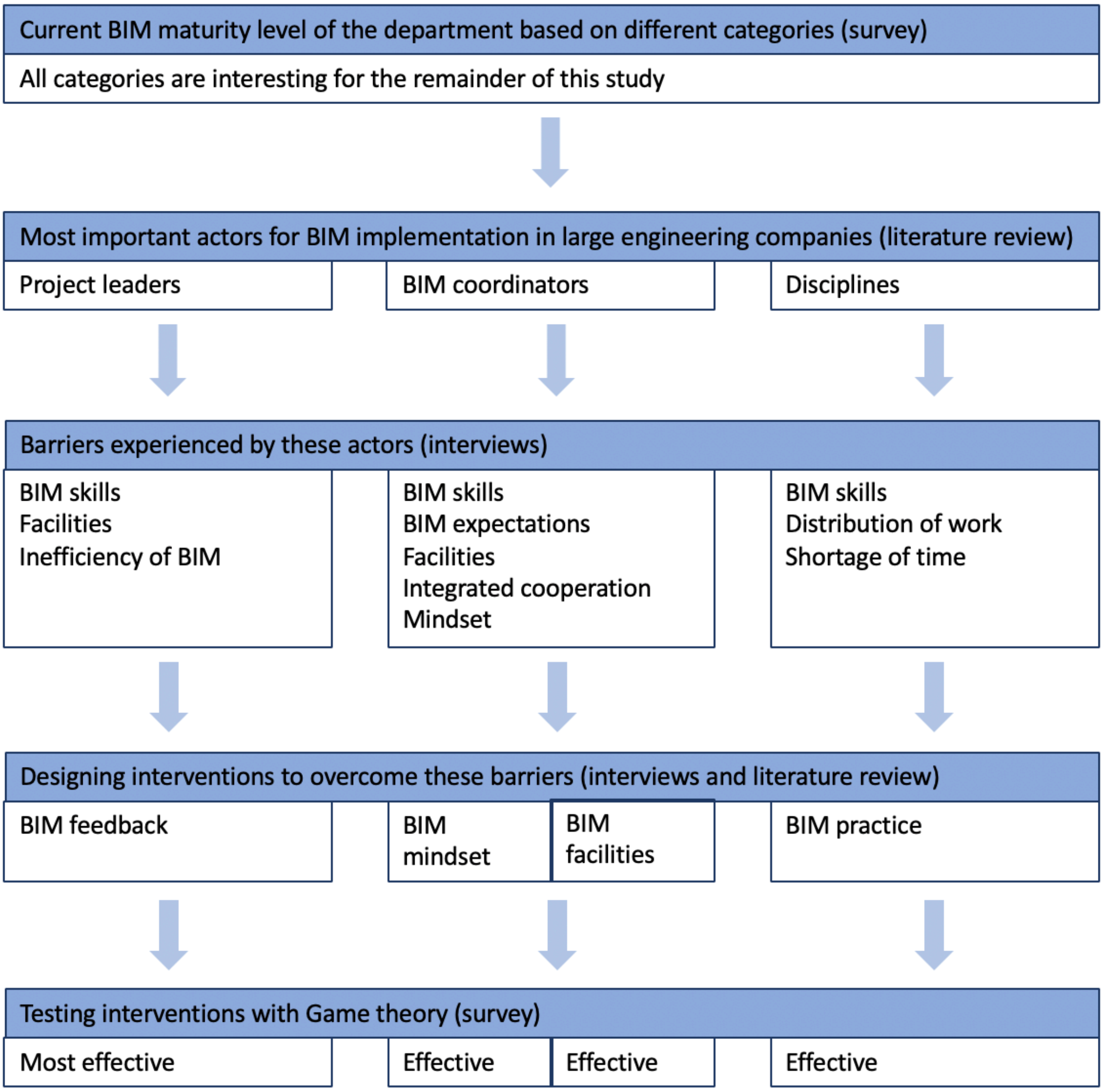

Figure 4.1. Overview of the results presented in this chapter.

4.1 Current BIM maturity level

Table 4.1 provides an overview of the types of respondents. Twelve percent of participants indicated a different role. These included management roles and roles that included tasks from all disciplines. The extent to which participants work with BIM differs as can be seen in Table 4.2. Moreover, BIM is mainly used in the design stages.

Table 4.1

Type of respondents.

Type of respondent	**Frequency**	**Percent**
Discipline of architecture	4	12%
Discipline of building engineering	6	18%
Discipline of structural engineering	11	32%
Discipline of MEP engineering	9	26%
Other	4	12%
Total	34	100%

Table 4.2

Extent to which participants work with BIM.

Extend of working with BIM	**Frequency**	**Percent**
Never	4	12%
Rarely	7	21%
Sometimes	7	21%
Regularly	8	24%
Often	8	24%
Project stages in which BIM is used	**Frequency**	**Percent**
Planning study	10	10%
Preliminary design	28	28%
Definitive design	28	28%
Scope statement/ Price and contract formation	21	21%
Construction ready design	13	13%
Other	1	1%

4.1.1 BIM maturity level of the department

The BIM maturity scores for the categories and sub-categories can be found in Table 4.3. The average score of the department of Integrated Design (ID) was found to be 2.2 on a scale from zero to five. Figure 4.2 presents an overview of the score ranges for the sub-categories per category. These are indicated by the line. The dotted line indicates the average of the category. As can be seen the scores mainly represent the level were BIM is managed, but not yet clearly defined. As can be seen in Table 4.3, the categories of *strategy* (2.5) and *people and culture* (2.3) score higher than this average, whereas the categories *BIM processes* (2.0), *data (structure)* (1.9) and *ICT (infrastructure)* (2.1) score lower. The subcategory *management support* scores highest of all sub-categories, while the subcategory *BIM-facilities* scores lowest. The subcategory management support was divided into two questions. One regarding budgets and one for propagation of the relevance of BIM. Interestingly, participants are more aware of management support with regard to propagation of the relevance where only six percent chose 'I don't know' compared to available budgets, where almost one fourth indicated that they do not know this. Participants agree most on the sub-category *process change*, where 61% indicated that BIM is a motive for process improvement but that traditional structures and habits slow down this transition. An elaboration on the meaning of these scores can be found in Appendix B.1.

Figure 4.2. Score ranges of the sub-categories for the BIM maturity level per category.

Interestingly the percentages of unknown are especially high for the category of organisational structure. For people and culture, these percentages are relatively low compared to the other categories. For the other categories the percentages of 'I don't know' answers differ per subcategory.

Scores were also calculated for participants that used BIM at least sometimes. All participants that indicated to never work with BIM or only rarely were thus left out. In total 23 participants indicated to work with BIM at least sometimes. None of the sub-scores deviate more than 0.1 from the scores that include all participants. However, the percentages of 'I don't know' answers are significantly lower.

Concludingly, the BIM maturity development of the department can best be described as managed. The subcategory management support scores highest, while the subcategory of BIM-facilities scores lowest. Overall, the category of data (structure) deviates most from the average over all categories.

Table 4.3

Average BIM maturity scores.

(Sub)Category	Average score for category	Score for subcategory	Percentage of answers 'I don't know'
Strategy: BIM-vision and goals	2.5	2.5	23.5%
Strategy: Management support	2.5	2.9	10.3%
Strategy: BIM-expertise	2.5	2.0	18.0%
Organisational structure: Tasks and responsibilities	2.2	2.2	23.5%
Organisational structure: Contractual aspects	2.2	2.1	20.6%
People and culture: Personal motivation and willingness to change	2.3	2.6	9.1%
People and culture: Requesting actor (internal)	2.3	2.4	14.7%
People and culture: Education, training and support	2.3	2.5	11.8%
People and culture: Cooperation, openness and transparency	2.3	1.7	11.8%
BIM processes: Procedures and work instructions	2.0	2.1	20.6%
BIM processes: Process change	2.0	1.9	11.8%
ICT (infrastructure): Hardware and network environment	2.1	2.4	14.7%
ICT (infrastructure): Software	2.1	2.6	20.6%
ICT (infrastructure): BIM-facilities	2.1	1.2	14.7%
Data (structure): Information structure	1.9	1.9	11.8%
Data (structure): Object structure/ object decomposition	1.9	1.8	26.5%
Data (structure): Object library and object attributes	1.9	2.0	29.4%
Data (structure): Data exchange	1.9	2.2	11.8%

4.1.2 BIM maturity level per discipline

Table 4.4 gives an overview of scores for each category per discipline. An elaboration on this table is given below. Important to note is that there are differences between the sample size per discipline as well as in the extent to which they work with BIM. Half of the four architects indicated to work with BIM regularly, whereas the other two indicated to rarely use it or even never use it. Half of the building engineers indicated to work often with BIM and all of them work at least rarely with BIM. For the structural engineers there is a large difference in the extent to which they work with BIM. Most of them indicated to work rarely (28%), sometimes (27%) or regularly (27%) with BIM. The MEP engineers also gave diverse answers. Most of them indicated to work with BIM rarely (34%). Sometimes and regularly were both chosen by two people. Finally, two of the people who did not fit in one of the four disciplines work often with BIM, one never works with BIM and one sometimes.

A comparison between the different disciplines on the maturity level showed that the building engineers score higher than average on every category. The architects, on the other hand, have a score below the average for each category. If the average scores of each discipline are compared with the overall average (2.2), the building engineers and MEP engineers score highest, the structural engineers score exactly the same and the architects and others score below the overall average. Table 4.4 gives the results for each discipline for each category.

Table 4.4

Average BIM maturity scores per discipline.

Discipline	Strategy	Organisational structure	People and culture	BIM processes	ICT (infrastructure)	Data (structure)	Average score over categories
Average maturity score per category	2.5	2.2	2.3	2.0	2.1	1.9	**2.2**
Architecture	1.9	2.3	1.6	1.4	2.0	1.5	**1.8**
Building engineers	2.6	2.4	2.6	2.2	2.3	2.1	**2.4**
Structural engineers	2.3	2.1	2.5	2.2	2.1	1.9	**2.2**
MEP engineers	3.0	2.0	2.5	2.3	2.0	2.0	**2.3**
Other	2.2	2.3	1.9	1.5	2.1	1.8	**2.0**

4.1.3 Summary and implications

All in all, the results show that BIM is managed within the department of ID, but not yet clearly defined. The categories of strategy, organizational structure, people and culture, and ICT (infrastructure) showed to be a bit more developed than level 2 – managed. The category of BIM processes is found to be exactly at level 2 – managed. However, the category of data (structure) is not yet completely on level 2 – managed. The average BIM maturity level fits best with Level 2 – Managed. A comparison between the different disciplines showed that the differences are relatively small. Interestingly, a study conducted in 2015 found a slightly lower BIM maturity level (Bokx, 2015).

The results indicate that the differences in BIM maturity for the different categories are small. Moreover, the differences between disciplines are also limited. Therefore, all categories and disciplines were taken into account in the remainder of this study. However, some interesting results were found for several sub-categories. For example, with regard to the percentage of 'I don't know' answers. Moreover, the results contribute to understanding which areas may need extra attention. These insights were used in order to optimise the interventions that are discussed in Section 4.4.

4.2 Significant actors in the BIM implementation process

Literature, as presented in Section 2.5, indicated three main groups of actors to consider: specific BIM actor roles, technical users and non-technical users. However, more specific actors were necessary as input for the Game theoretic model. Therefore, the three actor groups were further specified with the help of a BIM expert and a design leader from the department of ID. With regard to a BIM specific actor role it was decided that the BIM coordinator was most relevant for the department. With regard to non-technical users, the project leader was chosen, since this actor can decide whether or not to use BIM and needs to be able to work with the model. Finally, for the technical users it was decided to combine all disciplines which includes architects, building engineers, structural engineers and MEP engineers, since they create the model and add the initial data.

4.2.1 Summary and implications

The three actors that are most relevant for the BIM implementation process in the engineering firm of focus are project leaders, BIM coordinators and the disciplines: architecture, building, structural and MEP engineering. Hence, this study focusses on the barriers experienced by these actors.

4.3 Most common barrier per actor and suggested measures

Ten employees of the department of ID gave input on the barriers they experience with regard to BIM and possible measures that could help to lower these barriers. Moreover, verification of the game tree was done during the interviews. Three project leaders and three BIM coordinators were interviewed. From each of the four disciplines one person was interviewed. This section presents an introduction with general characteristics of the interviewees. Secondly, the barriers are discussed per role. Thereafter, the possible measures that were suggested are discussed. The verification of the game tree is presented in Section 4.5.1. Finally, a short summary of each interview can be found in Appendix C.2.

4.3.1 General characteristics

All participants gave definitions of BIM that are in line with the definition used in this thesis. Several participants also mentioned the importance of BIM in integrated cooperation.

With regard to the attitude towards BIM, all interviewees were very positive about BIM. Two of them stated specifically that BIM should only be applied in cases where it is beneficial. Some interviewees also mentioned that it is currently not yet living up to its full potential.

> *"I am very positive about it [BIM]. It is a very good development. However, what I do need to say, it needs to fulfil its purpose instead of blindly applying it to everything you are doing."* (P10, Discipline of architecture)

> *"Well, a lot of 3D modelling takes place, but I think that with information exchange, that more can be done with it."* (P1, Discipline of MEP engineering)

Interviewees were also asked to what extend they worked with BIM themselves. Interestingly, this differed quite strongly between people in different roles. The BIM coordinators indicated to work almost constantly with BIM. The disciplines indicated that this varies per project. Project leaders are not modelling anything themselves but do work with the BIM model.

> *"I do not work substantively with BIM, but I do work with it in the sense that I use BIM360 and that I use it to show the model to the client … and I also use it to make decisions with regard to the design."* (P3, Project leader)

Interviewees were also asked which organizational component was most important with regard to the implementation of BIM according to them. Interestingly, most participants indicated management here. Several interviewees also indicated that everyone is responsible for the implementation and one participant clearly stated that designers are the ones that clarify what is needed for further implementation and therefore are most important.

4.3.2 Most common barrier(s) per actor

This section describes the common barriers for the project leaders (0), BIM coordinators (0) and disciplines (0).

4.3.2.1 Project leaders

Three barriers were mentioned by all interviewed project leaders: *lack of facilities, lack of BIM skills* and *inefficiency of BIM.*

One of the participants described a combination of both the barrier related to *lack of facilities* and *lack of BIM skills.* This participant referred to the lack of BIM skills of the modeler.

> *"From the start of it [BIM] I am trying to get as much out of it as possible. But that mainly depends on the knowledge of the modeler and the systems that are used whether that is possible."* (P3, Project leader)

Another participant explained the barrier of *lack of facilities* by relating it to the barrier *mindset not in favour of BIM*.

> *"You need to be very driven in order to overcome the obstacles, to overcome the burden and familiarize yourself with things. And … in the heat of the moment we often do it the old-fashioned way because we know it and it is safer and easier. You know, it is also annoying when an external party is at the office, the facilities are present, but you do not always feel comfortable to open a model and to make a cross section like this and like this and to rotate it and then it disappears again, it makes you think. So, there are personal reasons why you sometimes not use it [the facilities]."* (P5, Project leader)

An example with regard to the *lack of BIM skills* in a more general way is provided by another project leader.

> *"I also experience the skills that you need to have for Revit but also related programs such as Dynamo and other programs, that is still a barrier, it [the skills] is present with us, but it could be much better, much broader."* (P9, Project leader)

Another example of the barrier *lack of BIM skills* is provided by the third participant.

> *"For me personally it [the strongest barrier] is the trust that everyone is well aware of what they should do. So, I need to have a lot of trust in the modeler …, because I am not able to judge it [BIM model] as well as a [2D] drawing that was used in the past."* (P5, Project leader)

The barrier *inefficiency of BIM* was discussed in several ways. First of all, not everyone is capable of working with 3D models, which results in a situation in which 2D drawings are still being used. This leads to extra work:

> *"The added value does not become clear because the client still prefers 2D … and with that a lot of time goes wasted to convert the product to 2D… and also not all modelers are able to work with it [BIM] so you do not get one model [part of it is done in 3D and part of it in 2D]."* (P5, Project leader)

Another *inefficiency of BIM* is caused by the *lack of (properly modelled) existing situations*. Especially in cases were existing constructions only have to be modified, BIM is very inefficient, since the existing situation has to be modelled first. Finally, an ideal BIM model can be used throughout all project stages. However, practice shows, that this is often not the case. Clients often ask for one project stage at a time and companies often do not know in advance whether the next project stage is going to be requested as well. Because a company does not know if it is worth to align the way of modelling with future project stages, they often do not invest the extra effort.

Other barriers that were mentioned by two out of three project leaders include: *increased dependence on integrated cooperation* and *organizational culture hindering BIM.*

The following barriers were all only mentioned by one of the project leaders: *false BIM expectations, lack of BIM knowledge and experience, uneven distribution of work, lack of BIM protocol, lack of clear roles with regard to BIM, lack of smart linkage between models* and *mindset not in favour of BIM.*

Concludingly, the project leaders agreed on three barriers: *lack of facilities, lack of BIM skills* and *inefficiency of BIM*. The barrier *lack of facilities* relates both to the barrier *lack of BIM skills* and to the barrier *shift in mindset.* The barrier *lack of BIM skills* refers both to a lack of drawing skills as well as a lack of skills to use the facilities. The barrier *inefficiency of BIM* refers to the lack of a modelled current situation and to the combination of 2D and 3D drawings.

4.3.2.2 BIM coordinators

Five barriers were mentioned by all BIM coordinators that participated in the interviews including *false BIM expectations, increased dependence on integrated cooperation, mindset not in favour of BIM, lack of BIM skills* and *lack of facilities.*

False BIM expectations are forming a barrier because people do not know what is expected from them in a BIM project. One of the BIM coordinators gives an example of this that also relates to the barrier *mindset not in favour of BIM*:

> *"Mainly managers [project leaders] often think, well with BIM, then I need to collaborate less, that is more efficient collaboration because you need to see each other less. But in my opinion, it is the other way around, things are just better arranged … and to align everything properly more is expected from collaboration and communication compared to a traditional project."* (P8, BIM coordinator)

Two examples of the barrier *increased dependence on integrated cooperation* are given below. The first one focusses on difficulties during collaboration, while the second one focusses on finding each other during the project in general. This latter barrier also relates to the barrier *lack of awareness of other disciplines*.

> *"And what also often happens, is that, someone, when one part in the process falters a little, then it is quite difficult to continue all together. … because you are undoubtedly depending on other parties. Even though it is within the organization."* (P2, BIM coordinator)

> *"As it is currently going, it is actually, it is like there are walls between the different departments and disciplines, and well, that doesn't work."* (P8, BIM coordinator)

One of the BIM coordinators described the barrier *mindset not in favour of BIM* as follows:

> *"People consider it as quite a challenge, they see it as something that is very complex. … Some of the modelers, especially the ones who have been around for many years, experience difficulty in switching [to BIM] and experience a burden in what is expected of them."* (P4, BIM coordinator)

Another barrier that was also described by all three BIM coordinators is *lack of BIM skills.* It was indicated that people do not have the necessary skills, but that they may also not have the capability to learn these skills.

> *"Not everyone can meet the [BIM] level that is for example necessary to become a good modeler…. Because I feel that a specific level of thinking is necessary in order to satisfy all demands that are placed on a modeler. And not everyone is able to do so."* (P2, BIM coordinator)

With regard to *lack of facilities*, version control, licenses and the availability of software and screens were mentioned. With regard to standards, both the lack of standards and the fact that standards are not used were brought up.

> *"In my opinion, actually, in every meeting a [digital] 3D model should be present. That is currently not possible, because we do not have screens everywhere. People do not use it either, but if they wanted to, it would not be possible."* (P4, BIM coordinator)

> *"Because we have only been busy with getting everyone to know the standards since a couple of months, which has been kind of a battle since people need to be willing to use them and that relates to naming, materialization, families, objects, coding, and everything, if someone does not know that it needs to be included [in the model] it does not happen. If someone does not think of it as important, it does not happen. If there is no coordinator who tells them to, it does not happen."* (P2, BIM coordinator)

Barriers that were mentioned by two out of three interviewed BIM coordinators are *lack of BIM knowledge and experience, inefficiency of BIM, organizational culture hindering BIM* and *shortage of time.* The barriers *lack of BIM knowledge and experience* and *shortage of time* are already explained above. The barrier *inefficiency of BIM* was brought up BIM coordinators regarding the presence of 2D, while BIM models require 3D modelling. Both clients and people within the firm keep asking for 2D drawings. This requires extra work when a project is modelled in 3D.

The following barriers were only mentioned by one BIM coordinator: *lack of awareness of other disciplines, information exchange with external* parties and *lack of clear roles with regard to BIM*.

All in all, BIM coordinators agree on five main barriers: *false BIM expectations, increased dependence on integrated cooperation, mindset not in favour of BIM, lack of BIM skills* and *lack of facilities.* As became clear from the examples given above, several barriers are interlinked.

