MATURITIES IN BUILDING INFORMATION MODELLING

A MULTI-LEVEL PERSPECTIVE

SANDER SIEBELINK

**MATURITIES IN
BUILDING INFORMATION MODELLING**

a multi-level perspective

Sander Siebelink

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BUILDING INFORMATION MODELLING
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Table of Contents

Chapter 1 Introduction	9
1.1 Building Information Modelling: the path towards effective collaboration?	10
1.2 Problem statement and objective	11
1.3 Sub-aims and research questions	12
1.4 Research methodology	16
1.5 Thesis outline.....	21
 Chapter 2 Developing and testing a tool to evaluate BIM maturity	 23
2.1 Introduction.....	25
2.2 Assessment of existing maturity models	27
2.3 Developing a new BIM maturity model.....	31
2.4 Method and data collection.....	38
2.5 Results of the BIM maturity assessment interviews	41
2.6 Discussion.....	49
2.7 Conclusions	53
 Chapter 3 Understanding barriers to BIM implementation.....	 57
3.1 Introduction.....	59
3.2 Theoretical background	60
3.3 Methodology	64
3.4 Results	72
3.5 Discussion.....	92
3.6 Conclusions	96
 Chapter 4 Exploring strategies for managing maturity variations among project partners	 99
4.1 Introduction.....	101
4.2 Background	102
4.3 Methodology	104
4.4 Results	112
4.5 Cross-case analysis	128
4.6 Discussion.....	131
4.7 Conclusions	134

Chapter 5	Team Mental Models for BIM use in construction projects	137
5.1	Introduction	139
5.2	Research model	140
5.3	Methodology	145
5.4	Results	151
5.5	Discussion	172
5.6	Conclusions	178
Chapter 6	Conclusions	181
6.1	Major conclusions	182
6.2	Theoretical contributions	187
6.3	Managerial contributions	192
6.4	Reflections on the methodology	196
6.5	Future research directions	200
	Summary	204
	Samenvatting	208
	References	214
	Acknowledgements	226
	About the author	229

CHAPTER 1

INTRODUCTION

1.1 Building Information Modelling: the path towards effective collaboration?

The construction industry is seen as one of the least digitalized sectors with productivity growth lagging behind other manufacturing industries (McKinsey Global Institute, 2017). However, over the last decade, the construction industry is catching up in terms of digitalization by widely adopting Building Information Modelling (BIM) (McGraw Hill Construction, 2014). Based on a literature review of BIM definitions, this PhD thesis identifies the following elements as essential elements of Building Information Modelling:

- An object-based definition of a construction and the construction elements thereof (Eastman, Teicholz, Sacks, & Liston, 2011).
- Cooperation between multiple disciplines within and across the different phases of a project (Miettinen & Paavola, 2014).
- A life cycle perspective of a construction object (Eastman et al., 2011; Gu & London, 2010; Miettinen & Paavola, 2014).
- A consistent digital representation (in 3D) of a construction object supported by Information Technology (Eastman et al., 2011; Gu & London, 2010).
- A consistent centralized repository for all project- and asset-related data (Gu & London, 2010; Succar, 2009).

To summarize, BIM should be seen as an object-based, multidisciplinary approach that aims to facilitate collaboration between parties and to integrate object-related information over the entire life cycle of an asset. This function is supported by IT that is often used to capture building objects as 3D representations. BIM is claimed to contribute to effective collaboration, and has also made the interdependency of parties apparent (Whyte, 2019). These interdependencies are clearly visible in the implementation of Building Information Modelling (BIM), where some organizations are only just taking the first steps whereas others have progressed far further. Below, I explain further how these variations pose challenges to inter-organizational BIM use, that motivated the research leading to this thesis.