4.3.2.3 Disciplines

Three barriers were mentioned by all four disciplines including *uneven distribution of work, shortage of time* and *lack of BIM skills.*

Interestingly, regarding the *lack of BIM skills*, two participants indicated specifically that this relates to the lack of BIM skills of people in projects, while the other two mentioned that BIM skills are lacking behind because of a lack of projects where these skills can be developed. An example of both is given below.

> *"You can only do it [work on BIM projects] when you have the right people together. If that is not the case, and usually it is like that, you can be willing to do it, but then it is best to acknowledge in advance that it is better not to aim too high because we cannot realize it."* (P6, Discipline of structural engineering)

> *"They [management] do not understand that it is part of a development process, that someone needs a year of continuous practice to acquire the skills. That year of continuous development is not the reality, there are peaks and troughs when drawing. You do not have a year. You are actually working too little with it. There are still few projects, for example for the department of MEP engineering, where we can work in BIM."* (P1, Discipline of MEP engineering)

One of the participants describes the barrier *shortage of time* in combination with a *lack of BIM skills*, since there is no time to develop skills.

> *"Maybe the largest [barrier] is the time pressure that we experience every time. ... In case you would take more time for it [a project], than it might be possible to take some more time for the model…. And maybe the step of transforming the first sketch to a 3D model should also be done by us [architects] in case we have the space and time to do so. So, I think time is probably the largest [barrier], being able to develop skills therein."* (P10, Discipline of architecture)

The barrier *uneven distribution of work* also relates to the barrier *shortage of time*.

> *"Another problem, but that holds for everything, is that very often things are time related. Very often there is too little time to do things properly. That is my presumption and then in hindsight you have to repair and then it will cost you double the time. Occasionally, too much is put on the plate of one person. Proper distribution of work is lacking."* (P1, Discipline of MEP engineering)

Both the *lack of a BIM protocol* and the *mindset not in favour of BIM* were mentioned as a barrier by three disciplines. The first one was not mentioned by the discipline of structural engineering and the latter one was not mentioned by MEP engineering. The quote below describes the barrier *mindset not in favour of BIM* in combination with the barrier *lack of BIM knowledge and experience.*

> *"The motivation and the knowledge level of people. I would prefer that everything works at once but that is a utopia. But the difference in the level of knowledge, that for some it is necessary to you very clearly explain how it works… The idea that everyone would just know how to work with BIM360, that would already be so nice but that is not the case."* (P7, Discipline of building engineering)

Several barriers were mentioned by two out of four participants. These included: *increased dependence on integrated cooperation, lack of facilities, inefficiency of BIM* and *information exchange with external parties.* Interestingly, these barriers were mentioned to a similar extent by the participants from the disciplines of building engineering, architecture and MEP engineering. None of these barriers was mentioned by the interviewee of the discipline structural engineering.

The following barriers were only mentioned by one of the participants: *accuracy of BIM is too high, lack of BIM knowledge and experience, lack of smart linkage between models* and *organizational culture hindering BIM.* Each of these barriers was mentioned by a different discipline consecutively the discipline of architecture, building engineering, structural engineering and MEP engineering.

Concludingly, the participants from the four different disciplines agreed on the barrier's *uneven distribution of work, shortage of time* and *lack of BIM skills.* Again, these barriers were in some cases related to other barriers. Slightly less barriers were mentioned by the discipline of structural engineering compared to the other disciplines.

4.3.3 Suggested measures

In order to overcome the barriers, several measures are suggested by participants. For each role the interventions are presented based on the most common barriers mentioned.

4.3.3.1 Project leaders

Three barriers were mentioned by all three project leaders: *lack of facilities, inefficiency of BIM* and *lack of BIM skills*. A solution to lower the barriers *inefficiency of BIM* and *lack of BIM skills* was proposed by all three project leaders. However, only two project leaders came up with a possible measure to lower the barrier *lack of facilities* barrier.

With regard to the barrier *lack of BIM skills*, training and practice are proposed, but also feedback needs to be given in order to continuously improve the development of BIM skills.

> *"Training alone does not work. You also have to put it into practice and maybe the people responsible for the BIM development should get back to it. Like, we proposed this, did anyone use it, what are the experiences, what could be improved. I think that this holds for all courses and activities. So, you have to educate, you need to use it and then you need to look back, like is it going alright now, or do we still need improvement."* (P3, Project leader)

Another project leader proposed to invest more in training and set more strict requirements to develop BIM skills. This should be started by management. In case people are not able to work according to this standard they should be helped and trained. Moreover, the project leader also indicated that training alone is not sufficient, and practice should be facilitated. Specifically, is proposed to link a modeler with a project leader in order to facilitate practice for project leaders by watching what the modeller is doing. The third project leader suggests creating a proper team of modellers with sufficient knowledge and independence. This should be done by hiring new people and training existing employees. Moreover, small improvement projects should be replaced by larger, integrated projects:

> *"I am an advocate of larger, integrated projects and less small improvement projects… That offers more opportunities to indeed improve your organizational processes and also include development of skills therein."* (P9, Project leader)

With regard to the barrier *inefficiency of BIM*, all participants proposed very different interventions. One of the project leaders experiences the inefficiency of BIM mainly in the lack of existing BIM models. In case improvement projects have to be done in BIM and no 3D model exists of the current situation yet, this participant proposed to hire a small, cheap firm. This firm can then create the existing situation in BIM in order to save time and costs. However, for this measure the department needs to be very clear about expectations. The second project leader relates the *inefficiency of BIM* to the lack of appreciation of a BIM model by the client.

> *"Then the 3D model needs to be recognized by the client as sufficient, like, rights to add it to the contract file. In that case the client thus needs to have sufficient knowledge to judge the model. Because otherwise he does not dare to do so [add it to the contract file]."* (P5, Project leader)

Finally, the third project leader suggested automation in order to overcome the barrier *inefficiency of BIM*. According to this participant, when things are automated, no attention has to be given to those parts anymore. This results in time savings.

Only two participants made a suggestion to overcome the barrier regarding *lack of facilities*. The first suggestion refers to a change in organizational culture in order to make sure that every has the appropriate programs and knows how to use them. The second project leader proposes a more transparent approach compared to the current situation.

> *"I think that they [people included in the BIM meetings] should delve into what is possible and whether that can be developed easily with the tools we currently have…. It would help if they would be transparent about it. Moreover, a couple of people could participate in the decision-making process, like maybe a couple of representatives from the project management group of advisors or maybe even someone from the structural engineers and the modelers themselves."* (P3, Project leader)

Concludingly, project leaders came up with several different interventions for different and similar barriers. Regarding the *lack of BIM skills*, they suggest training, practice, feedback and more pressure to use BIM. To lower the barrier *inefficiency of BIM* two suggestions are made with regard to external parties. With regard to the *lack of facilities* a transparent, inclusive decision-making process should be used to find BIM possibilities, developments and tools.

4.3.3.2 BIM coordinators

Five barriers were mentioned by all BIM coordinators: *false BIM expectations*, *increased dependence on integrated cooperation*, *mindset not in favour of BIM*, *lack of BIM skills* and *lack of facilities*. For none of these barriers a suggestion was given by all three BIM coordinators. For the barriers *false BIM expectations*, *mindset not in favour of BIM* and *lack of facilities* two participants proposed an intervention. Only one interviewee made a suggestion to overcome the other two barriers.

With regard to the barrier *false BIM expectations*, both BIM coordinators described the distribution of costs and benefits with the client. In order to give the client doable offers, a BIM coordinator should be asked how much time a project takes. Moreover, project managers and leaders should know the BIM terms and consequences of standards. One of the BIM coordinators also mentioned the lack of clear BIM roles as part of this barrier. However, someone within the department is already working on a matrix to clarify roles and responsibilities in BIM projects. According to the interviewee, this should lower this barrier.

Two BIM coordinators made a suggestion to lower the barrier *mindset not in favour of BIM*. Both acknowledged that this should come from both management and employees. One interviewee supports linking people with more BIM knowledge, to people with less knowledge in order to change their mindset. This participant added:

> *"In my opinion the necessity needs to come from management and should be supported by people in the workplace. So, starting from a project, that management demands to use BIM and you need this, and we will work in this way and if you require more information, you can go to him or her, and they can explain it to you. Like this. Because, currently, there is no obligation to use it."* (P2, BIM coordinator)

Another interviewee explained that BIM coordinators are able to change the mindset if they have time for this.

> *"People really want to come along [use BIM], but I can only do one thing at a time…. You really need to be included in a project to be able to use BIM and to get people along and that is the problem. We really need to be included in a project and then it is possible to get people to work according to new ideas."* (P4, BIM coordinator)

Regarding *lack of facilities* both BIM coordinators made a different suggestion. One of them suggested more screens and smart boards in meeting rooms and stimulating the use of these. The other participant made a suggestion that is applicable in a broader sense.

> *"Those IT barriers, well indirectly it is management, but we are missing a link. Currently, a lot of pioneering has to be done. The one buying the IT services is literally someone who just passes along forms and that is not someone who is aware of new developments or new features in new realizes… So, there should be a link between IT managers, the IT people who provide a decent structure and the wishes that exist in projects."* (P8, BIM coordinator)

One of the BIM coordinators combined both the barrier *lack of BIM skills* and *increased dependence on integrated cooperation* in one suggestion. According to this interviewee all employees need to be required to open the BIM model during a meeting and need training in order to know how to work with these kinds of tools. Moreover, training can also contribute to improved communication.

To summarize, according to BIM coordinators, both management and people from the workplace should be involved in the implementation of BIM. Proper communication should take place between them. Moreover, more time is needed for BIM coordinators in order to get others motivated to use BIM in projects.

4.3.3.3 Disciplines

The disciplines agreed on three barriers: *uneven distribution of work*, *shortage of time* and *lack of BIM skills*. Each participant made a suggestion to lower the barrier regarding the *lack of BIM skills*. For the shortage of time two interviewees made a suggestion and only one of them provided an intervention for the uneven distribution of work.

In order to develop BIM skills, more practice in projects is needed. The participants propose two ways for this. First of all, the department should work on more BIM projects. Secondly, longer running projects are favourable over shorter projects.

> *"Longer running projects, because than it [BIM use] will go without saying. I mean, we want to. We clearly see the positive aspects of BIM…but what happens is that every time there is high time pressure, planning completely filled, and then what happens is that you do it the old way because you really have to make that deadline."* (P1, Discipline of architecture)

In order to have more people who are able to work with BIM, both interviewees proposed to give training. Both participants indicate that it is also important to practice in projects.

> *"Allowing people to work in [BIM] projects. Even if is only to watch, just to get familiar with the programs and the alignment etc…. I have the feeling that mainly the people who can already do it [work with BIM] are included in [BIM] projects. In my opinion it would be good, even if it is just as a training and sitting next to someone like you are going to do it, I will help you. There is more potential."* (P7, Discipline of building engineering)

In order to lower the barrier *uneven distribution of work*, a proper overview should be made that clarifies when someone is working on a project and how important someone is for that project. If BIM projects are distributed over more and different employees this also contributes to the development of BIM skills.

> *"People should be included in projects, not necessarily that it puts extra pressure on projects, but like a training project, or fifty-fifty. A proper distribution should be found so people can get more experienced and get out of their own niche to take some work from others who are very busy."* (P7, Discipline of building engineering)

The barrier *shortage of time* relates to two other barriers. First of all, it relates to false BIM expectations. Often, the time needed for a project is not aligned with the ones who have to execute the project. This sometimes results in too little hours for what has to be done. In order to lower this barrier, the people making the offers should ask the different disciplines for input. Secondly, the barrier *shortage of time* relates to a *lack of BIM skills*. When projects are under high time pressure it is very difficult to develop new BIM skills.

> *"You need projects where you have sufficient time, because then you can experiment a little and there is time for trial and error. And once you are familiar with it [BIM], you can also apply it in projects under time pressure where everything has to be right at once."* (P6, Discipline of structural engineering)

In conclusion, all participants from the disciplines made a suggestion for the *lack of BIM skills*. In order to lower this barrier, more BIM projects and longer running projects should be done. Moreover, training and practice can help to increase BIM skills. Two or less interviewees made a suggestion for the other two barriers this group agreed on. For the *uneven distribution of work* a clear overview should be made to see when someone is working on a project and how important this person is for that project and people without BIM skills should be included to gain skills for future projects. Regarding the *shortage of time*, a more realistic estimate of the hours should be made for the offer.

4.3.4 Summary and implications

Many different barriers are indicated by participants. Similar barriers were found in literature. Table C.1 in Appendix C gives an overview of how the indicated barriers can be linked to barriers found in literature as presented in Section 2.6. Although barriers differ on individual level, several common barriers were found for the actor groups. These are presented in Table 4.5. The barrier *lack of BIM skills* was the only barrier mentioned by every interviewee. This indicates that this barrier is strongly present and should be considered when designing interventions. Since barriers differ per role, interventions should be designed for specific roles rather than in general.

Table 4.5

Overview of barriers for each group.

Project leaders	BIM coordinators	Disciplines (architecture, building engineering, structural engineering and MEP engineering)
Inefficiency of BIM Lack of BIM skills Lack of facilities	False BIM expectations Increased dependence on integrated cooperation **Lack of BIM skills** Lack of facilities Mindset not in favour of BIM	**Lack of BIM skills** Shortage of time Uneven distribution of work

Regarding the measures, participants came up with very specific interventions to overcome the barriers. Suggested measures differed per actor group. Table 4.6, Table 4.7 and Table 4.8 provide an overview of the suggested measures for each barrier per group. These suggestions are relevant for designing interventions to overcome the barriers. Finally, the interview results showed that the suggested measures are most similar to literature on overcoming barriers.

Table 4.6

Overview of suggested interventions per barrier by project leaders.

Most common barriers for project leaders	Suggested interventions
Inefficiency of BIM	• Use cheap firms to create existing situation. • Client needs to get sufficient knowledge to judge the model. • Automation.
Lack of BIM skills	• Training, practice and feedback to continuously develop BIM skills. • Training and setting more strict requirements to set the standard. • Training and hiring new employees.
Lack of facilities	• Facilitate appropriate programs and teach how to use them. • Inclusive decision-making process on BIM possibilities, developments and tools.

Table 4.7

Overview of suggested interventions for barriers by BIM coordinators.

Most common barriers for BIM coordinators	Suggested interventions
False BIM expectations	• BIM coordinator should be involved in cost/benefit distribution and project leader should know the BIM terms. • Clarification of roles in BIM projects (already in progress)
Increased dependence on integrated cooperation	• Open BIM model during meeting and training.
Lack of BIM skills	• Open BIM model during meeting and training.
Lack of facilities	• More screens and smartboards and stimulating the use of these. • Adding an extra role to link IT management and needs from BIM project team.
Mindset not in favour of BIM	• Linking people with more and less favourable attitude towards BIM. • Management needs to demand BIM.

Table 4.8

Overview of suggested interventions for barriers by disciplines.

Most common barriers for the disciplines	Suggested interventions
Lack of BIM skills	• More BIM projects. • Longer running projects. • Training and practice.
Shortage of time	• Make more realistic estimate of hours needed in offer. • Become familiar with BIM first, then apply it in projects under time pressure.
Uneven distribution of work	• Include people in projects to gain skills for future projects. • Overview to see when someone is working on a project and how important that person is for the project.

4.4 Proposed interventions

Interventions are based on the barriers and suggested measures presented in the previous section, and on the literature described in Section 2.8. The proposed interventions for each group are presented below.

4.4.1 Intervention based on barriers indicated by project leaders

Project leaders are responsible for proper execution of a project. They communicate expectations and working methods to others involved in the project. The project leader has therefore influence in how a project is executed. According to the project leaders, a lack of BIM skills, inefficiency of BIM and lack of facilities are the main barriers. It is chosen to focus on the barrier lack of BIM skills for several reasons. First of all, the barrier lack of BIM skills was mentioned by all project leaders and also by all BIM coordinators and interviewees from the disciplines. Secondly, the interventions proposed for the inefficiency of BIM all relate to external parties and are thus less related to the department. Finally, only two out of three project leaders proposed an intervention for the barrier lack of facilities, while all three proposed an intervention for the other two most common barriers. It must be noted here that the barrier lack of BIM skills relates both to the lack of BIM skills of project leaders themselves as well as to the lack of BIM skills of modellers.

4.4.1.1 BIM feedback system

Olawumi and colleagues (2018) propose interventions for the barriers lack of skills, education and knowledge of BIM. According to them, educational and skill development initiatives are best for facilitating BIM implementation and lowering the barriers followed by establishing feasible ways to move away from common practice. Currently, education is already provided, but it should be better aligned with the needs. Moreover, education is currently, not put into practice and this would contribute to the development of skills. Therefore, a BIM feedback system is proposed. BIM coordinators should continuously gather feedback on the training, experiences and progress in BIM skills. A variety of trainings and other possibilities to develop skills should be offered. The feedback should be shared with management in order to adapt the training and practice possibilities where necessary. Employees should actively participate in trainings and other activities and should provide feedback. Table 4.9 gives an overview of this intervention.

Table 4.9

Overview of proposed intervention 'BIM feedback system' for project leaders.

<table>
<tr><th>Responsible actor</th><th>Actions</th><th>Expected effect</th></tr>
<tr><td>Management</td><td>• Facilitate training and practice
• Allow for more tailored development</td><td rowspan="3">• Increased BIM skills
• BIM skills are continuously updated
• More efficient development since it is better aligned with people's needs</td></tr>
<tr><td>BIM coordinators</td><td>• Gather feedback on training, experiences and progress in BIM skills
• Share feedback with management who can change development setup</td></tr>
<tr><td>Everyone</td><td>• Participate in trainings, practice and share feedback</td></tr>
</table>

4.4.2 Intervention based on barriers indicated by BIM coordinators

BIM coordinators are responsible for BIM development and have very diverse tasks. BIM coordinators at the department usually also fulfil other roles. They give an advice on the use of BIM for projects, facilitate new developments and are involved in the implementation of applications and standards. According to the BIM coordinators the most common barriers are false BIM expectations, increased dependence on integrated cooperation, mindset not in favour of BIM, lack of BIM skills and lack of facilities. Two different interventions were designed. One for the barrier lack of facilities and one for the barrier mindset not in favour of BIM. These barriers were chosen for the following reasons. First of all, most interventions were proposed for the barriers false BIM expectations, mindset not in favour of BIM and lack of facilities. As described by BIM coordinators, false BIM expectations link to the mindset. Therefore, it is assumed that if the mindset is changed in favour of BIM, people also put more effort in understanding what is expected. Moreover, BIM coordinators are able to actively contribute to a change in mindset. They indicated that they are able to get people along with BIM when they are included in projects. However, currently they can only contribute to a small number of projects. Regarding the lack of facilities, this barrier is also interesting since the findings with regard to the current BIM maturity level showed that data structure and ICT infrastructure scored below average. The different aspects that were mentioned during the interviews as part of the barrier lack of facilities are included in these categories. On top of that, this barrier was also indicated by all project leaders.

4.4.2.1 Change in mindset in favour of BIM

According to Olawumi and colleagues (2018), barriers related to mindset can be overcome by positively embracing changes and developments. This can be done by proactively adopting BIM principles and projects. In this case, a shift in mindset is more likely. This should be facilitated by both management and employees. Management should more strongly insist on the use of BIM and support obtaining BIM projects. This allows more people to work with BIM. Moreover, it should be clear where people can find information regarding BIM and whom is responsible to answer questions. This lowers the threshold to experiment with BIM and therefore makes it easier to understand the benefits. People already in favour should proactively adopt BIM principles. Moreover, people who are supporting BIM should be linked with people who are not yet convinced. Table 4.10 gives a summary of this intervention.

Table 4.10

Overview of proposed intervention 'change in mindset' for BIM coordinators.

Responsible actor	Actions	Expected effect
Management	• More strongly insist on the use of BIM • Support obtaining BIM projects • Clarify where to go with questions	• Better understanding of benefits • Greater need to work with BIM • Easier to ask for help
People already in favour of BIM	• Proactively adopt BIM principles	
Everyone	• Linking people in favour of BIM to people who are not (yet) in favour of BIM • Proactively adopt BIM principles	

4.4.2.2 Linking wishes for BIM facilities to possibilities

The literature provided by Kekana and colleagues (2015) is used for this intervention. They state that the implementation of BIM can be facilitated by increasing the availability of BIM technology. It is proposed to change the current workflow in favour of BIM. In order to provide the right facilities an extra role at the department is proposed. The person in this role should understand the needs experienced in BIM projects. This person should have knowledge about which tools offer which possibilities in order to optimally serve the needs experienced in BIM projects. This knowledge can then be used to communicate what should be bought by the one responsible for buying new technology. Regarding the standards, it is important that especially project leaders, but also others are aware of the abbreviations and terms regarding BIM.

Table 4.11

Overview of proposed intervention 'wishes BIM facilities' for BIM coordinators.

<table>
<tr><th>Responsible actor</th><th>Actions</th><th>Expected effect</th></tr>
<tr><td>Management</td><td>• Create an extra role to link needs from BIM projects with possibilities of facilities</td><td rowspan="3">• It becomes easier to work according to BIM by having the right facilities
• More awareness of standards
• Increased availability of BIM technology</td></tr>
<tr><td>Project leaders</td><td>• Understand BIM standards</td></tr>
<tr><td>Everyone</td><td>• Understand BIM terms and abbreviations</td></tr>
</table>

4.4.3 Intervention based on the barriers indicated by the disciplines

According to the disciplines the most common barriers are the uneven distribution of work, shortage of time and lack of BIM skills. It is chosen to focus on a combination of these three because of the following reasons. First of all, the barriers are strongly interlinked as described by the interviewees. It is very difficult to gain BIM skills when there is a shortage of time, since learning takes extra time. Because only a few people have the necessary BIM skills for BIM projects and projects are often under time pressure, the people who already have BIM skills are usually deployed in a project. Secondly, all suggested measures are focussed on allowing to gain BIM skills. Finally, a lack of BIM skills was indicated by all other participants as well and is therefore interesting for the department as a whole.

4.4.3.1 Allowing for BIM practice time

Literature states that barriers related to education and knowledge can be overcome by increasing the capacity of employees and by creating opportunities for skill and capacity developments. Sharing experiences can also help to overcome this barrier (Olawumi et al., 2018). It is proposed to, besides the educational sessions that are already given, allow for practice. This can be done in several ways. First of all, this can be done by allowing people to watch along in another project. Secondly, this can be done by allowing more time in projects to experiment with BIM. This can be facilitated by making a more realistic estimate of the hours needed, by adopting more BIM projects or longer running (BIM) projects. Moreover, BIM projects should be better distributed in order to allow inexperienced people to work with BIM. However, this should not have a negative influence on the BIM skills of those who are already more experienced. Once people gained BIM skills, they can apply these skills under time pressure and help to relieve the workload of others who are already experienced with BIM. Management should therefore provide an option to spend time on BIM practice. An overview of this intervention is given in Table 4.12.

Table 4.12

Overview of proposed intervention 'BIM practice time' for disciplines.

Who is responsible	Which action	Expected effect
Management	• Allowing time for practice by giving people the opportunity to watch along in other projects • Providing more BIM projects and longer running projects • Allowing people with less BIM skills to develop BIM skills	• Increase of BIM skills • More people with BIM skills • More optimal distribution of work
Everyone	• Practice with BIM	

4.4.4 Summary and implications

This section presented four different interventions. The first intervention, *BIM feedback system* is aimed at overcoming the barrier lack of BIM skills which was indicated by all actors. The second intervention, *change in mindset in favour of BIM,* is based on the barrier mindset not in favour of BIM indicated by the BIM coordinators. Thirdly, the intervention *linking BIM wishes for facilities to possibilities* is based on the barrier lack of facilities that was found for both project leaders and BIM coordinators. Finally, the intervention *allowing for BIM practice time* is based on the combination of the barriers lack of BIM skills, uneven distribution of work and shortage of time indicated by the disciplines. These interventions are tested on their effectiveness in a game theoretic model. In the remainder of this thesis the interventions are referred to as *BIM feedback, BIM mindset, BIM facilities* and *BIM practice.*

4.5 Results experimental game theory

This section first elaborates on the game tree validation. The second sub-section describes the results regarding the interventions.

4.5.1 Game tree validation

Validation of the game tree was part of the interviews. The initial game tree was created in cooperation with a BIM expert and a project leader from the department and based on the current BIM process. During the interviews, the decision-making actors and their possible moves were discussed. Based on this, participants indicated whether or not the different choice options were possible and whether parties should be added or changed. Overall the initial structure of the game tree was confirmed. Two players were given a different name, since these names better covered the roles of those groups. The final game tree is presented in Figure 4.3.

Four players are included in the model: the client (C), the project leader (P), the BIM coordinator (B) and the disciplines (D): architecture, building, structural and MEP engineering. Firstly, the client decides whether or not the deliverables should be according to BIM standards. Although, the client is not present at the department, the client is important for the process at the department. Therefore, it was decided to include this external actor. Based on the choice of the client, the project leader decides whether he works according to BIM and whether he assigns a BIM coordinator. In case a BIM coordinator is assigned, this player can decide whether or not to provide a BIM protocol. Finally, the disciplines can decide whether to work according to BIM or not. Only when all disciplines are working according to BIM the line 'disciplines work according to BIM' is applicable. In every other case, the line 'disciplines do not work according to BIM' is applicable.

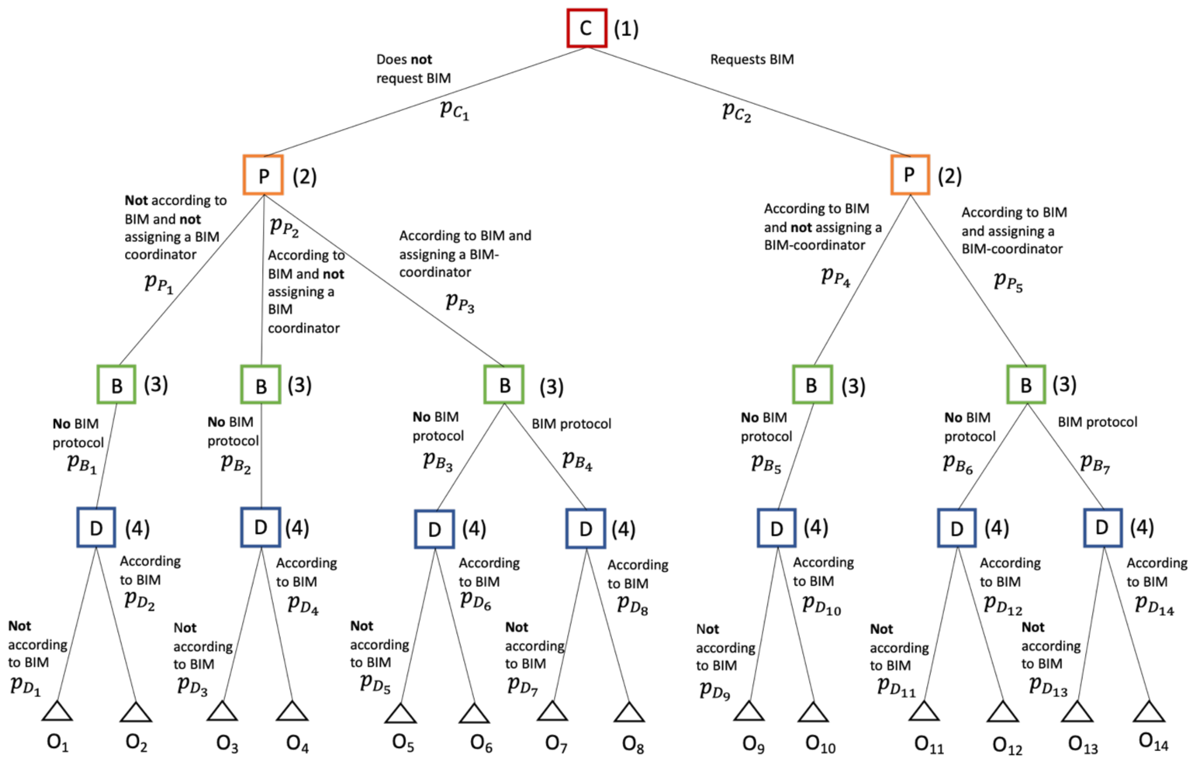

Figure 4.3. Validated game tree.

4.5.2 Effectiveness of interventions

This section presents the results with regard to the game theoretic model. Firstly, the results with regard to the survey are presented indicating the preferences of the different players. Secondly, the SPNE for each intervention is presented and finally, the outcome probabilities are discussed.

The distribution of participants among the different roles can be seen in Table 4.13. More than half of the participants worked at least regularly with BIM. Participants worked on average ten years for the company. Participants were also asked towards the importance of the three aspects on which the utility is based. Design quality was indicated to the most important aspect, followed by internal and external communication. Lead time was found to be least important for the utility as can be seen in Table 4.14. Finally, the average utility over all outcomes, as presented at the bottom row of Table 4.16, was compared for the different interventions. It was found that the interventions *BIM feedback* and *BIM practice* scored highest with an average increase in utility of consecutively 4.9 and 4.8. Participants indicated an increase in utility of 4.4 for the intervention *BIM mindset* and an increase of 4.1 in utility for the intervention *BIM facilities.* Because of the sample size, it is not possible to differentiate between actors.

Table 4.13

Type of respondents.

Type of respondent	Frequency	Percent
Client	**3**	**13.6%**
Project leader	**6**	**27.3%**
BIM coordinator	**3**	**13.6%**
Disciplines	**10**	**45.5%**
Building engineering	3	13.6%
Structural engineering	4	18.2%
MEP engineering	3	13.6%
Total	22	100%

Table 4.14

Importance of the aspects included in the utility.

Scoring aspects	Player	Importance
Design quality	C	9.3
	P	9.2
	B	9.0
	D	9.2
Average		**9.2**
Internal and external communication	C	8.7
	P	8.3
	B	9.0
	D	8.9
Average		**8.7**
Lead time	C	8.0
	P	8.0
	B	7.0
	D	8.2
Average		**7.8**

Table 4.15

The extent to which participants work with BIM.

Extent of working with BIM	Frequency	Percent
Never	4	18.2%
Rarely	3	13.6%
Sometimes	2	9.1%
Regularly	9	40.9%
Often	4	18.2%

As can be seen in Table 4.16, the SPNE for the interventions *BIM feedback*, *BIM mindset* and *BIM practice* results in outcome fourteen, whereby everyone is working according to BIM standards and principles. With regard to the intervention *BIM facilities*, the Sub game Perfect Nash Equilibrium (SPNE) leads to outcome eight where the client does not request BIM, but all other players do work according to BIM. Since this thesis focusses specifically on engineering firms, the strategies chosen by actors from the department are most interesting. When the client is left out, two sub games have to be considered. One subgame results from the scenario indicating that the client does not request BIM (subgame A) and one results from a scenario where the client does request BIM (subgame B). For the interventions *BIM feedback* and *BIM practice*, the choice of the client does not influence the strategies chosen by the other actors. Whether the client does or does not request BIM, the project leader, BIM coordinator and disciplines work according to BIM. However, for the interventions *BIM mindset* and *BIM facilities,* the clients' strategy does influence the strategies of the other actors. For the latter intervention the Nash equilibrium for subgame A can be presented as (According to BIM and assigning a BIM coordinator, BIM protocol, According to BIM) and for subgame B as (According to BIM and assigning a BIM coordinator, No BIM protocol, According to BIM) as can be seen in Figure 4.4. For the intervention *BIM mindset* the Nash equilibrium for subgame A can be written down as (According to BIM and assigning a BIM coordinator, No BIM protocol, According to BIM) and subgame B as (According to BIM and assigning a BIM coordinator, BIM protocol, According to BIM) as presented in Figure 4.5.

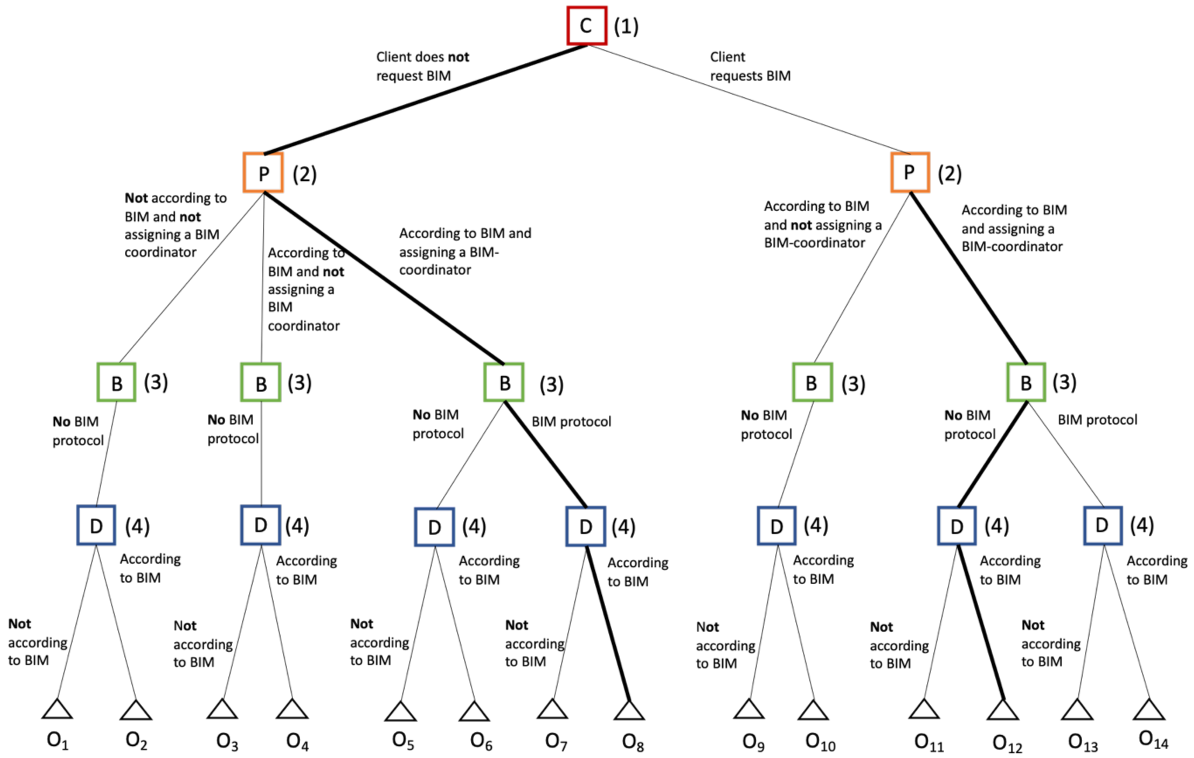

Figure 4.4. Strategies in subgame A and B for intervention BIM facilities.

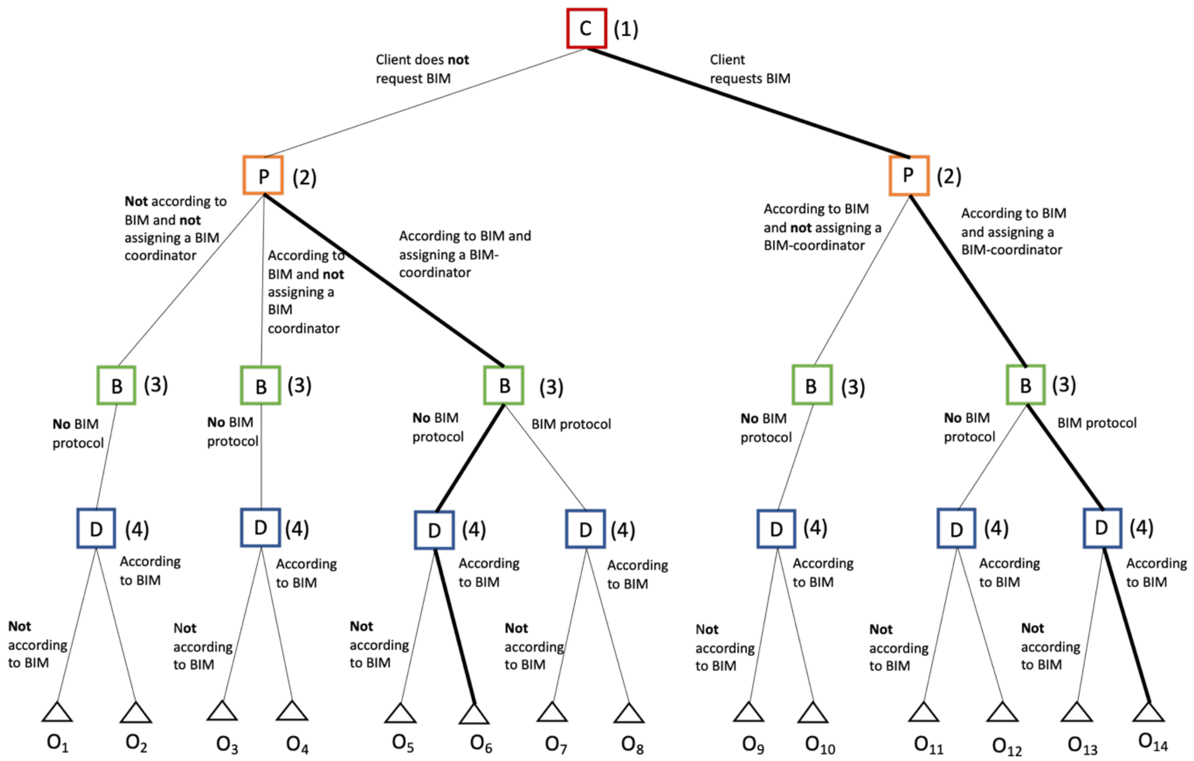

Figure 4.5. Strategies in subgame A and B for intervention BIM mindset.

Table 4.16. *Overview of utilities and SPNE.*

End branch	Player	Utility BIM feedback	SPNE	Utility BIM mindset	SPNE	Utility BIM facilities	SPNE	Utility BIM practice	SPNE
O_1	**C**	1.0		1.0		1.0		1.2	
	P	1.8		1.7		2.5		3.0	
	B	3.3		1.3		1.7		2.0	
	D	1.6		1.3		1.5		1.5	
O_2	**C**	5.2		3.4		3.5		3.7	
	P	4.1		3.5		3.5		4.0	
	B	4.4		4.0		3.4		5.4	
	D	3.0		2.9		2.7		3.2	
O_3	**C**	3.3		1.8		3.2		3.2	
	P	2.7		2.3		2.8		3.1	
	B	2.6		2.7		2.6		3.4	
	D	1.9		1.9		2.3		2.0	
O_4	**C**	5.7		4.1		3.8		3.6	
	P	4.9		4.9		4.7		4.9	
	B	6.0		4.6		4.3		6.4	
	D	4.0		3.8		3.7		4.2	
O_5	**C**	6.9		5.0		3.4		4.6	
	P	3.6		3.2		3.4		3.5	
	B	3.2		3.8		3.4		4.4	
	D	3.2		3.3		3.2		3.1	
O_6	**C**	6.9		5.9		3.4		4.4	
	P	5.9		5.4		5.2		6.0	
	B	7.6		5.4		4.8		7.5	
	D	5.8		6.4		6.1		5.9	
O_7	**C**	6.9		4.9		3.2		4.2	
	P	3.9		3.9		4.1		3.9	
	B	2.3		3.3		3.8		4.2	
	D	5.0		4.6		4.2		4.6	
O_8	**C**	7.8		6.7		4.6	X	5.9	
	P	7.5		6.8		6.1		7.0	
	B	7.9		5.2		5.2		8.0	
	D	7.8		7.6		7.5		7.6	
O_9	**C**	4.2		4.1		2.9		2.9	
	P	2.9		2.9		3.2		3.1	
	B	2.2		3.0		3.5		3.6	
	D	2.1		2.4		2.7		2.8	
O_{10}	**C**	5.7		5.0		3.8		4.7	
	P	4.4		4.9		4.6		4.9	
	B	5.5		5.2		4.9		6.8	
	D	4.1		4.6		4.7		4.6	
O_{11}	**C**	6.0		5.4		4.1		4.8	
	P	4.3		4.0		3.6		3.7	
	B	3.5		3.8		3.7		4.1	
	D	4.7		3.7		4.8		4.3	
O_{12}	**C**	6.9		6.0		4.5		6.2	
	P	6.0		5.4		5.1		5.9	
	B	7.2		5.6		5.8		7.4	
	D	7.3		7.3		7.5		7.3	
O_{13}	**C**	6.2		5.7		3.6		5.0	
	P	4.2		3.9		4.3		4.3	
	B	2.2		3.9		3.5		4.2	
	D	4.1		4.9		5.0		5.5	
O_{14}	**C**	8.2	X	7.5	X	5.3		7.0	X
	P	7.9		7.8		6.5		7.2	
	B	8.2		6.1		5.6		8.3	
	D	8.5		8.2		8.2		8.4	
Average utility		4.9		4.4		4.1		4.8	

Figure 4.6 shows the outcome probabilities. The outcome probabilities show that there are no major differences between the different interventions. Outcome fourteen represents the scenario with the highest payoff, where the client requests BIM and every actor from the department works according to BIM standards and principles. This outcome is most likely for all interventions, but the intervention *BIM feedback* is most likely to result in this outcome. For the interventions *BIM feedback, BIM* mindset and *BIM practice,* the SPNE and the highest outcome probability are found for the same game outcome.