1.2 Problem statement and objective

The adoption of BIM is widely expected to significantly increase productivity as well as to significantly reduce costs. The Boston Consulting Group (2016) estimated the cost savings to be between 10-20% over the coming ten years. However, the expected benefits of BIM, such as increased efficiency and enhanced collaboration with partners (Bryde, Broquetas, & Volm, 2013; Eadie, Browne, Odeyinka, McKeown, & McNiff, 2013; Eastman et al., 2011; Miettinen & Paavola, 2014), are not always realized in practice (Dainty, Leiringer, Fernie, & Harty, 2017; Georgiadou, 2019; Neff, Fiore-Silfvast, & Dossick, 2010). It seems that some projects make use of BIM in a professional manner, but others do not. This degree of professionalism is referred to as BIM maturity. Parties working together in a project will have different individual levels of BIM maturity, and this will hamper realization of project-related BIM goals. Indeed, Adriaanse, Voordijk, and Dewulf (2010a) stated that some parties are limited by their BIM maturity or capabilities. This claim is supported by case studies showing that varying BIM maturity levels among project partners limit the degree to which BIM goals and accompanying expectations, such as reduced failure costs or more efficient project execution, can be realized (Siebelink, Adriaanse, & Voordijk, 2015, 2016). Various explanations have been put forward for the variations in BIM maturity levels of organizations. One of them relates to the multidisciplinary character of construction involving many different firms that vary in size, with most being small and often regionally oriented (Lönngren, Rosenkranz, & Kolbe, 2010; Poirier, Staub-French, & Forgues, 2015). These small firms in the construction supply chain often lack both the financial and the human resources required to make adopting new technology and innovation viable (Benjaoran, 2009; Lönngren et al., 2010). Thus, while some firms invest heavily in digitization, many others are reluctant or not financially able to do so. Moreover, the faith in BIM as a beneficial approach for a project seems to vary among the different disciplines involved (Dainty, Briscoe, & Millett, 2001). These authors argue that the active involvement of many supplier companies in integrated construction processes is hindered by a lack of belief in there being mutual benefits. The involvement of the various disciplines is deemed important because of the reciprocal interdependencies in construction, i.e. both between sequential phases and overlapping phases in the construction process (Bankvall, Bygballe, Dubois, & Jahre, 2010; Dubois & Gadde, 2002).

To summarize, implementation and use of BIM in inter-organizational collaborations is complicated by variations in BIM maturity. These variations in maturity can be identified on different levels of analysis, i.e., subsectors,

organizations, and projects. First, the degree of professionalism in using BIM varies between organizations. On the subsector level, which can be viewed and measured as an aggregation of organizations within a particular discipline, maturity in BIM may differ because of discipline-specific uses, expected benefits, and associated investments in implementing BIM. Finally, on the project level, the non-aligned maturity of partners, or a complete lack of BIM experience from one of the partners, could hamper collaborative BIM use among disciplines within and across life cycle phases of a construction object (e.g., design, construction). As such, achieving the essential elements found within the definition of BIM, particularly supporting an effective multidisciplinary collaboration over the entire life cycle, is at stake. The aforementioned relevance of understanding cause and effect of variations in BIM maturity from a multilevel perspective has, however, not yet been addressed in literature. From this, the main objective of this thesis is derived as follows:

The objective of this thesis is to disentangle and explain variations in BIM maturity and their effects on the implementation and use of BIM on different levels of analysis in the construction industry.

This main objective highlights the interdependencies across the multiple levels: inter-organizational BIM use in projects cannot be understood without considering the individual participating organizations and their subsector-specific aims and contributions to a project. From a practical perspective, the industry can utilize the gathered insights on the effects of variations in BIM maturity on different levels of analysis to overcome challenges and reap the benefits of inter-organizational BIM use.

1.3 Sub-aims and research questions

Existent research gaps are identified in the assessment of BIM maturity variations, the analysis of consequences stemming from BIM maturity variations on different levels of analysis, and the understanding of how to cope with consequences of variations in BIM maturity, so to enhance a project's performance. Following, five sub-aims have been derived for this thesis:

- Provide a method to evaluate the actual level of BIM maturity for different subsectors and on different levels of analysis, i.e., subsector, organization, and project levels.

- Understand subsector variations in BIM maturity in construction and their implications.
- Identify barriers to increasing BIM maturity in different stages of the implementation process within organizations.
- Understand how to cope with variations in BIM maturity among project partners.
- Explore how a shared understanding of BIM use in projects, a Team Mental Model, could contribute to a project's BIM maturity and other project outcomes.