Outcome eight is also interesting, since the department is mainly interested in the actors present at the department. Although it represents a scenario in which the client is not requesting BIM, every actor from the department works according to BIM. The intervention *BIM mindset* scores highest if both outcome eight and outcome fourteen are considered. As can be seen from Figure 4.6, the probabilities of outcome twelve are relevant as well. This outcome represents a scenario in which the client requests BIM, the project leader works according to BIM and assigns a BIM coordinator, the disciplines work according to BIM, however, no BIM protocol is present. All scenarios that include the disciplines not working according to BIM have a very low outcome probability, indicating that the disciplines most likely work according to BIM regardless of which of the four interventions is implemented.

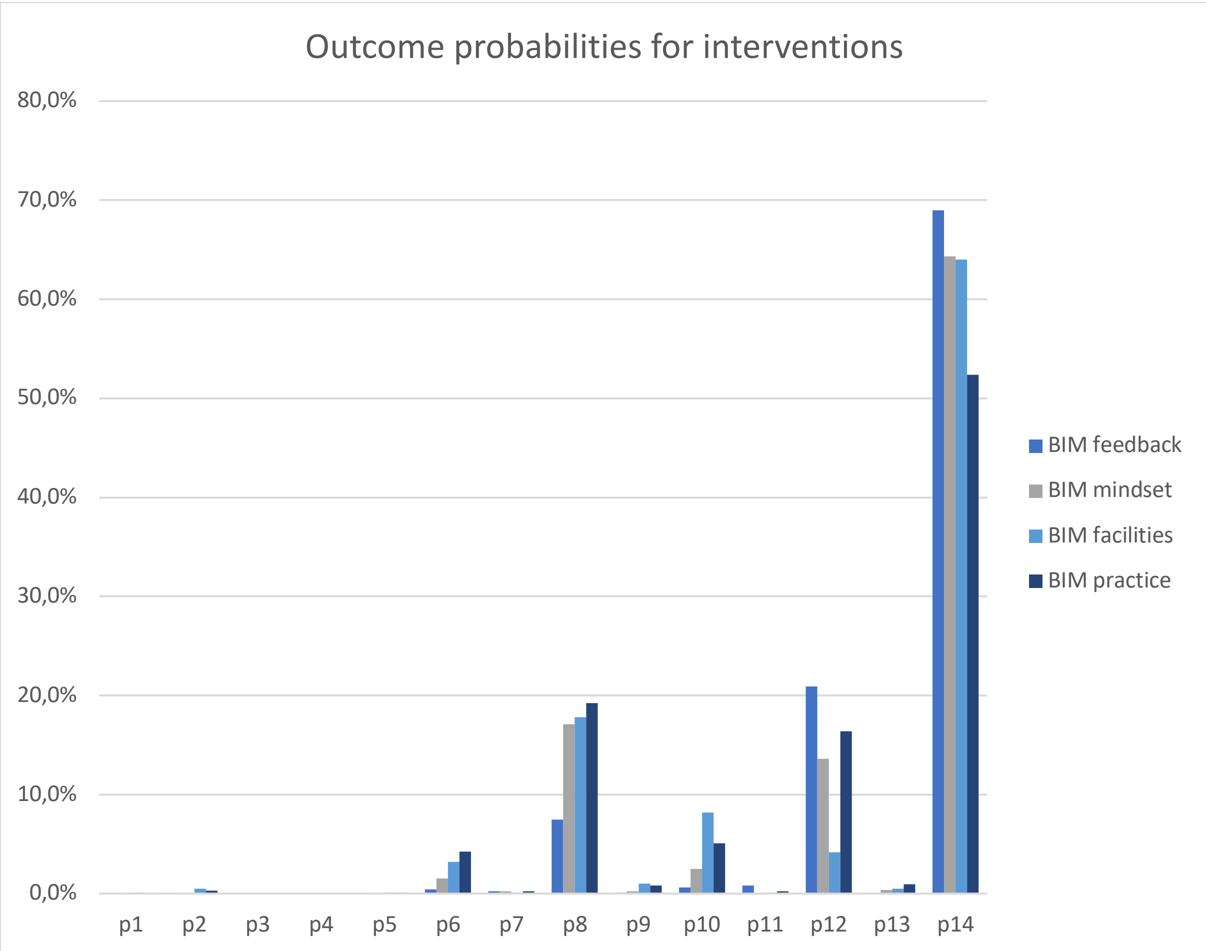

Figure 4.6. Outcome probabilities of the game theory model.

4.5.3 Summary

All in all, the interventions *BIM feedback* and *BIM practice* have the highest average utility. The solution concepts of the interventions *BIM feedback, BIM mindset* and *BIM practice* are equally favourable. Finally, the outcome probabilities indicate that all interventions are effective, but that the intervention *BIM feedback* is most likely to result in a scenario where both the client requests BIM and the department works according to BIM. The intervention *BIM feedback* is thus found to be most effective.

5 Discussion

This chapter elaborates on the validity and limitations of this study. Section 5.1 focusses on the BIM maturity level, Section 5.2 on significant actors and Section 5.3 on the barriers that were found. Section 5.4 elaborates on the design of interventions and Section 5.5 on the effectiveness of interventions and the use of game theory. Finally, Section 5.6 elaborates on the generalizability.

5.1 Current BIM maturity level of large engineering firms

The BIM maturity model from Siebelink (2017) was used to determine the BIM maturity level. This model came about by three studies in which the matrix was continuously improved, it has to be noted that the latest matrix dates from 2017. However, no model was found in literature with higher accuracy. Moreover, the model proved to be accurate for the Dutch construction industry on subsector level (Siebelink, 2017; Siebelink et al., 2015).

The BIM maturity level was determined specifically for the department of Integrated Design (ID). Siebelink (2017) determined the BIM maturity level of 32 engineering firms in 2016 and found an average level similar to the level that was found for the department by this study in 2020. It is expected that the average level of BIM maturity for engineering firms has increased over the past years. The department may therefore be behind on BIM implementation compared to other engineering firms. Another explanation is that the results were influenced by a lack of knowledge of participants. For example, in the subcategory contractual aspect, participants indicated that no guidelines and standards exist, while these are present at the department. The results showed that most respondents who answered with ‘I don’t know’ were either never working with BIM or rarely working with BIM. Awareness of BIM is thus significantly lower for people working rarely or never with BIM. Hence, they are less aware of the benefits and therefore less inclined to start working (more) with BIM.

Finally, this study is the first to report on the BIM maturity level per discipline within an organization. The disciplines architecture, building engineering, structural engineering and MEP engineering were included, and it was found that the difference in BIM maturity level is rather small. Interestingly, the MEP engineers scored above the average, whereas the interview results indicated that many struggles regarding integrated collaboration are caused by this discipline. This could be explained by the difference in sample size between the disciplines. Another explanation could be that participants indicated the desired BIM maturity level instead of the actual level. This might have been possible since the answer options were presented in the order of the different levels. However, it was emphasized that accurate results were in the interest of the department itself. Further research is necessary to understand how differences in the BIM maturity level of different disciplines influence the average BIM maturity level.

5.2 Significant actors for the intra-firm BIM implementation process

In order to understand the barriers per actor it was necessary to identify the actors that play a significant role in the BIM implementation process within engineering firms. Although many sources describe relevant actors for BIM, few specify actors on intra-organizational level. Although the importance of actors is based on selective literature, the literature available agreed on three actor groups that are relevant for BIM implementation within organizations. A project leader and a BIM specialist from an engineering firm identified actors at the department that are relevant for BIM implementation. These were in line with the groups found in literature on intra-organizational actors. Moreover, Fikkers and colleagues (2012) found similar actors for the implementation of BIM in Dutch engineering firms. The actor groups found in literature are thus useful to identify significant actors for BIM implementation in Dutch engineering firms. Since the actor roles depent on the size of an organization, it is possible that the number of actors and their tasks differ. More research is needed to understand how the size of an organization influences the number and tasks related to relevant BIM actor roles.

5.3 Barriers experienced in large engineering firms

This study is the first that links barriers experienced with regard to BIM to a BIM maturity level. Ten interviews were conducted with randomly chosen participants to find the barriers. The barriers that were found with interviews did not significantly differ from barriers found in literature (e.g. Bosdriesz, 2018; Siebelink, Adriaanse, & Voordijk, 2015). This indicates that the barriers do not depend on the BIM maturity level and that these barriers are most likely also experienced by other engineering companies. The interview results suggested that the barriers differ per actor. Although the barriers in general do not seem to depend on the BIM maturity level, actor specific barriers may depend on this level. Further research is necessary to clarify this.

Secondly, interviews indicated that barriers differ per actor role, as was also found by Graaff & Simons (2014) who analysed barriers for BIM users, project managers and decision makers. This study showed that, regarding BIM users, different barriers are experienced by BIM coordinators compared to the disciplines. Moreover, this study showed that barriers do not only differ per actor but also on individual level. This has to be considered when implementing interventions to stimulate BIM. Moreover, since barriers differ per role and the tasks of different disciplines differ, it would be interesting for future studies to analyze the differences in barriers for different disciplines.

A downside of interviews is that participants may experience barriers of which they are not aware. Hence, these cannot be found by using interviews. If this is the case, interviews are not a suitable way to find these barriers. For future studies it is advised to use interviews in combination with observations. Through observations it is possible to find barriers of which participants are unaware. This might also explain why some barriers found in literature on barriers experienced in engineering firms, where not found in this study. Kaner and colleagues (2008) studied the barriers by analysing recordings of building models and found four main barriers: lack of adequate interoperability between different BIM software tools, development of new workflows and standards, shortage of skilled BIM personnel and high initial investment. Sebastian (2011) observed two pilot projects in the Netherlands and found that the shift in mindset and the change in contractual relationships are a barrier. The barriers shortage of skilled BIM personnel and shift in mindset were also found as main barriers in this study. The barriers lack of adequate interoperability between software tools and the development of new workflows and standards were indicated during the interviews, but not found to be common barriers. Finally, the barriers high initial investment and a change in contractual relationships were not found in this study. These differences may be caused by the difference in method. However, another explanation is the fact that the latter two barriers are mainly related to management, an actor that was not considered to be significant for BIM implementation within Dutch engineering firms. Moreover, the difference in barriers compared to the study of Kaner and colleagues (2008) may be explained by the difference in focus. While this study focussed on barriers in building projects in general, Kaner and colleagues (2008 focussed specifically on the implementation of BIM for precast concrete design. Finally, the barriers found in this study are in line with other studies which used interviews to determine the barriers for large engineering firms (Bosdriesz, 2018; Siebelink et al., 2015).

5.4 Designing interventions

Since little literature is available about interventions to overcome barriers to BIM, literature on change management, innovation diffusion, intra-organizational networks and implementation frameworks was also considered in this study. However, the measures proposed by interviewees were most similar to the ones found in literature specifically about overcoming barriers to BIM (e.g. Kekana, Aigbavboa, & Thwala, 2015; Olawumi, Chan, Wong, & Chan, 2018). These measures are more specific and practical. This indicates that the implementation of BIM benefits most from more specific and practical interventions. Hence, it is very relevant to conduct studies specifically aimed at overcoming the barriers to BIM.

5.5 Interventions to overcome barriers

The effectiveness of interventions to overcome barriers was tested using game theory. Each intervention was found to be effective. It has to be noted that interventions were tested on their effectiveness in stimulating BIM in general. Each intervention is based on one barrier or a combination of two barriers and the effectiveness is compared based on the increase in utility. It is thus unclear to what extent interventions are effective in overcoming specific barriers. Further research is needed to understand how the interventions affect different barriers.

Secondly, it could be argued whether game theory is a proper method to analyse actor behaviour in the given context. Game theory is in general criticized for assuming players to be completely rational decision makers. Therefore, this study is based on experimental game theory. Experimental game theory includes experimental testing and therefore does not hold this assumption, since respondents' estimates are used to find the SPNE and the outcome probabilities. Experimental game theory also overcomes the criticism that game theory only presents one solution concept by providing an understanding of the strategies of players in different scenarios.

Moreover, for three out of four interventions the SPNE was found for the same game outcome as the most probable game outcome, indicating that players act rationally, and that backwards induction is a suitable method. For the intervention *BIM facilities,* the SPNE and the most probable game outcome were not found for the same game outcome. This may indicate that players do not behave exactly as would be expected under this intervention. However, the difference in utility with the SPNE outcome and the game outcome with the highest probability was very small.

An interesting finding was done with regard to the strategies chosen by players for the interventions *BIM mindset* and *BIM facilities.* In case the client does not request BIM after implementation of the intervention *BIM mindset*, the department would choose a strategy where everyone works according to BIM, but no BIM protocol is drawn up. Whereas this would be present if the client would request BIM. However, for the intervention *BIM facilities*, it is the other way around, hence the strategy profile indicates that no BIM protocol is drawn up in case the client does request BIM. This supports the finding that players do not act rationally for the intervention BIM facilities. This may indicate that the utilities do not precisely reflect the preferences, which may be due to the sample size. However, another explanation is that participants make different assumptions on whether the client provides the BIM protocol under the different interventions.

A survey was used to find the utilities. Although this is a suitable method, it was intended to host a focus group in order to gather the utilities. However, because of a pandemic this was not possible. Although a lot of effort was put into the questionnaire to make it as simple as possible, participants indicated that it was complicated and very extensive. This resulted in a sample size that included slightly less than half of the employees from the department. However, since some actor groups were only represented by three people at the department, and at least three people from each actor group participated, a higher response rate might have caused a bias because of the difference in sample size between the different groups. Moreover, only one inconsistency was found in the results, as described above, indicating that the results are at least mostly accurate. Although the utility could be estimated with a survey it is advised to host a focus group if possible, since this is less complicated for participants.

The results obtained with game theory indicated that each intervention is useful in order to stimulate BIM. Moreover, the differences in average increase in utility and outcome probabilities are relatively small. The SPNE was found for the same outcome for three out of four interventions. Although a different SPNE was found for the fourth intervention, the strategy only differed for the client and not for any of the actors from the department. This indicates that whether or not the client requests BIM does not influence the most preferred BIM process at the department. Moreover, this may indicate that the characteristics of a specific intervention do not matter, but rather, it is important to actively support BIM use. For future studies it is therefore advised to focus on how BIM use can best be supported to achieve long term benefits.

Each intervention was found to be effective in stimulating BIM. However, each intervention contributes to an increase in the BIM maturity level in a different way. The intervention BIM feedback is likely to result in an increase of the BIM maturity of the category people and culture. Indirectly, this intervention can also contribute to an increase of the BIM maturity level of the category BIM processes, since it increases the extent to which BIM has a driving role for change.

The intervention BIM mindset is likely to result in an increase in the BIM maturity for the category people and culture. It is expected that this increase is mainly noticeable for the sub-categories: personal motivation, willingness to change and requesting actor. Since this intervention also includes that management more strongly insists on the use of BIM it is necessary to clarify tasks and responsibilities. This contributes to an increase of BIM maturity for the category organizational structure.

The intervention BIM facilities aims at an increase of the BIM maturity level of the categories ICT (infrastructure) and data (structure). Both the needs regarding software and hardware, as well as needs with regard to object libraries and data exchange options can be better fulfilled when this intervention is implemented.

Finally, the intervention BIM practice aims at an increase in BIM maturity level of the category people and culture. People can develop competencies to execute BIM related tasks with this intervention. This influences their personal motivation. By being more skilled with BIM, people become more willing to work according to BIM. A long-term benefit of this is that BIM projects can be executed by more people contributing to an increase in the BIM maturity level of the category BIM processes. All interventions contribute to an increase in the BIM maturity level of the category strategy, since management support is crucial for proper implementation of each intervention.

Each intervention has effect on different BIM maturity categories. Because the survey, that was used to clarify the increase in utility for each intervention, was already very extensive, a combination of the interventions was not included in the survey. Future research into the effectiveness of a combination of interventions could clarify the effect of a combination of interventions.

Although game theory has downsides, it is a suitable way to analyse actor behaviour which has not yet been applied to study BIM in the intra-organizational context. By using game theory this study gave new insights in how actors involved in collaboration through BIM respond in different scenarios and how choices of one actor influence the choices of other actors. Moreover, it allows managers of engineering firms to understand the effectiveness of interventions before implementing them.

5.6 Generalizability

The generalizability of this study differs per part. First of all, the BIM maturity level that was found, is very specific for the engineering firm were data was collected. This is thus not generalizable to other engineering firms. Future research is necessary to clarify the extent to which the found BIM maturity level is similar to BIM maturity levels of other Dutch engineering firms. Since many different studies, including this study, report on the same barriers, it is unlikely that the barriers depend on the BIM maturity level. The barriers and interventions found in this study are thus also useful for engineering firms with other BIM maturity levels. However, for the firm of focus, all categories scored close to the average BIM maturity level.
It is advised that engineering companies always start with an analysis of the current BIM maturity level. In case one of the categories is far behind on the average BIM maturity level, this category should be taken as a basis to find related barriers and to choose a suitable intervention.

Movares originates from a governmental agency, whereas most other engineering firms have started as commercial companies. This is still observable in the company culture. Barriers may therefore differ. However, barriers found in this study are to a large extent similar to the ones found in other studies, which were conducted at other engineering firms. Since these studies were carried out at different firms and at different moments, it appears that barriers do not depend on the BIM maturity level of an engineering firm. Barriers in general are thus similar for other engineering firms. However, this study showed that barriers do differ per actor. Although the relevant actor groups found in this study have to be present in every organization to properly implement BIM, the diversity of roles within these actor groups differs based on the organizational size. Since it depends on the size of an organization which actors are involved, it may be the case that actor specific barriers differ for organizations of different sizes.

This study showed that the intervention BIM feedback is most effective in stimulating BIM in the company of focus. Since the development of BIM skills was also found as a suitable intervention in literature, it is expected that this intervention is useful for engineering firms in general. Moreover, this intervention aims at overcoming the barrier lack of BIM skills, which was found as a barrier for all actors in this study and also in literature. However, for engineering companies where the BIM maturity level of categories differs more, a different intervention may be more effective. If one BIM maturity category is far behind the others, it may be more effective to start with an intervention specifically aimed at increasing the BIM maturity of that category. The other proposed interventions: BIM mindset, BIM facilities and BIM practice, are aimed at overcoming barriers that are experienced by specific actors. Since the actor roles may differ based on the organizational size, these interventions may not be effective to the same extent. Concludingly, all interventions aim at overcoming barriers which can be generalized to other engineering firms. Therefore, the interventions are useful for engineering firms in general, but the precise effectiveness may differ per firm.

6 Conclusion

This thesis aimed at finding interventions that can help to overcome the barriers experienced by significant actors in the BIM implementation process within large engineering firms. This final chapter presents the conclusions with regard to the research question in Section 6.1. Furthermore, Section 6.2 offers a discussion on theoretical and methodological contributions. Recommendations for future research are presented in Section 6.3 and, finally, recommendations regarding the implementation of BIM are discussed in Section 6.4.

6.1 Answer to research question

This thesis aims to provide interventions that are effective in overcoming the barriers experienced in the use of intra-organizational BIM. The focus is specifically on barriers experienced by actors who are significant in the BIM implementation process in large engineering firms. The research question is answered based on several methods and has been subdivided in four objectives: (1) analysing the current BIM maturity level of large engineering firms, (2) identifying actors that are significant for the BIM implementation process in large engineering firms, (3) understanding which barriers are experienced by these actors that hinder them in working with BIM, and (4) analysing which interventions are effective in lowering or removing these barriers. The following sub-sections provide a conclusion for all these objectives. This conclusion is based on data collected at a department within Movares. The advantage of collecting data at one department compared to multiple departments or firms is that the BIM process could be studied more in-depth.

6.1.1 Current BIM maturity level of large engineering firms

Based on a BIM maturity model on subsector level for the Dutch industry provided by Siebelink (2017), it was found that BIM is managed and already partly defined at the department of focus within Movares. Moreover, it was found that the difference in BIM maturity between the categories (strategy, procedures and processes, human and culture, BIM processes, ICT, and data) is small. It was found that the category strategy scored highest on BIM maturity, while the category ICT scored lowest. The survey results also indicated that many participants were not aware of the current possibilities and status of BIM within the organization. Finally, the survey indicated that there is no significant difference between the BIM maturity level of the different disciplines.

The findings indicate that BIM is managed at the department of focus within Movares, but not yet completely defined. Moreover, the findings imply that BIM implementation is not hindered by one specific category or discipline. Since there are no clear guidelines available on how to implement BIM, engineering firms use different strategies. Therefore, it is expected that other engineering firms score differently on the BIM maturity categories.

6.1.2 Significant actors for the intra-firm BIM implementation process

Significant actors for the BIM implementation process in engineering firms were found based on a literature study. Literature indicated BIM specific actor roles, non-technical users and technical users to be most important. For the department of focus the actor groups were narrowed down to BIM-coordinators, project leaders and the disciplines (architects, building engineers, structural engineers and MEP engineers). So, different parties have to be considered in identifying barriers and designing interventions for intra-organizational BIM implementation in engineering firms. The specific job titles and tasks included in the actor groups may differ per engineering firm.

6.1.3 Barriers experienced in large engineering firms

Barriers experienced by different actors differ. However, all interviewed actors indicated that the lack of BIM skills was hindering BIM use. This finding indicates that although barriers differ per actor, BIM skills are relevant for all actors. Besides BIM skills, project leaders all indicated the barriers inefficiency of BIM and lack of facilities. The disciplines indicated the barriers lack of BIM skills, shortage of time and uneven distribution of work. Finally, BIM coordinators agreed on the barriers false BIM expectations, increased dependence on integrated cooperation, lack of BIM skills, lack of facilities and mindset not in favour of BIM. These findings indicate that barriers are very different for different actors. Moreover, the barriers that were found in this study have shown that intra-firm barriers differ from inter-organizational barriers found in literature. Since the barriers found in this study are similar to barriers found in literature on intra-organizational BIM implementation it is expected that these barriers are experienced by engineering firms in general.

6.1.4 Effectiveness of interventions to overcome barriers

Based on the barriers, four different interventions were designed and tested. The intervention *BIM feedback* focussed on overcoming the barrier lack of BIM skills, the intervention *BIM mindset* to overcome the barrier mindset not in favour of BIM, the intervention *BIM facilities* for the barrier lack of facilities, and the intervention *BIM practice* to overcome a combination of the barriers lack of BIM skills and shortage of time.

The interventions *BIM feedback* and *BIM practice* result in the highest increase in average utility. By using the SPNE it was found that the interventions *BIM feedback*, *BIM mindset* and *BIM practice* would all result in every actor working according to BIM. For the intervention *BIM facilities*, the SPNE was found for an outcome were all actors from the department work according to BIM, however, the client does not request BIM. Finally, the outcome probabilities indicated that that all interventions are most likely to result in the most preferred outcome, but the interventions *BIM feedback* has the highest probability of resulting in the most preferred outcome. Hence, *BIM feedback* was found to be most effective. Since barriers found in this study are similar to intra-organizational barriers to BIM found in literature, it is expected that the proposed interventions are effective for engineering firms in general.

Concludingly, to stimulate BIM, it is most effective to introduce a BIM feedback system aimed at understanding individual needs to lower the barrier lack of BIM skills, which is experienced by project leaders, BIM coordinators and the disciplines. Nonetheless, other interventions are also effective to increase the BIM maturity level of Dutch engineering firms.

6.2 Scientific and social relevance

The previous section presented an answer to the research question. This section provides a reflection on the scientific and social relevance.

6.2.1 Scientific relevance

The benefits of BIM are elaborately discussed in literature. Although previous studies indicate that intra-organizational BIM implementation is a requirement for inter-firm BIM, little studies have focused on intra-organizational BIM use. Moreover, most studies report on the barriers in general and do not give insight in the differences in barriers for different actors. Hence, this thesis contributed scientifically by exploring the barriers in an intra-organizational context. This study reveals that barriers differ per actor.

Moreover, current literature does not link barriers to specific BIM maturity levels. This study showed that barriers in general do not depend on the BIM maturity level, but that actor specific barriers may relate to this level.

Moreover, as described in Section 2.8, little research has been done on how to overcome barriers to BIM. A limited number of studies are available that propose guidelines on how to overcome barriers to BIM. However, studies that have been done often focus on an industry or project perspective. This is the first study that focusses on how barriers to BIM can be overcome in Dutch engineering firms.

Finally, game theory is not often used to study BIM, as discussed in Section 3.6.2. In studies that do apply game theory, it is often done in an inter-organizational context and a cooperative form. By knowledge of the researcher, this is the first study that applies the non-cooperative form of game theory to study BIM implementation in an intra-organizational context.

6.2.2 Social relevance

The results of this thesis are based on data collected at Movares and hence, especially relevant for the company. However, the results are also relevant for other engineering firms. Based on the results of the study it is clarified which barriers are hindering further BIM implementation. Engineering companies should place extra attention on these barriers in case they want to increase their BIM maturity level. Moreover, an advice is given on how to overcome these barriers. The advice is presented in Section 6.4. This advice can be used by engineering companies to increase their BIM maturity level. A higher BIM maturity level is favorable since this results in more advantages, such as a reduction in costs. Finally, game theory is found to be useful in testing the effects of interventions. Although it is a complex method, companies can use it to test the effects of interventions before implementation. This prevents companies from costs for ineffective interventions.

6.3 Recommendations for future research

Several recommendations for future research are presented in this section.

First of all, this study used a non-cooperative form, since costs and benefits are not distributed over the involved actors. However, a cooperative form is interesting for future research in order to understand how the costs and benefits of interventions need to be distributed in order to result in active participation and long-term benefits. This is not only relevant for intra-organizational actors, but also for external parties. For example, is the client be willing to pay for part of the intervention in order to receive a better BIM model. In an intra-organizational context, cooperative game theory is interesting to understand what management and employees are willing to invest in BIM. For example, whether people are willing to work extra hours to gain BIM skills or to create extra workload for themselves by working on a BIM project to develop skills they do not yet have. Cooperative game theory would allow to understand what is necessary to make people willing to work according to BIM. This would also give insight in what needs to be done to implement interventions in such a way that people are motivated to participate. If employees are more motivated, long term benefits are more likely achieved.

This study showed that all proposed interventions are effective in increasing the BIM maturity level. However, in order to be effective, interventions need to be implemented in the right way. Future research should therefore consider how interventions can be implemented in an efficient and effective manner to achieve lasting benefits. Besides the use of cooperative game theory, it is advised to study the implementation in practice in order to provide good practices for engineering companies.

Something else that is interesting for future research is the effectiveness of interventions on actor level. Although the interventions were based on barriers experienced by specific actors in this study, their effectiveness was not evaluated per actor because of the sample size. It is useful to understand whether it would be more effective to have different interventions for different actors or one intervention for all actors. Moreover, it would be interesting whether a single intervention or a combination of interventions would be more effective. It would be best to study this from a cost-benefit perspective.

Fourthly, this study did not find any barriers that significantly differed from the ones found in literature. This may indicate that the BIM maturity level does not influence the barriers that are experienced. Future research on the difference in barriers per BIM maturity level could clarify this. This is especially interesting on actor level.

Finally, further research on the influence of management is advised. Management was not found to be an important actor in literature. However, the interviewees mentioned barriers and measures that relate to management. Moreover, two management related barriers were found in literature that were not found in this study. Therefore, it would be interesting to understand the importance of management in the BIM implementation process.

6.4 Recommendations for BIM implementation

This study aimed at providing interventions that can help to overcome barriers regarding BIM, experienced in large engineering firms. This section presents recommendations for the implementation of such an intervention. Although results were collected at a department of one large engineering firm, the actors and barriers are very similar to the ones found in literature. Therefore, it is expected that other engineering firms have similar actors who experience similar barriers in the BIM implementation process, irrespective of the BIM maturity level. Hence similar interventions can help to overcome these barriers.

Engineering firms which are implementing BIM are advised to focus on three main actor roles: BIM coordinators, technical users and non-technical users. All have to be present in order to properly implement BIM. Technical users are those who create the model and add data to the model. Non-technical users include people who are responsible for planning, budgets, requirements and managing the work of technical users. The specific tasks of the BIM coordinator depend on the size of an organization. Large engineering firms have to consider that the barriers differ per actor and even per individual. Hence, the reason that people do not always work according to BIM differs per individual. When implementing interventions this should be considered.

According to the results every intervention helps to increase the BIM maturity. Therefore, it is recommended to actively support the implementation of BIM use at all times in order to increase the BIM maturity level. The intervention *BIM feedback* was found to be most effective to overcome the most common barrier lack of BIM skills that was experienced by all main actors. Hence, it is recommended to implement this intervention for engineering firms were the barrier lack of BIM skills is most strongly present. This intervention implies that feedback is gathered to understand individual needs with regard to BIM skills. Training and other possibilities should be provided according to those needs. Figure 6.1 provides an overview of the actions that have to be taken. Moreover, it clarifies how development of skills can be facilitated.

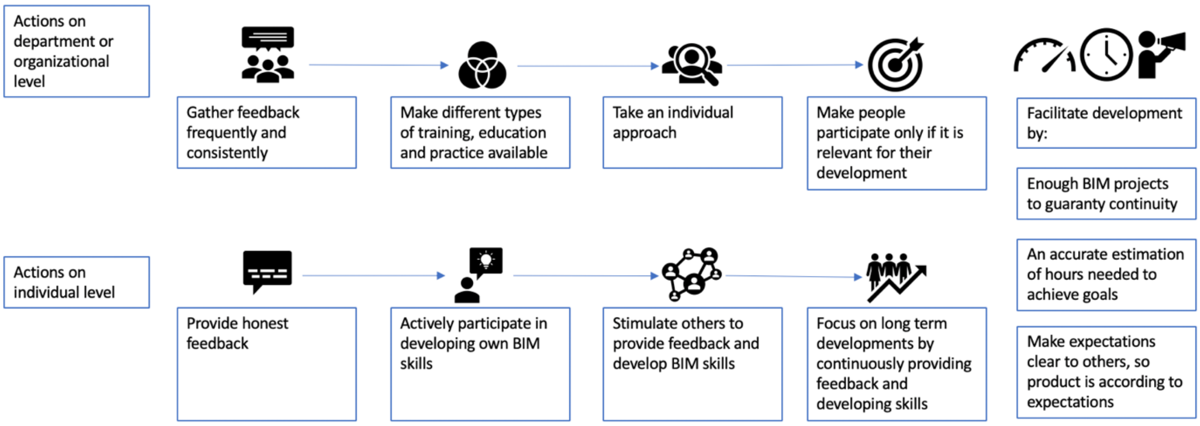

Figure 6.1. Overview on how to implement the intervention *BIM feedback*.

On departmental or organizational level, it is important that feedback is gathered frequently and consistently to make sure that it is accurate. It is advised to make a BIM coordinator responsible for collecting the feedback. Moreover, this feedback can best be collected during small group meetings. Group meetings are more likely to result in active participation compared to (online) feedback forms. This feedback should include several aspects:

- What is the personal BIM maturity level of a person?
    - Which BIM-maturity categories need extra attention? The role of the individual has to be taken into account for this.
- Which barriers are experienced by the individual?
- What is needed for the development of this individual?

Since it is a very time-consuming process to collect feedback from every individual, it is best when project leaders collect this information from the individuals in their team. During the feedback group meetings, the project leaders can then express both their own needs as well as the needs of their team.

A tailored BIM development programme for each individual requires more work and hence, more costs. However, it is assumed that this has benefits in the long run. First of all, this approach allows individuals to develop BIM skills at their own level and not waist time on e.g. trainings that are way above or below their level. This results in a more effective development of BIM skills. Secondly, this intervention results in an increase in job satisfaction in three ways. During the interviews, people indicated that they are annoyed when they have to participate in trainings that are not relevant for them. If the BIM development programme is tailored to the individual, trainings are always on the right level and about a relevant topic for that individual. Moreover, the shift in mindset is difficult for several people because experience the technology as very complex. When they can develop their skills at their own pace and start at a suitable level, these people are more likely to change their mindset in favour of BIM. Finally, a complaint is that people who are provided with opportunities to develop their BIM skills often leave the company. A higher job satisfaction makes this less likely. If the company aims at increasing the BIM maturity level, this intervention saves costs in the long run.

Although management can put some pressure on the use of this system, internal motivation of employees is very important. It is expected that this system contributes to the personal motivation, since it focussed on individual needs. However, the distribution of costs and benefits is important to realise a shift in mindset and to achieve long-term benefits. It is advised that the department or organization understands how benefits and costs of interventions can best be distributed among management, project leaders, BIM coordinators and the disciplines and acts accordingly. This supports an effective development of BIM skills with long-term benefits.

7 References

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Appendix A: Movares

A.1. Introduction to company

Movares originates from 'Ingenieursbureau NS', that was separated from NS and renamed to Holland Rail consult in 1995. In 2006 the name was changed to Movares. Movares changed its organisation structure in October 2019 in order to separate the two main parts: a knowledge component and a business component. Both components are supporting each other. The business components main task is to find new projects and maintaining customer contact. The knowledge component is responsible for executing these projects. Figure A.1 shows the current organisational structure of Movares. The knowledge component is indicated in blue, while the business component is indicated in orange. Both components can be divided in four departments that are again subdivided to sub-departments. Movares has five different locations: Amsterdam, Arnhem, Eindhoven, Rotterdam and Utrecht.

Movares does not have a specific definition for BIM within their company. They do make a difference between Building Information Management and a Building Information Model. BIM is mainly present within the knowledge component of the organisation, which is located in Utrecht. Movares has been working on the implementation of BIM for several years now.

The knowledge components are located in Utrecht and since BIM is most interesting there, the BIM maturity level measurement focusses on this location. Four departments are present with sub-departments in Utrecht. For this study, two options were considered regarding the distribution of the survey: over all departments or only within one department. It was chosen to only focus on the department of Integrated Design because of several reasons that are presented in the next section. Within the department of Integrated Design, four main disciplines are present: architecture, building, structures and MEP engineering.

A.2. Department of Integrated Design

First of all, BIM is used over multiple departments, but currently, the departments of Integrated Design A & B are ahead of other departments in the use of BIM. Integrated Design A & B can be seen as one department. The only difference is that they are going to have a different manager in the future because there are currently too many people in the group for one manager. Secondly, it would take more time to process results of the BIM maturity survey of many different departments since the response rate would most likely be higher. On top of that, for this study it is interesting to see how the BIM maturity level differs per position. When all departments are taken into account, the results should be checked for many different positions. Thirdly, the aim of this study is to find interventions that can be used to stimulate the implementation of BIM with game theory. This makes it more useful to focus on the implementation of BIM within one department, because more detailed barriers can be found and therefore also more straight forward interventions. If multiple departments would be taken into account, employees with different positions within different departments most likely come up with different barriers. Due to the complexity of a Game Theoretic model and the time limitations, it would not be possible to include several positions from each department. In that case, either a very small part of the existing positions could be taken into account or the barriers experienced by employees with different positions in one department should be generalized to organizational level. This would result in very generic interventions.

Finally, this study focusses on one, to be defined, project stage. Since projects within Movares usually have a long duration, it is unlikely that it is possible to conduct interviews with people of different departments while all having at least one project in the same project stage.

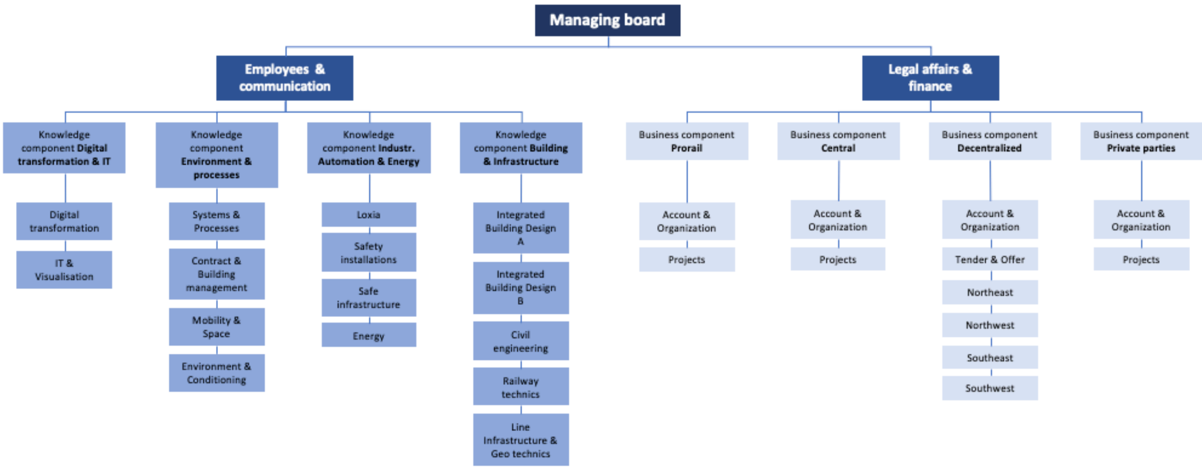


Figure A.1. Organisational structure of Movares.

A.3. BIM process

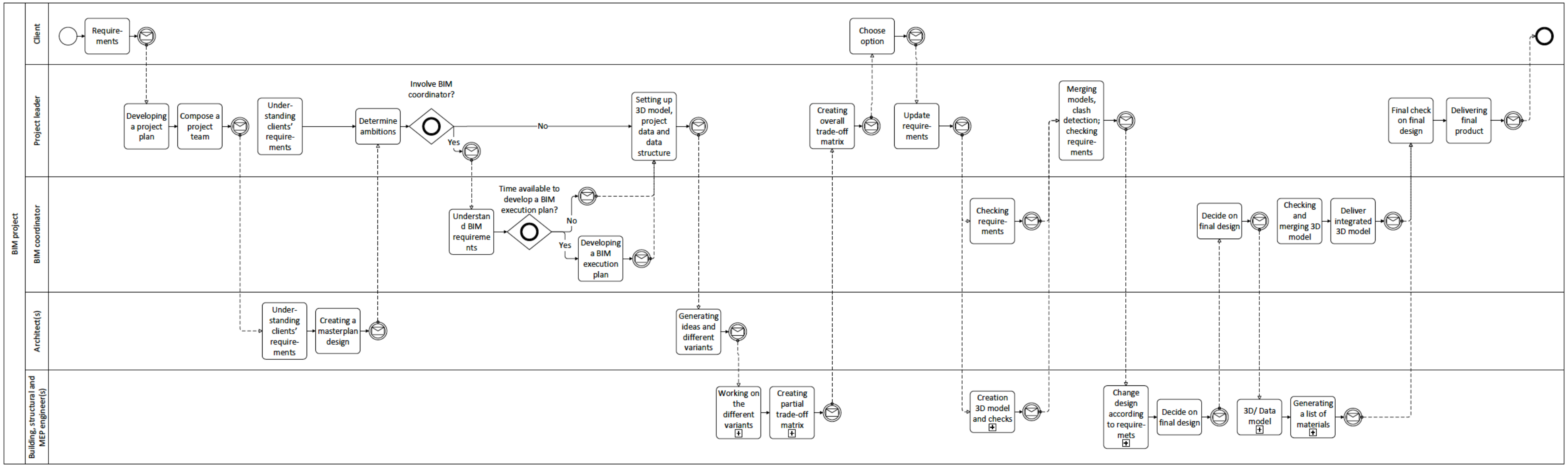


Figure A.2 BIM process at the department of ID.

Appendix B: BIM maturity

B.1. BIM maturity tables translated from Siebelink (2017)

Table B.1

BIM maturity table for the category strategy (Siebelink, 2017).

Category	Description	Description maturity level					
Strategy	**De vision and goals for BIM, how these are supported by management and how the implementation of BIM is supported by experts and teams.**	**0 – Not present**	**1 – Initial**	**2 – Managed**	**3 – Defined**	**4 – Quantitatively managed**	**5 - Optimized**
BIM-vision and goals	*In order to guide the BIM implementation process, a BIM-vision can be created, and BIM-goals can be used.*	No vision or BIM-goals are present.	A (basic)vision for BIM is defined, but no concrete goals are linked to this.	Generic BIM goals are used. A BIM-vision is either not present or not in line with the BIM-goals.	The BIM-vision matches the organisational vision/strategy and is tuned to close cooperation partners.	BIM-goals are defined SMART.	A BIM-vision and goals are actively monitored and adjusted if necessary.
Management support	*The extent to which management supports the implementation and developments of BIM by having budgets available and explain the relevance of BIM.*	There is no support for BIM from management.	Limited, unstructured support for BIM. Budgets are available ad hoc.	The importance of BIM is verbally spread, but the budgets are limited.	BIM is supported with sufficient/ appropriate budgets.	Appropriate means are made available to develop BIM and to implement new applications.	Support for a continuous effort to implement BIM and to guarantee BIM-implementation for the future.
BIM-expertise	*Depending on the organisational size, a BIM-expert, BIM-team and/or BIM-related department can be present. These often have a guiding, advising and supporting role for the implementation of BIM.*	No BIM-expert, BIM-team or BIM-related department is present.	A BIM-expert with little time for BIM-initiatives. A BIM-team or group of core-users gather irregularly to discuss the implementation of BIM.	BIM-expert(s) with sufficient time/ capacity for the implementation of BIM.	BIM-expert works in close cooperation with the relevant parts from the organisation. All (relevant) company parts are represented in a BIM-team or group of core users.	Among the BIM-expert(s) or BIM-team higher management is represented. There is close cooperation with parts/ teams responsible for BIM-tasks.	BIM-related discussion making of the expert/ team is considered in order to adjust the BIM-strategy based on knowledge, experience and developments.