Below, these aims are further explained and translated into the thesis's main research questions. The research questions have been structured to reflect the addressed levels of analysis (subsector, organization, and project) and match the Chapters 2 to 5 of this thesis.

1.3.1 Maturity assessment and variations on organization and subsector levels (Chapter 2)

The BIM maturity of an organization, in terms of both soft and technical aspects, has a great influence on the extent to which it is able to leverage the potential of information technology (Alshaw, 2007). Differing levels of BIM maturity between organizations representing the various disciplines within the Dutch construction industry are a serious barrier to implementing BIM-supported collaboration among parties. To address this requires a method that can help identify differences in BIM maturity levels between organizations and subsectors. To this end, existing BIM maturity models should be evaluated for their appropriateness for assessing supply chain processes in construction (Lockamy & McCormack, 2004), their ease of use, their clarity in definitions of maturity levels (Liang, Lu, Rowlinson, & Zhang, 2016), and coverage of organizational aspects alongside purely technical BIM aspects (Gu & London, 2010). In addition, to provide comparable outcomes in differing contexts of the construction industry requires an appropriate way to assess all the various disciplines. Further, the results from a BIM maturity model should support individual organizations in identifying priorities for improving their BIM implementation process. Moreover, sectoral associations should be able to use the model's output in defining policies and measures to stimulate BIM from a sector's perspective. The abovementioned needs are captured in the first research question:

1. What assessment model is appropriate to evaluate organizational BIM maturity in different types of organizations in the construction industry?

1.3.2 Maturity variations in organizations related to implementation barriers (Chapter 3)

Furthermore, the implementation of BIM and increasing the maturity in BIM use has been hindered by several barriers. Previous studies have identified many, such as a lack of motivation to switch to BIM practices (e.g. Chien, Wu, & Huang, 2014; Eastman et al., 2011; Gu & London, 2010), insufficient BIM knowledge and competence (e.g. Adriaanse et al., 2010a; Arayici et al., 2011; Liu, Xie, Tivendal, & Liu, 2015), insufficient technological means, Information Technology (IT) support or interoperability issues with different software and data exchange systems (e.g. Chien et al., 2014; Li, Lu, & Huang, 2009; Miettinen & Paavola, 2014). However, the lengthy list gathered from the literature fails to provide a sufficiently advanced understanding of occurrence of barriers in different organizational levels, i.e., from top management down to the operational level of projects. Such in-depth organizational view is essential to understand obstacles in different stages of BIM adoption (Pichlak, 2016) and provide insight into the level at which interventions are likely to be effective. Here, the question is whether organizations can prepare for or avoid barriers by recognizing situations in which typical barriers can be expected. Organizations with a strong focus on BIM and well-structured BIM use, hence higher levels of BIM maturity, are expected to encounter different barriers than organizations that have only recently taken the first steps towards BIM implementation. This raises the need to investigate the barriers to BIM implementation and use in relation to BIM maturity. These efforts could be summarized in the generation of actionable knowledge on how organizations could identify barriers that relate to typical levels of BIM maturity, so to enable appropriate measures to be taken against them. Thereby, organizations can foster the implementation process of BIM. To this end, the following research questions are defined:

- 2a. How can the barriers an organization encounters with respect to BIM implementation and use be mapped on to the particularly affected organizational levels?
- 2b. To what extent are the barriers to BIM implementation and use that occur related to organizational BIM maturity?