Table B.2

BIM maturity table for the category organizational structure (Siebelink, 2017).

Category	Description	Description maturity level					
Organisational structure	**The organisational structure includes the formal composition of the organisation, including the hierarchical structure and job descriptions. The project structure describes how the BIM tasks, responsibilities and risks between parties in a project are documented.**	**0 – Not present**	**1 – Initial**	**2 – Managed**	**3 – Defined**	**4 – Quantitatively managed**	**5 - Optimized**
Tasks and responsibilities	*The extent to which tasks and responsibilities regarding BIM-processes are formalised and the extent to which these are present in practice.*	No tasks and responsibilities for BIM-related processes are documented.	BIM-tasks and responsibilities are only partly or insufficiently documented.	Tasks and responsibilities for BIM-processes are sufficiently documented, but to limited extent integrated in the regular job descriptions.	Tasks and responsibilities for BIM-processes are documented on project level. Project teams use (standard) task and role descriptions for this.	Tasks and responsibilities are adjusted on organisation level to stay accurate for the current BIM use.	Documented BIM-related tasks and responsibilities are regularly evaluated, in order to keep them updated in a changing (BIM-) environment
Contractual aspects	*The extent to which clear agreements are made about BIM with other parties. The focus is on agreements that are formalised through a contract, BIM-protocol or in another way.*	BIM is not included in contracts, protocols, or other documented agreements.	BIM is included in contracts or protocols based on the project or project team. No standard is present for this within the organization.	The organization established clear guidelines for the inclusion of BIM in contracts or protocols, but these are insufficiently used in practice.	The cooperation with BIM is explicitly documented in contracts or protocols with other parties. The organization is able to take the lead in this formalisation.	BIM-related agreements are specific and measurable documented in contracts or protocols: this gives clarity about which and when information needs to be delivered.	Changing BIM use, new insights with respect to BIM and possible changes in legal conditions are closely monitored in order to adjust contracts and protocols to this.

Table B.3

BIM maturity table for the category people and culture (Siebelink, 2017).

Category	Description	Description maturity level					
People and culture	**Characteristics and competences of people and organization. Individual motivation or the business culture can, e.g. determine the current BIM use, but also the transition to new work methods and technologies.**	**0 – Not present**	**1 – Initial**	**2 – Managed**	**3 – Defined**	**4 – Quantitatively managed**	**5 - Optimized**
Personal motivation and willingness to change	*Personal drivers to accept and support BIM implementation. This motivation is leading for the willingness of people to adjust their way of working to BIM use. Personal drivers also have a strong influence on the extent and pace in which organisational changes come along. The current organisational culture can have a high influence on individual motivations.*	People are reluctant regarding the implementation of BIM.	Personal drivers determine on project level whether BIM is used. The culture does not contribute to the transition towards BIM within the organisation.	Despite the motivation from the top and early adaptors, there is not enough enthusiasm for BIM from the majority of the organisation.	A wide enthusiasm for BIM is present within the organisation. This results in an increasing willingness to change the way of working in favour of BIM.	The current organisational culture is stimulating the implementation of BIM. Traditional job descriptions and processes are adjusted to BIM use.	The strong motivation to improve and implement BIM, makes it possible for the organisation to adjust quickly to new BIM developments.
Requesting actor (internal)	*An asking actor helps to set the process of BIM implementation in motion. This so-called BIM-champion guides and stimulates others in the organisation regarding BIM.*	No asking actor (BIM champion) is present.	A BIM champion is present, but this person has too little time and capacity to execute this role properly.	The BIM champion has limited time for his role, despite he is able to get BIM to a higher level.	The number of BIM champions present, and their background is suitable to support BIM-perspectives from different people, target groups and departments.	A BIM champion is present within the managing board. This person is closely connected to people who are responsible for operational BIM tasks.	One or more BIM champions within the organisation are closely working together with BIM champions from other organisations.
Education, training and support	*Education, training and support for BIM includes general information on organisational level and instruction and guidance for specific people/target groups. This leads to the development of competencies to execute BIM related tasks.*	No education or specific training for BIM is present.	Education and training for BIM is unstructured and ad hoc. It is offered when individuals insist on this.	A structured programme regarding education and training for BIM is present. This is offered to people who will be working with BIM a lot.	General information about BIM is communicated on organisational level to motivate people and create awareness. Elaborate training is given for BIM-oriented people and groups.	The educational and trainings programme for BIM is in line with the needs of people and target groups. Training on the job is done to give guidance and support in practice.	Education and training for BIM is kept up to date and constantly improved based on practical experience. Good/bad practices from projects are important input for this.
Cooperation, openness and transparency	*The extent to which the attitude of people is focused on collaboration. Important aspects for this are openness and transparency to collaboration parties.*	The organisation is strongly intern orientated. This is also the case for BIM use.	Collaboration with other parties is ad hoc and reactive instead of proactive. Openness and transparency are missing and hindering joint activities.	Efforts for structural collaboration are only partly successful. Significant improvement in collaboration with other parties is possible if the organisational culture would be more supportive.	Breakthrough with regard to the focus of organisations on collaboration within the supply chain. BIM tasks and processes are successfully aligned with other parties.	External collaboration is part of the organisational strategy and is a competitive instrument. Increasing mutual trust between partners leads to an increase in openness and transparency.	A joint network within the construction chain transcends interests of individual organisations. The mutual dependency is great, making collaboration leading in the competitive position and joint performances.

Table B.4

BIM maturity table for the category BIM processes (Siebelink, 2017).

Category	Description	Description maturity level					
BIM processes	**A collection of BIM related activities aimed at achieving a specific result. These interdependent activities may, for example, be an application area.**	**0 – Not present**	**1 – Initial**	**2 – Managed**	**3 – Defined**	**4 – Quantitatively managed**	**5 - Optimized**
Procedures and work instructions	*The extent to which organisational and project related processes are documented. For example, procedures and working instructions. This influences the consistency and performance of processes.*	No procedures or working instructions are documented for BIM use.	BIM processes are limitedly documented in procedures or working instructions. Because of this, BIM processes are unpredictable and to a large extent depending on personal competences.	Working instructions and/ or procedures are established for important BIM applications. Although working instructions and procedures are partly present, the traditional way of working is often still used.	The BIM use of an organisation is documented in working instructions and/ or procedures. Good practices are included in this with a focus on collaboration with other parties (external processes).	A detailed process documentation is present to secure the quality of BIM processes. This leads to predictable processes and achievements within acceptable boundaries.	Process documentation is kept up to date and improved based on new (BIM) developments. This is done to ensure that existing documentation is kept relevant for the actual BIM use.
Process change	*The extent to which BIM can have a driving role for change and improvement or organisational processes.*	BIM is seen as tool for certain activities but does not lead to fundamental process optimisation.	BIM is to a limited extent a motive for change and improvement of processes. This is highly depending on competences and motives of specific people/ teams.	BIM is a motive for the improvement of processes, but traditional structures and habits slow down this transition. Adjustments on projects are limitedly transferred to other parts of the organisation.	BIM is seen as an effective booster for process optimisation. Changes are shared with other departments/ teams and have a positive influence on both internal and external processes.	BIM-driven changes and improvements of processes are actively contributing to monitoring and adjusting processes.	BIM contributes to process optimisation, at least partly through intensive collaboration with other parties and disciplines.

Table B.5

BIM maturity table for the category ICT (infrastructure) (Siebelink, 2017).

Category	Description	Description maturity level					
ICT (infrastructure)	**The ICT-related means to facilitate BIM including hardware and software. Also meeting rooms and associated facilities are included in this criterium.**	**0 – Not present**	**1 – Initial**	**2 – Managed**	**3 – Defined**	**4 – Quantitatively managed**	**5 - Optimized**
Hardware and network environment	*Physical elements and systems that are necessary to use and store software and data. The quality of the network environment determines the convenience with which BIM data can be accessed and exchanged.*	The existing hardware is insufficient to support BIM software.	The hardware supports applications of BIM to a limited extent. Processing large amount of data gives problems. The infrastructure for the network environment hinders the exchange of data with other parties.	Suitable hardware is available for people working with BIM. Infrastructure for the network environment is sufficient to exchange BIM data with other parties.	Powerful hardware systems are partly present within the organisation. The allocation is done based on the dependency of BIM applications.	The hardware is organisational wide able to execute advanced BIM software applications. The network environment supports simultaneous working in a building model by multiple parties.	Current and future needs regarding BIM are actively monitored to keep the hardware systems present up to date.
Software	*Control and application programmes with which BIM applications are facilitated.*	No BIM software is available.	BIM software is available, but it only supports BIM use to a limited extent.	The necessary BIM use is sufficiently supported by the available software. However, further implementation of BIM is hindered.	The collaboration with other parties, among which the exchange of data, is properly facilitated by the available software.	All necessary and desired BIM applications are supported by the available software. The BIM software acts as a catalyst for further implementation of BIM.	Future needs regarding BIM are regularly mapped to keep the used software packages up to date.
BIM-facilities	*The presence, availability and quality of project and meeting rooms including corresponding facilities. This also includes which functions these rooms have regarding the support of BIM use.*	No project room or meeting room is available to support BIM use.	Project rooms and/ or meeting rooms are available, but lacking facilities. These rooms contribute little to BIM use.	The meeting room(s) present are sufficiently equipped to facilitate collaboration with BIM. This offers the possibility to work together with multiple people by using a common screen/ monitor.	One or more meeting rooms are present that can be used by teams for a longer duration. This stimulates multidisciplinary and integrated cooperation.	One or more meeting rooms are sufficiently equipped to host coordination sessions and support those with BIM through large projection screens or smartboards.	The need for BIM related facilities is actively monitored, and necessary changes are identified and implemented.

Table B.6

BIM maturity table for the category data (structure) (Siebelink, 2017).

Category	Description	Description maturity level					
Data (structure)	**Management, structure, (re)use and the exchange of project related data.**	**0 – Not present**	**1 – Initial**	**2 – Managed**	**3 – Defined**	**4 – Quantitatively managed**	**5 - Optimized**
Information structure	*Use of document management system (DMS) in order to save data in a structured manner and have access to project data.*	No document management system is used.	The use of a document management system is unstructured and highly depending on competencies of project teams.	The use of a document management system is part of the working method of the organisation. No link is made between this system and the BIM environment.	The data within the DMS is partly accessible for other parties on project level. Moreover, rights can be granted to add/ change documents.	The DMS is completely integrated in the BIM environment. The DMS acts as a primary source of information during projects and is an effective means of communication between parties.	The project bound data is managed by an organization overarching system. One central person is appointed to ensure the quality and consistency of the data.
Object structure/ object decomposition	*Decomposition of a building, in which physical and functional parts are defined at different levels of detail. The structure that follows from this can be used to provide insight into different parts of the building, to create and manage working packages and to link information to certain elements.*	No method is used for the object structure/ decomposition of a building.	The used object structure is defined on project level. No uniform method is available within the organisation for the object structure.	A uniform method for the object structure is available within the organisation.	The organisational method for the object structure is aligned with projects and shared with other parties.	The method for the object structure is consequently aligned with standards in the sector. Agreements about the used method are made with partners beyond the project.	Developments on sector level to improve and align the method for object decomposition are closely monitored to keep it up to date.
Object library and object attributes	*During the construction of a structure, standardised objects or concepts from an object library can be used. The object attributes form an addition of non-graphic information, with which, among others, features and characteristics of an object are defined.*	No object library is used.	Within the organisation different object libraries are present, which are not aligned: no standard is present. The addition of attributes is random.	On organisational level an (overarching) object library is present. Non geometric basic data is linked to objects.	The used object library is structured, and the naming of objects is consistent. The object library is in line with sector standards.	When creating structures and the development of libraries, available objects and matching attributes from external libraries and open standards are used.	Object libraries are continuously kept up to date with additional data from projects. Object attributes are added to support other parties and reuse information.
Data exchange	*The exchange of data through or from the structure with other parties. This way partial designs or data from partners can be used as* a basis.	No exchange of data from the model takes place.	Exchange from data through or from the model is limited and unstructured. This exchange is largely depending on competencies of project teams.	Exchange of data is mainly present between teams/ departments within the organisation. External exchange of data is more difficult due to the lack of mutual agreements and/ or data standards.	Data exchange with other parties is properly defined in contracts or associated BIM protocols. This is the basis for successful data exchange and offers the possibility to continue with the (partial) structure of other parties.	The exchange of BIM data mostly happens through open standards. The interoperability of structure/ BIM data is strongly increased by this.	The exchange of BIM data includes indicators to give insight into the success of BIM applications. This allows for continuous monitoring and adjusting, for example, of the implementation of new applications and technologies.

B.2. Survey BIM maturity

General

1. In which discipline are you working?
    a. Architecture
    b. Building engineering
    c. Structures
    d. MEP (mechanical, electrical, and plumbing) engineering

2. What is your role within the department?
    a. Advisor/ Sr. Advisor/ Consultant/ Specialist
    b. Constructor
    c. Chief designer/ Design leader
    d. Manager
    e. Designer/ Modeller
    f. Design leader
    g. Project manager/ Project leader
    h. Other:

3. How many years have you been working at Movares?

………………………………………………………………………………………………….

4. What are the mayor activities for your position?
    a. Administer
    b. Analysing
    c. Calculating
    d. Checking
    e. Coordinating/ Supervise
    f. Modelling
    g. Maintaining contacts
    h. Organising/ Planning
    i. Speaking/ Presenting
    j. Drawing
    k. Quantifying
    l. Other:

5. In which project stage are you usually working?
    a. Planning study
    b. Preliminary design
    c. Definitive design
    d. Scope statement/ Price and contract formation
    e. Construction ready design
    f. Other:

6. To what extent do you work with BIM? (BIM is defined here as A 3D model, where digital information models are present for collaboration throughout multiple stages of the building lifecycle.)
    a. Never
    b. Rarely
    c. Sometimes
    d. Regularly
    e. Often

Strategy

7. To what extent are a BIM vision and BIM related goals present in your company?
    a. No vision or goals are present.
    b. A defined (basic)vision for BIM, but no goals.
    c. Main BIM-goals are present, but no BIM vision.
    d. The BIM-vision fits within the organisational vision/ strategy and is aligned with partners.
    e. BIM goals are SMART defined.
    f. BIM-vision and goals are actively monitored and updated.
    g. I don't know.

8. To what extent is management supporting the implementation of BIM by **making budgets** available?
    a. No support from management.
    b. Budgets are made available ad hoc.
    c. Budgets are limited.
    d. There are sufficient budgets.
    e. Resources are made available for further development and implementation of BIM.
    f. Budgets are available for the development of BIM for now and the future.
    g. I don't know.

9. To what extent is management supporting the implementation of BIM by **propagating the relevance of BIM**?
    a. No support from management.
    b. Limited, unstructured support for BIM.
    c. The importance of BIM is verbally expressed.
    d. BIM is sufficiently supported.
    e. Resources are made available for further development and implementation of BIM.
    f. Support for continuous use of BIM is secured for the future.
    g. I don't know.

10. <u>To what extent is a BIM-expert present within the department?</u>
    a. No BIM-expert or BIM-supporting department is present.
    b. A BIM-expert is present, but with little time for BIM-initiatives.
    c. BIM-experts with sufficient time and capacity for the implementation of BIM are present.
    d. A BIM-expert works in close cooperation with relevant others within the organisation.
    e. Higher management is also represented in the group of BIM experts.
    f. BIM-related decision making by the expert is used to adjust the strategy.
    g. I don't know.

11. <u>To what extent is a BIM-team present within the department?</u>
    a. No BIM-team is present.
    b. A BIM-team is present, but with little time for BIM-initiatives.
    c. A BIM-team with sufficient time and capacity for the implementation of BIM are present.
    d. All relevant business units are represented in a BIM-team.
    e. Higher management is also represented in the BIM-team.
    f. BIM-related decision making by the team is used to adjust the strategy.
    g. I don't know.

Organisational structure

12. <u>To what extent are tasks and responsibilities with regard to BIM-processes documented and present within the department?</u>
    a. Those are not documented.
    b. Those are only partly documented or on an insufficient level.
    c. Sufficient documentation is present, but there is limited integration in regular job descriptions.
    d. Those are documented on project level and task or role descriptions are linked to this.
    e. On organisational level, tasks and responsibilities have been adjusted to match the actual BIM use.
    f. BIM related documents are regularly evaluated to keep them up to date.
    g. I don't know.

13. To what extent are clear agreements made with other parties regarding BIM? (The focus is on agreements through contracts, BIM-protocols or other ways of formal agreements.)
    a. BIM is not included in contracts, protocols or other formal agreements.
    b. On project level, BIM is (partly) included in contracts or protocols. No standard or guidelines are present for this.
    c. The organisation provides clear guidelines, but those are not sufficiently used.
    d. The organisation acts proactively in order to document agreements explicitly when BIM is used.
    e. BIM-related agreements are specific and measurable documented in contracts and protocols.
    f. Changes around BIM are closely monitored to adjust contracts and protocols.
    g. I don’t know.

People and culture

14. Is there support for the use of BIM within the department according to you?
    a. There is aversion.
    b. On an organisational level there is no motivating culture.
    c. Motivation from the top is present, but not from the majority in the organisation.
    d. BIM is widely supported by the organisation.
    e. The current culture has a stimulating effect on the implementation of BIM.
    f. A strong motivation is present to apply BIM and implement new developments.
    g. I don’t know.

15. Are there ‘BIM-champions’ present at the department? (BIM-champions are people that take the lead and are also facilitated to coach other regarding BIM.)
    a. No
    b. Yes, but those do not have enough time available.
    c. Yes, but those have limited time.
    d. Yes, and they influence the BIM use on one or more departments.
    e. Yes, and one or more of them are coming from the managing board.
    f. Yes, and they are closely cooperating with BIM-champions from other organisations.
    g. I don’t know.

16. To what extent is counselling and guidance provided for the use of BIM?
    a. No education or specific training for BIM.
    b. Education and training are unstructured and ad hoc.
    c. A structured programme is offered to people working with BIM.
    d. General information about BIM is communicated on organisational level.
    e. The education and trainings programme are in line with the needs of different BIM users.
    f. Education and training for BIM is kept up to date and constantly improved.
    g. I don’t know.

17. To what extent is Movares focussed on collaboration?
    a. The organisation is strongly intern orientated. This is also the case for BIM use.
    b. Collaboration with other parties is ad hoc and reactive.
    c. Collaboration with other parties is only partly successful despite efforts for structural collaboration.
    d. BIM tasks and processes are successfully aligned with other parties.
    e. External collaboration is part of the organisational strategy.
    f. A joint network within the building chain transcends interests of individual organisations.
    g. I don't know.

BIM processes

18. To what extent are organisational and project related processes documented at the department?
    a. No procedures or working instructions are documented for BIM.
    b. BIM processes are limitedly documented in procedures or working instructions.
    c. Working instructions and/ or procedures are documented for important applications of BIM.
    d. BIM use of the organization is documented in working instructions and/ or procedures.
    e. A detailed process documentation is present to secure the quality of BIM processes.
    f. Process documentation is kept up to date and continuously improved.
    g. I don't know.

19. To what extent is BIM used to optimise processes within and between departments?
    a. BIM does not lead to fundamental process optimization.
    b. BIM is to a limited extent a motive for improvement of processes.
    c. BIM is a motive for process improvement, but traditional structures and habits slow down this transition.
    d. BIM is an effective booster for process optimization.
    e. BIM driven improvements contribute to monitoring and adjusting processes.
    f. BIM contributes to continuous process optimization.
    g. I don't know.

ICT (infrastructure)

20. To what extent are physical systems present for the use of BIM?
    a. The existing hardware is insufficient to support BIM software.
    b. The hardware supports BIM applications to a limited extent.
    c. Suitable hardware is available for people working with BIM.
    d. Powerful hardware systems are available for BIM users.
    e. Hardware is organisational wide able to execute advanced BIM software applications.
    f. Hardware systems are kept up to date for current and future needs.
    g. I don't know.

21. <u>To what extent are BIM-application facilitated at the department?</u>
    a. BIM software is not available.
    b. BIM software is available, but it supports BIM use to a limited extend.
    c. The necessary BIM use is sufficiently supported by the available software.
    d. BIM use and collaboration with other parties is properly facilitated by available software.
    e. All necessary and desired BIM applications are supported by the available software.
    f. Software packages are kept up to date with future BIM needs.
    g. I don't know.

22. <u>How would you describe the presence, availability and quality of the facilities?</u>
    a. No project room or meeting room is available to support BIM use.
    b. Project and meeting rooms are available but lacking facilities.
    c. The rooms present are sufficiently equipped to facilitate collaboration with BIM.
    d. Available rooms stimulate multidisciplinary and integrated cooperation.
    e. Meeting rooms are sufficiently equipped to host BIM coordination session by using large projection screens or smartboards.
    f. The need for BIM related facilities is actively monitored to make changes if necessary.
    g. I don't know.

Data (structure)

23. <u>To what extent is a document management system used at the department?</u>
    a. This is not used.
    b. This is used, but in an unstructured way.
    c. This is used and it is part of the organisational standard.
    d. This is used and this data is (partly) accessible for other parties on project level.
    e. The system is used and completely integrated in the BIM environment.
    f. This is used and someone is appointed to ensure the quality and consistency.
    g. I don't know.

24. <u>How is a methodology used for an object structure?</u>
    a. No method is used for the object structure.
    b. This is done on project level.
    c. A uniform method for object structure is available within the organisation.
    d. The organisational method is aligned with other parties on project level.
    e. The method is consequently aligned with standards and agreements are made with partners beyond the project.
    f. Developments are closely monitored to keep the methodology up to date.
    g. I don't know.

25. <u>To what extent is an object library present within Movares?</u>
    a. This is not present.
    b. Different object libraries are present that are not aligned with each other.
    c. An object library is present on organisational level.
    d. The object library is aligned with standards from the sector.
    e. When developing object libraries existing objects from external libraries are used as well as open standards.
    f. Object libraries are continuously kept up to date with data from projects.
    g. I don't know.

26. <u>To what extent is data through or from the building models exchanged with other parties?</u>
    a. No data exchange takes place.
    b. Data exchange is limited and unstructured.
    c. This happens mainly between departments within the organisation.
    d. Data exchange with other parties is defined in contracts and BIM protocols.
    e. The exchange of BIM data is mainly done through open standards.
    f. The exchange of BIM data includes indicators to give insight into the success of BIM applications.
    g. I don't know.

27. By ticking the box 'I accept', you indicate that you are aware that you are participating in scientific research and that you can terminate your participation at any time by sending an e-mail to merel.backx@movares.nl

Thank you for participating. In case you have any comments, you can leave them here.
………

Appendix C: Barriers to BIM

C.1. Interview questions

General

- What is your role within the department of Integrated Design?
- How would you describe BIM?
- To what extent are you working with BIM?
- What is your opinion about BIM?

Barriers experienced (up to and including the definitive design stage)

- What was the latest BIM project you were involved in that included either a preliminary design or a definitive design?
  - Which parties are/were involved in the project both intra- and inter-organizational?
  - What is/was your role within this project?
  - Which barriers do/did you experience due to which you were not able to apply BIM standards and features as you would have desired?
  - Which other barriers are/were experienced by the team?
  - How do/did these barriers influence the project?
- Besides the barriers experienced in this project, did you experience other barriers to BIM in other projects?
- Are you able to use BIM as you would like? Why?
- Which barrier is most strongly present for you personally?

Interventions

- In your opinion, how could the before mentioned barriers be solved or lowered?
- Which organizational level is most important in overcoming these barriers?
- How do you experience the current measures to implement BIM?
  - What is already being done to implement BIM?
  - What do you think works in this approach?
  - What does not work?
- What should be the next step in order to properly facilitate the implementation of BIM?

Verifying game tree

The following parties are included: client, project leaders, BIM coordinators and the different disciplines.

- To what extent is this a proper representation of the BIM process?

C.2. Summaries of interviews

This section includes a summary of each interview. The summaries give insight into specifics of each interview and which deviations from the list of questions were made.

<u>P1, Discipline</u>

The first interview was conducted with someone in the role of discipline. He indicated that his primary role was advisor of installations. His definition of BIM was similar to the one used in this report. He did not create models himself but did still now how to do it from the past. Therefore, he sometimes made small changes in models. Extra information was asked regarding the software Fabi that came up. Although a lot of 3D modelling already takes place, a lot more can be done with BIM according to him. An appropriate project that included a preliminary design and a definitive design was taken to discuss the barriers. All disciplines from the department were involved in the project. However, no specific person was involved for the BIM process. The building and structural engineers modelled in 3D and the MEP engineers made 2D drawings. Several barriers were discussed with regard to this project. Moreover, barriers related to previous projects were also discussed. Training was mentioned and an extra question was asked about how this training is included in paid working hours, since these hours have to be booked on specific projects. A few new barriers came up while discussing interventions. The current measures were discussed as well as the organizational component most important in the implementation of BIM. Thereafter, the participant indicated how the implementation should continue. Finally, the game three was discussed.

<u>P2, BIM coordinator</u>

The second interviewee was a BIM coordinator. However, his official role is head designer, since the term BIM coordinator did not exist when he started. The definition of BIM given by the participant was in line with the definition used in this study. The participant indicated to work as much as possible according to BIM. However, he indicated that some projects only include 3D modelling, whereas others also include the collaboration where everyone can see the model and where all information is exchanged through the model. The participant is very much in favour of using BIM. The barriers were discussed based on project including a definitive design. It is a small project that is part of a large BIM project. Several external parties were involved in the project as well as several disciplines of the department. Barriers experienced in previous projects were also discussed. Several new barriers came up during the questions about possible interventions. The organizational level and current measures were discussed. An extra question was asked in order to understand the current system of training within the department. The participant did not come up with any concrete next step for the BIM implementation process. Finally, the game tree was discussed.

<u>P3, Project leader</u>

The third participant was interviewed as project leader, but also fulfils the role of senior advisor or building and structural engineer. The definition of BIM is similar to the one used in this study. The interviewee does not model anything in BIM himself, but does use BIM360 as a tool for insights, and is in favour BIM. A base project was used that included a preliminary design stage and several external actors. It was a small project were one person fulfilled the role of multiple disciplines and only a couple of others from the department were involved. The cooperation in the project went smoothly because of the introduction of BIM360. No new barriers came up during the questions about possible interventions for the before mentioned barriers. The organizational level and the current measures were discussed. The participant described a desired next step and verified the game tree.

P4, BIM coordinator
The fourth interviewee was a BIM coordinator. The definition of BIM provided by the participant is similar to the one used in this report. Moreover, the participant is constantly working with BIM, but is sceptical to its application. It should be applied in a goal-oriented way. A base project which included a preliminary design or definitive design was taken in which several parties were involved, including two disciplines from the department. Barriers experienced in previous projects were also discussed. An extra question was asked with regard to the benefits of BIM for the department compared to the costs. Several new barriers came up while discussing interventions. The organization level, current measures and the next step were discussed. Finally, the game tree was discussed.

P5, Project leader
This interviewee worked as project leader at Movares for one year at the time of interviewing. The definition of BIM provided by the participant was similar to the one used in this report. The interviewee does not model in BIM directly, but does use the model for, for example, clash controls. The participant is positive about BIM but also clarifies that a lot of effort is put in the models which does not yet results in benefits. The base project that was used included a preliminary and definitive design. However, the participant joined the project halfway the definitive design. Two disciplines from the department were involved in this project and external parties. An extra question was asked to clarify the extra value of a 3D model compared to a 2D drawing. The participant did not experience other barriers in other projects while working at Movares. Several new barriers came up while interventions were discussed. The interviewees opinion about the organizational level and the current measures was asked. The current measures were not discussed separately, since they came up in an earlier phase of the interview. Finally, the game tree was discussed.

P6, Discipline
The sixth interviewee is a structural engineer that works as an advisor. The definition of BIM was in line with the one used in this report. The participant only works part of the time with BIM, depending on the project, and is very positive towards it. The base project taken for the barriers included two disciplines from the department. The participant did not mention any other barriers when this person was asked to previous projects. Several new barriers came up while questions were asked about possible solutions for the beforementioned barriers. An extra question was asked about why one discipline is behind the other disciplines with regard to BIM and 3D modelling in general. The organizational level and the current measures were discussed. A next step was not asked for, since the participant already provided this information in an earlier phase of the interview. Finally, the game tree was discussed.

P7, Discipline
This participant is a building engineer that works as an advisor as well as integrated design leader. Therefore, it was asked to focus specifically on the role of building engineer. The definition of BIM provided by the participant is similar to the one used in this study. The participant works only limitedly with BIM, since project are mainly about 3D modelling, but do not include the exchange of information through the model. The interviewee is very

positive about BIM, but also sees some difficulties. A base project was taken that included both a preliminary and definitive design. Two disciplines from the department were involved and external parties. Regarding the barriers, an extra question was asked to understand the differences in barriers experienced by an integrated design leader and a building engineering advisor. Other barriers based on previous projects were also discussed. Several new barriers came up when interventions were discussed. The organizational level, current measures and the next step were discussed. Finally, the game tree was explained, and input was given by the participant.

P8, BIM coordinator
The eight participant is a BIM coordinator that also works as an advisor and integrated design leader. Therefore, this participant was asked to answer questions according to the role of BIM coordinator. The definition of BIM of the interviewee is in line with the one used in this report. The participant works with BIM depending on the project stages that are asked and is very positive towards BIM. A project with a masterplan design stage was taken as a basis for the question about barriers, since this participant did not work on projects that included a definitive or preliminary design project stage yet. Several external parties and departments within Movares were involved in this project, but only one discipline from the department of integrated design. Barriers experienced in other projects executed at the department were also discussed. Several new barriers came up when discussing interventions. The organizational level, current measures and the next step. The game tree was not discussed in the interview, since the participant requested to do this by mail.

P9, Project leader
This participant is a MEP engineer and works as an advisor but also as a project leader. The interviewee was asked to focus on this latter role. The definition of BIM provided by the participant is similar to the one used in this study. The participant indicated to work a lot with 3D modelling, but that this is not necessarily BIM. The interviewee explained to be very positive about BIM. A base project was taken that included a preliminary design or a definitive design and where several external parties were involved. The participant brought up barriers in other projects, so this was not asked for in this interview. More barriers came up during the discussion of interventions. The organizational level was discussed. The participant was not able to say anything about the current measures. Finally, the next step and game tree were discussed.

P10, Discipline
The final interviewee worked at the discipline of architecture as an architect. The definition of BIM given by the participant was in line with the one used in this study. The participant indicated to work often in early project stages and therefore not work with BIM very often. The interviewee is very much in favour of BIM. Since this participant did not participate in any projects that included a preliminary or definitive design. Therefore, the barriers were discussed based on other projects in which colleagues of the participant participated. In these projects, other disciplines from the department also contributed. The role of the architects in the cooperation with the other disciplines was extensively discussed. The organizational level important for BIM implementation was discussed. The questions about current measures was not asked, since these already came up in an earlier phase of the interview. Finally, the next step with regard to the implementation of BIM and the game tree were discussed.

C.3. Top- and sub-nodes

Barriers

- Accuracy of BIM is too high
- False BIM expectations
- Increased dependence on integrated cooperation
- Inefficiency of BIM
- Information exchange with external parties
- Lack of awareness of other disciplines work
- Lack of BIM knowledge and experience
- Lack of BIM protocol
- Lack of BIM skills
- Lack of clear roles with regard to BIM
- Lack of facilities
- Lack of smart linkage between models
- Mindset not in favour of BIM
- Organizational culture hindering BIM
- Shortage of time
- Uneven distribution of work

BIM enablers

- Coordination
- Faster cost calculation
- General
- Less re-do
- Openness and communication

Extend of BIM use

Game tree

- Suggested to add players
- Suggested to change players
- Verification of game tree

Interventions

- Adding extra role at the department
- Capacity overview
- Changing organizational culture
- Communication
- Creating awareness
- Facilities
- Feedback
- Hiring people
- Making clear agreements in advance
- Practice

- Providing facilities
- Selling BIM to client
- Shift in mindset
- Training

Interventions for barrier

- Accuracy of BIM is too high
- False BIM expectations
- Increased dependence on integrated cooperation
- Inefficiency of BIM
- Information exchange with external parties
- Lack of awareness of other disciplines work
- Lack of BIM knowledge and experience
- Lack of BIM protocol
- Lack of BIM skills
- Lack of clear roles with regard to BIM
- Lack of facilities
- Lack of smart linkage between models
- Mindset not in favour of BIM
- Organizational culture hindering BIM
- Shortage of time
- Uneven distribution of work

Next step

- Automate
- Change in mindset
- Continuous development
- Creating strong team of modellers
- Deciding in advance to include BIM
- Decreasing workload of BIM specialists
- Including BIM in business policy
- Licenses
- Practice
- Providing templates
- Training

Organizational component in BIM implementation

Personal BIM attitude

C.4. How barriers found in interviews relate to literature

Table C.1

Relation of barriers found in literature and barriers found in interviews.

Barriers from interviews	Barriers from literature	Explanation
Accuracy of BIM is too high	Accuracy	
Difficulty in information exchange with external parties	Lack of collaborative work processes and standards	The information exchange with external parties also relates to the time estimation made for projects.
False BIM expectations	Distribution of costs and benefits	False BIM expectations includes the distribution of costs and benefits, but also the BIM expectations of the ones working on the project.
Increased dependence on integrated cooperation	Lack of trust, openness and transparency, lack of collaborative work processes and standards	
Inefficiency of BIM	Enforcement and recognition by owners, not all partners work with BIM	Inefficiency of BIM also relates to the lack of a BIM model of the existing situation.
Lack of awareness of other disciplines work	Inadequate knowledge	Disciplines do not have enough understanding of each other's work in order to properly take this into account.
Lack of BIM knowledge and experience	Inadequate knowledge, overall understanding of BIM	
Lack of BIM protocol	Lack of collaborative work processes and standards	The barrier lack of BIM protocol is assigned when the lack of collaborative work processes and standards is caused by the lack of a BIM protocol
Lack of BIM skills	Lack of skilled personnel	
Lack of clear roles with regard to BIM		
Lack of facilities	Availability and quality of ICT facilities	
Lack of smart linkage between models	Accessibility of models/ interoperability	
Mindset not in favour of BIM	Shift of mindset	
Organizational culture hindering BIM		
Shortage of time	Time constraints	
Uneven distribution of work	Increased workload	Uneven distribution of work includes both the increased workload as well as a shift in workload towards the ones who are experienced with BIM.

Appendix D: Utility

D.1. Survey questions

Which measures are most effective in supporting BIM use?

Thank you for opening this questionnaire. The goal of these questions is to understand which interventions can best be used to support the BIM use at the department of Integrated Design. The measures that are presented in this questionnaire are based on barriers that are experienced with regard to BIM. These barriers were found by conducting interviews at the department.

This questionnaire consists of four parts. Every part describes a different measure. For each measure the same fourteen scenarios are presented. These scenarios are based on the current BIM process at the department and exactly the same for every measure.

For every scenario, the same question is asked. This question consists of three aspects that should each be rated.

The questionnaire starts below with four general questions.

1. What is your role at the department?

- o Project leader
- o BIM coordinator (or BIM specialist)
- o Discipline of architecture
- o Discipline of building engineering
- o Discipline of structural engineering
- o Discipline of MEP engineering
- o From the viewpoint of the client

2. How often do you work with BIM?

BIM is defined here as at least a 3D model, where collaboration is done through digital information models in multiple phases of the building life cycle.

- o Never
- o Rarely
- o Sometimes
- o Regularly
- o Often

3. How long have you been working at Movares?

……………………………

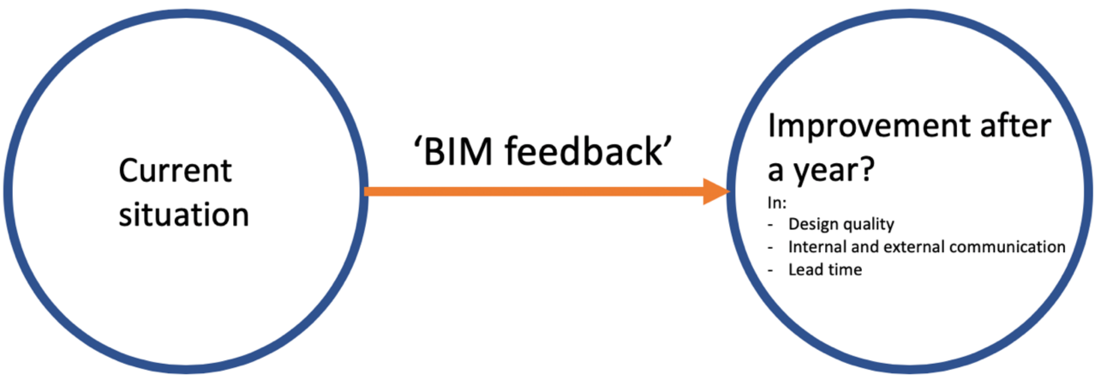
4. How important are each of the following aspects with regard to the BIM process at the department?

	0 Not important	1	2	3	4	5	6	7	8	9	10 Very important
Design quality	○	○	○	○	○	○	○	○	○	○	○
Internal and external communication	○	○	○	○	○	○	○	○	○	○	○
Lead time	○	○	○	○	○	○	○	○	○	○	○

Measure 1: Development of BIM skills with feedback system
During the interviews many people indicated that a training alone is not enough to start working according to BIM.

Therefore, the following measure is proposed:
Besides providing trainings, both project leaders and the disciplines get the opportunity to practice with BIM. BIM coordinators gather feedback about how the trainings and practice are contributing to an increase in BIM skills. Based on this feedback, the trainings and practice options are continuously improved.

In order to understand the effect of this measure, this section presents fourteen scenarios. For every scenario three questions are asked based on this measure.



1.1 Imagine that the measure 'BIM feedback' is used for a year already. To what extent would this, in comparison to the current situation, lead to an improvement in the scenario presented below?

Scenario 1	Yes (according to BIM)	No
Client requests BIM		No
Project leader works according to BIM		No
A **BIM coordinator** is assigned for the project		No
A **BIM-protocol** is present		No
Disciplines all work according to BIM		No

	0 No improvement	1	2	3	4	5	6	7	8	9	10 Much improvement
Design quality	○	○	○	○	○	○	○	○	○	○	○
Internal and external communication	○	○	○	○	○	○	○	○	○	○	○
Lead time	○	○	○	○	○	○	○	○	○	○	○

1.2 Imagine that the measure 'BIM feedback' is used for a year already. To what extent would this, in comparison to the current situation, lead to an improvement in the scenario presented below?

Scenario 2	Yes (according to BIM)	No
Client requests BIM		No
Project leader works according to BIM		No
A **BIM coordinator** is assigned for the project		No
A **BIM-protocol** is present		No
Disciplines all work according to BIM	Yes	

	0 No improvement	1	2	3	4	5	6	7	8	9	10 Much improvement
Design quality	○	○	○	○	○	○	○	○	○	○	○
Internal and external communication	○	○	○	○	○	○	○	○	○	○	○
Lead time	○	○	○	○	○	○	○	○	○	○	○

1.3 Imagine that the measure 'BIM feedback' is used for a year already. To what extent would this, in comparison to the current situation, lead to an improvement in the scenario presented below?

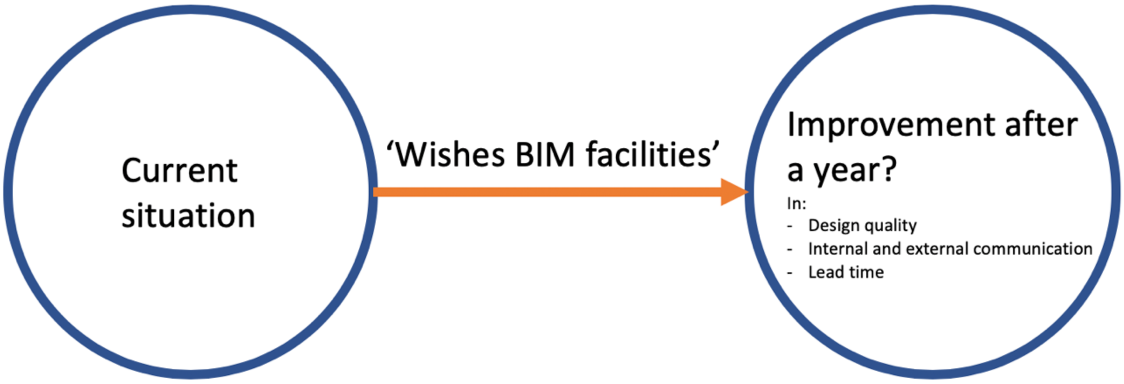
Scenario 3	Yes (according to BIM)	No
Client requests BIM		No
Project leader works according to BIM	Yes	
A **BIM coordinator** is assigned for the project		No
A **BIM-protocol** is present		No
Disciplines all work according to BIM		No

	0 No improvement	1	2	3	4	5	6	7	8	9	10 Much improvement
Design quality	○	○	○	○	○	○	○	○	○	○	○
Internal and external communication	○	○	○	○	○	○	○	○	○	○	○
Lead time	○	○	○	○	○	○	○	○	○	○	○

Measure 2: Linking wishes for facilities from BIM projects with possibilities
During the interviews many people indicated that the current facilities are not optimally aligned with BIM projects. Facilities include for example software and smartboards.

The following measure is proposed:
An extra role is added to the department. This person links the wishes from BIM projects with the possibilities of existing facilities. By informing this person about the needs and wishes from BIM projects and this persons' knowledge of possibilities of existing facilities, these can be aligned. By doing this, both existing and future tools can be optimized for the BIM process.

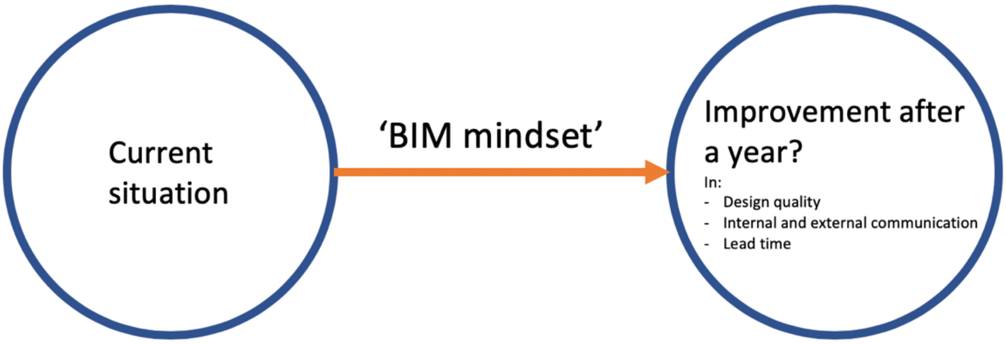
In order to understand the effect of this measure, this section presents fourteen scenarios. For every scenario three questions are asked based on this measure.



Measure 3: Change in mindset
During the interviews it was also indicated that not everyone is yet in favour of BIM.

The following measure could help:
Management, amongst others, more strongly insists more strongly on the use of BIM. This decreases the freedom to choose whether to work according to BIM or not. Moreover, people with a more positive BIM attitude are linked to people with a less positive BIM attitude. By doing this it becomes easier to show the benefits of BIM and to give insight into the BIM process.

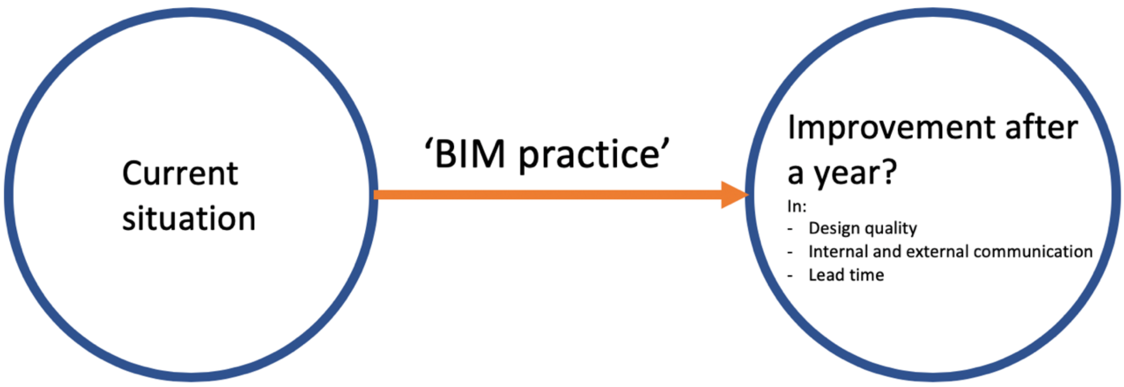
In order to understand the effect of this measure, this section presents fourteen scenarios. For every scenario three questions are asked based on this measure.



Measure 4: Allowing for BIM practice time
Interviewees also indicated that there are currently few possibilities to get acquainted with BIM.

Therefore, the following measure is proposed:
People are allowed more time to practice with BIM. People get the opportunity to watch along in BIM projects to gain experience. On top of that, people get the possibility to work in longer running projects in order to learn how to work according to BIM. Moreover, more projects are executed according to BIM at the department in order to provide more possibilities to work according to BIM. Finally, attention is paid to the distribution of BIM projects, so people with less BIM skills also get the opportunity to develop their skills.

In order to understand the effect of this measure, this section presents fourteen scenarios. For every scenario three questions are asked based on this measure.



By ticking the box 'I accept', you indicate that you are aware that you are participating in scientific research and that you can terminate your participation at any time by sending an e-mail to merel.backx@movares.nl

Thank you for participating. In case you have any comments, you can leave them here.
………..

D.2. Formulas utility

Relative importance of aspect *design quality (q)* for the player *disciplines (D) for participant 1*:

$$RI_{Dqn_1} = \left(\frac{I_{Dq}}{I_{Dq} + I_{Dc} + I_{Dt}}\right) * 100\%$$

The same is done for the aspects *internal and external communication (c)* and *lead time (t).*

Average utility for the player *disciplines (D)*, the intervention *BIM feedback (W)*, *end branch 1* and aspect *design quality (Q)*(U_{DW1Q}):

$$U_{DW1Qn_1} = RI_{Dqn_1} * Q_{DW1n_1}$$

The utility for the player *disciplines (D)* for intervention *BIM feedback (W)* for *end branch 1:*

$$U_{DW1n_1} = U_{DW1qn_1} + U_{DW1cn_1} + U_{DW1tn_1}$$

Average score on aspect *design quality (Q)* for *end branch 1* of the game tree for intervention *BIM feedback (W)*:

$$U_{DW1} = \sum_{0}^{n} Q_{DW1n_1} + Q_{DW1n_2} + \cdots + Q_{DW1n}$$

The same formulas are used to calculate the utility for each player under each intervention for each end branch of the game tree. Table D.1 provides an overview of the letters used in the formulas.

Table D.1

Overview of letters used in formulas.

Aspect	**Player**	**Intervention**	**End branch of game tree**
Q: Design quality	D: Disciplines	W: BIM feedback	1-14, where 1 indicates the far-left end branch.
C: Internal and external communication	B: BIM coordinator	X: BIM facilities	
T: Lead time	P: Project leader	Y: BIM mindset	
	C: Client	Z: BIM practice	

Appendix E: Game theory

E.1. Part-worth probabilities

In order to calculate the probabilities, the nodes of the project leader were split up in two stages as can be seen in the game tree below. This was done to make the probability calculations easier. The formulas are applied for the utilities found for the intervention *BIM feedback, BIM facilities, BIM mindset, and BIM practice.*

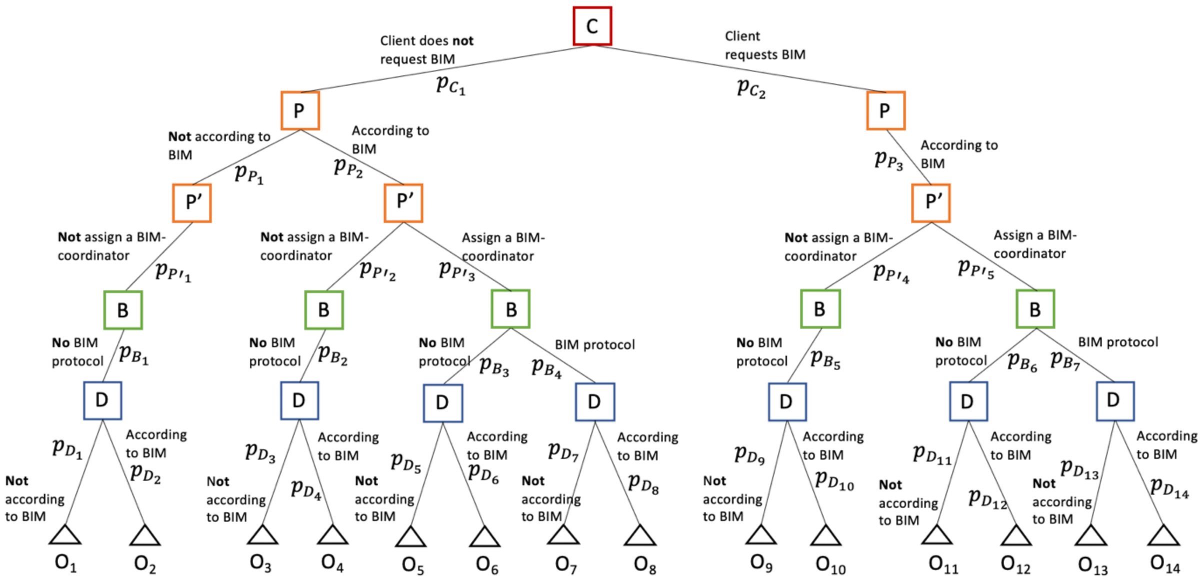


Figure E.1. Game tree used for probability calculations.

Probabilities players

$$p_{D_1} = \int_{-\infty}^{U_D(O_1) - U_D\,(O_2)} \emptyset(\eta_{WD12})d\eta_{WD12}$$

$$p_{D_2} = 1 - p_{D_1}$$

$$p_{D_3} = \int_{-\infty}^{U_D(O_3) - U_D\,(O_4)} \emptyset(\eta_{WD34})d\eta_{WD34}$$

$$p_{D_4} = 1 - p_{D_3}$$

$$p_{D_5} = \int_{-\infty}^{U_D(O_5) - U_D\,(O_6)} \emptyset(\eta_{WD56})d\eta_{WD56}$$

$$p_{D_6} = 1 - p_{D_5}$$

$$p_{D_7} = \int_{-\infty}^{U_D(O_7) - U_D\,(O_8)} \emptyset(\eta_{WD78})d\eta_{WD78}$$

$$p_{D_8} = 1 - p_{D_7}$$

$$p_{D_9} = \int_{-\infty}^{U_D(O_9) - U_D\,(O_{10})} \emptyset(\eta_{WD910})d\eta_{WD910}$$

$$p_{D_{10}} = 1 - p_{D_9}$$

$$p_{D_{11}} = \int_{-\infty}^{U_D(O_{11}) - U_D\,(O_{12})} \emptyset(\eta_{WD1112})d\eta_{WD1112}$$

$$p_{D_{12}} = 1 - p_{D_{11}}$$

$$p_{D_{13}} = \int_{-\infty}^{U_D(O_{13}) - U_D\,(O_{14})} \emptyset(\eta_{WD1314})d\eta_{WD1314}$$

$$p_{D_{14}} = 1 - p_{D_{13}}$$

$$p_{B_1} = 1$$

$$p_{B_2} = 1$$

$$p_{B_3} = \int_{-\infty}^{(p_{D_5}U_B(O_5) + p_{D_6}U_B\,(O_6)) - (p_{D_7}U_B(O_7) + p_{D_8}U_B\,(O_8))} \emptyset(\eta_{WB34})d\eta_{WB34}$$

$$p_{B_4} = 1 - p_{B_3}$$

$$p_{B_5} = 1$$

$$p_{B_6} = \int_{-\infty}^{(p_{D_{11}}U_B(O_{11}) + p_{D_{12}}U_B\,(O_{12})) - (p_{D_{13}}U_B(O_{13}) + p_{D_{14}}U_B\,(O_{14}))} \emptyset(\eta_{WB67})d\eta_{WB67}$$

$$p_{B_7} = 1 - p_{B_6}$$

$$p_{P'_1} = 1$$

$$p_{P'_2} = \int_{-\infty}^{\substack{(p_{B_2}p_{D_3}U_{P'}(O_3) + p_{B_3}p_{D_4}U_{P'}(O_4)) - (p_{B_3}p_{D_5}U_{P'}(O_5) + p_{B_3}p_{D_6}U_{P'}(O_6) \\ + p_{B_4}p_{D_7}U_{P'}(O_7) + p_{B_4}p_{D_8}U_{P'}(O_8))}} \emptyset(\eta_{WP'23})d\eta_{WP'23}$$

$$p_{P'_3} = 1 - p_{P'_2}$$

$$p_{P'_4} = \int_{-\infty}^{\substack{(p_{B_5}p_{D_9}U_{P'}(O_9) + p_{B_5}p_{D_{10}}U_{P'}(O_{10})) - (p_{B_6}p_{D_{11}}U_{P'}(O_{11}) + p_{B_6}p_{D_{12}}U_{P'}(O_{12}) \\ + p_{B_7}p_{D_{13}}U_{P'}(O_{13}) + p_{B_7}p_{D_{14}}U_{P'}(O_{14}))}} \emptyset(\eta_{WP'45})d\eta_{WP'45}$$

$$p_{P'_5} = 1 - p_{P'_4}$$

$$p_{P_1} = \int_{-\infty}^{\substack{(p_{P'_1}p_{B_1}p_{D_1}U_P(O_1) + p_{P'_1}p_{B_1}p_{D_2}U_P(O_2)) - (p_{P'_2}p_{B_2}p_{D_3}U_P(O_3) + p_{P'_2}p_{B_2}p_{D_4}U_P(O_4) + \\ p_{P'_3}p_{B_3}p_{D_5}U_P(O_5) + p_{P'_3}p_{B_3}p_{D_6}U_P(O_6) + p_{P'_3}p_{B_4}p_{D_7}U_P(O_7) + p_{P'_3}p_{B_4}p_{D_8}U_P(O_8))}} \emptyset(\eta_{WP12})d\eta_{WP12}$$

$$p_{P_2} = 1 - p_{P_1}$$

$$p_{P_3} = 1$$

$$p_{C_1} = \int_{-\infty}^{\substack{(p_{P_1}p_{P'_1}p_{B_1}p_{D_1}U_C(O_1) + p_{P_1}p_{P'_1}p_{B_1}p_{D_2}U_C(O_4) + p_{P_2}p_{P'_2}p_{B_2}p_{D_3}U_C(O_3) + \\ p_{P_2}p_{P'_2}p_{B_2}p_{D_4}U_C(O_4) + p_{P_2}p_{P'_3}p_{B_3}p_{D_5}U_C(O_5) + p_{P_2}p_{P'_3}p_{B_3}p_{D_6}U_C(O_6) \\ + p_{P_2}p_{P'_3}p_{B_4}p_{D_7}U_C(O_7) + p_{P_2}p_{P'_3}p_{B_4}p_{D_8}U_C(O_8)) - (p_{P_3}p_{P'_4}p_{B_5}p_{D_9}U_C(O_9) + \\ p_{P_3}p_{P'_4}p_{B_5}p_{D_{10}}U_C(O_{10}) + p_{P_3}p_{P'_5}p_{B_6}p_{D_{11}}U_C(O_{11}) + p_{P_3}p_{P'_5}p_{B_6}p_{D_{12}}U_C(O_{12}) \\ + p_{P_3}p_{P'_5}p_{B_7}p_{D_{13}}U_C(O_{13}) + p_{P_3}p_{P'_5}p_{B_7}p_{D_{14}}U_C(O_{14}))}} \emptyset(\eta_{WC12})d\eta_{WC12}$$

$$p_{C_2} = 1 - p_{C_1}$$

E.2. Outcome probabilities

These formulas are applied to four game trees. One for the intervention *BIM feedback*, *BIM facilities, BIM mindset, and BIM practice*

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$p_1 = p_{C_1} * p_{P_1} * p_{P'_1} * p_{B_1} * p_{D_1}$

$p_2 = p_{C_1} * p_{P_1} * p_{P'_1} * p_{B_1} * p_{D_2}$

$p_3 = p_{C_1} * p_{P_2} * p_{P'_2} * p_{B_2} * p_{D_3}$

$p_4 = p_{C_1} * p_{P_2} * p_{P'_2} * p_{B_2} * p_{D_4}$

$p_5 = p_{C_1} * p_{P_2} * p_{P'_3} * p_{B_3} * p_{D_5}$

$p_6 = p_{C_1} * p_{P_2} * p_{P'_3} * p_{B_3} * p_{D_6}$

$p_7 = p_{C_1} * p_{P_2} * p_{P'_3} * p_{B_4} * p_{D_7}$

$p_8 = p_{C_1} * p_{P_2} * p_{P'_3} * p_{B_4} * p_{D_8}$

$p_9 = p_{C_2} * p_{P_3} * p_{P'_4} * p_{B_5} * p_{D_9}$

$p_{10} = p_{C_2} * p_{P_3} * p_{P'_4} * p_{B_5} * p_{D_{10}}$

$p_{11} = p_{C_2} * p_{P_3} * p_{P'_5} * p_{B_6} * p_{D_{11}}$

$p_{12} = p_{C_2} * p_{P_3} * p_{P'_5} * p_{B_6} * p_{D_{12}}$

$p_{13} = p_{C_2} * p_{P_3} * p_{P'_5} * p_{B_7} * p_{D_{13}}$

$p_{14} = p_{C_2} * p_{P_3} * p_{P'_5} * p_{B_7} * p_{D_{14}}$

E.3. Expected utilities

Expected utilities player disciplines (D)

$$O_{D_1} = U_{D_1} * p_{O_1}$$

$$O_{D_2} = U_{D_2} * p_{O_2}$$

$$O_{D_3} = U_{D_3} * p_{O_3}$$

$$O_{D_4} = U_{D_4} * p_{O_4}$$

$$O_{D_5} = U_{D_5} * p_{O_5}$$

$$O_{D_6} = U_{D_6} * p_{O_6}$$

$$O_{D_7} = U_{D_7} * p_{O_7}$$

$$O_{D_8} = U_{D_8} * p_{O_8}$$

$$O_{D_9} = U_{D_9} * p_{O_9}$$

$$O_{D_{10}} = U_{D_{10}} * p_{O_{10}}$$

$$O_{D_{11}} = U_{D_{11}} * p_{O_{11}}$$

$$O_{D_{12}} = U_{D_{12}} * p_{O_{12}}$$

$$O_{D_{13}} = U_{D_{13}} * p_{O_{13}}$$

$$O_{D_{14}} = U_{D_{14}} * p_{O_{14}}$$

Expected utilities player BIM coordinator (B)

$$O_{B_1} = (U_{B_1} * p_{O_1}) + (U_{B_2} * p_{O_2})$$

$$O_{B_2} = (U_{B_3} * p_{O_3}) + (U_{B_4} * p_{O_4})$$

$$O_{B_3} = (U_{B_5} * p_{O_5}) + (U_{B_6} * p_{O_6})$$

$$O_{B_4} = (U_{B_7} * p_{O_7}) + (U_{B_8} * p_{O_8})$$

$$O_{B_5} = (U_{B_9} * p_{O_9}) + (U_{B_{10}} * p_{O_{10}})$$

$$O_{B_6} = (U_{B_{11}} * p_{O_{11}}) + (U_{B_{12}} * p_{O_{12}})$$

$$O_{B_7} = (U_{B_{13}} * p_{O_{13}}) + (U_{B_{14}} * p_{O_{14}})$$

Expected utilities player project leader assigning BIM coordinator (P')

$$O_{p'_1} = (U_{p'_1} * p_{O_1}) + (U_{p'_2} * p_{O_2})$$

$$O_{p'_2} = (U_{p'_3} * p_{O_3}) + (U_{p'_4} * p_{O_4})$$

$$O_{p'_3} = (U_{p'_5} * p_{O_5}) + (U_{p'_6} * p_{O_6}) + (U_{p'_7} * p_{O_7}) + (U_{p'_8} * p_{O_8})$$

$$O_{p'_4} = (U_{p'_9} * p_{O_9}) + (U_{p'_{10}} * p_{O_{10}})$$

$$O_{p'_5} = (U_{p'_{11}} * p_{O_{11}}) + (U_{p'_{12}} * p_{O_{12}}) + (U_{p'_{13}} * p_{O_{13}}) + (U_{p'_{14}} * p_{O_{14}})$$

Expected utilities player project leader working according to BIM (P)

$$O_{P_1} = (U_{P_1} * p_{O_1}) + (U_{P_2} * p_{O_2})$$

$$O_{P_2} = (U_{P_3} * p_{O_3}) + (U_{P_4} * p_{O_4}) + (U_{P_5} * p_{O_5}) + (U_{P_6} * p_{O_6}) + (U_{P_7} * p_{O_7}) + (U_{P_8} * p_{O_8})$$

$$O_{P_3} = (U_{P_9} * p_{O_9}) + (U_{P_{10}} * p_{O_{10}}) + (U_{P_{11}} * p_{O_{11}}) + (U_{P_{12}} * p_{O_{12}}) + (U_{P_{13}} * p_{O_{13}}) + (U_{P_{14}} * p_{O_{14}})$$

Expected utilities player client (C)

$$O_{C_1} = (U_{C_1} * p_{O_1}) + (U_{C_2} * p_{O_2}) + (U_{C_3} * p_{O_3}) + (U_{C_4} * p_{O_4}) + (U_{C_5} * p_{O_5}) + (U_{C_6} * p_{O_6}) + (U_{C_7} * p_{O_7}) + (U_{C_8} * p_{O_8})$$

$$O_{C_2} = (U_{C_9} * p_{O_9}) + (U_{C_{10}} * p_{O_{10}}) + (U_{C_{11}} * p_{O_{11}}) + (U_{C_{12}} * p_{O_{12}}) + (U_{C_{13}} * p_{O_{13}}) + (U_{C_{14}} * p_{O_{14}})$$