1.3.3 Project-level maturity variations and strategies for dealing with them (Chapter 4)

As a further step, this thesis aims to go beyond analyzing the maturity of single organizations and move the focus to inter-organizational collaboration in projects. Here we see that most existing models focus on assessments at the organizational level (Bew, Underwood, Wix, & Storer, 2008; Computer Integrated Construction Research Program, 2013) and only a few explicitly focus on project-level assessments (Chen, Dib, & Cox, 2014; Kam, Senaratna, McKinney, Xiao, & Song, 2014). However, knowledge is lacking on the effect of variations in organizational BIM maturity in the context of project organizations. In particular, previous studies focusing on the project level have provided maturity scores without referring to the diversity of maturity scores present in the project organization. Rajaguru and Matanda (2013) argue that such variations among collaborating parties do matter. In particular, parties should be compatible in terms of strategy, culture, and technology. For example, this could be in terms of software and hardware in the technological infrastructure, a cultural fit between collaborating parties, as well as an alignment of objectives and intentions. If such compatibility is present, higher levels of integration in their work practices and information systems can be achieved. Consequently, it should be possible for supply chains to enhance performance and achieve synergy (Rajaguru & Matanda, 2013; Sarkar, Echambadi, Cavusgil, & Aulakh, 2001). Within the context of construction projects, this study therefore aims to better understand how the individual organizational BIM maturities of the various project partners relate to the maturity of the project as a whole. In addition, the case study considers how project managers deal with the variations in project partner maturity, and situations where the maturity of some of the partners lag behind other parties' levels or the intended level of the project. To address these aims, the following research questions are defined:

- 3a. How is the BIM maturity of project partners related to the overall project maturity?
- 3b. What strategies do project managers use to deal with differences in organizational BIM maturity within a project organization?

1.3.4 Variations in Team Mental Models of BIM use in projects (Chapter 5)

As noted earlier, the use of BIM is often associated with enhanced collaboration among the parties and disciplines involved (Bryde et al., 2013; Porwal & Hewage, 2013). However, despite technological advances, many projects still suffer from barriers related to the industry's fragmented nature, i.e. working in silos, lack of information sharing among disciplines, and unclear task divisions (Oraee et al.,

2019). As a consequence, getting on the same page regarding a project's use of BIM can be challenging. Here, a shared and organized understanding of, for example, tools, work procedures, work strategy, and awareness of member responsibilities – also referred to as a Team Mental Model (Converse, Cannon-Bowers, & Salas, 1993; Klimoski & Mohammed, 1994) - has been linked in research to effective collaboration and high team performance (Cooke et al., 2003; DeChurch & Mesmer-Magnus, 2010; Druskat & Pescosolido, 2002; Fisher, Bell, Dierdorff, & Belohlav, 2012; Van den Bossche, Gijssels, Segers, Woltjer, & Kirschner, 2011). It is for this reason that effective inter-organizational project-level use of BIM is expected to benefit from well-coordinated tasks and shared understanding of the team's work. However, studies on TMMs in the particular context of construction have been scarce and focused on health and safety (Lingard, Peihua Zhang, Blismas, Wakefield, & Kleiner, 2015) or design and construction courses (Forgues & Becerik-Gerber, 2013). Therefore, this study aims to use the lens of Team Mental Models (TMMs) to explore variations of Team Mental Models of BIM in the construction industry. This exploration will help to better understand how team members coordinate their use of BIM. In addition, the study explores whether project outcomes in multidisciplinary projects using BIM can be related to the degree of sharedness in the project partners' mental models of BIM use. The following research questions are posed to achieve these research aims:

- 4a. What variations in project participants' mental models of BIM use are present within the cases studied?
- 4b. How do Team Mental Models of BIM use in the cases relate to the project outcomes?

1.4 Research methodology

The research has been designed in such a way that BIM maturity is addressed on various levels of analysis. The scope is initially broad at the organization level and an aggregation to the subsector level in Chapter 2. Subsequently, an in-depth analysis of the BIM implementation process on various organizational levels is conducted in Chapter 3. In Chapters 4 and 5, the particular focus is on the project level, where inter-organizational collaborations involving BIM take place. These final two chapters therefore mainly address the interfaces of organizational BIM maturities and their effects in real-world project contexts. The positioning and interdependencies of the chapters and accompanying research questions are visualized in Figure 1.

Figure 1. Schematic of research scope representing variations and interdependencies of BIM maturity across multiple levels of analysis: subsector, organization, and project. Arrows link the chapters and research questions with the levels of analysis concerned.

This thesis adopts a case study approach in order to gain a deep understanding of the BIM maturity-related dynamics present within natural settings (Eisenhardt, 1989). In doing so, this thesis extends BIM-maturity-related research, which to date has paid little attention to variations in BIM maturity. Observations from the case studies are analyzed in order to identify relationships between variables involved in the research questions, identify patterns, and find explanations with the goal of extending existing theory or generating new theories (Gioia, Corley, & Hamilton, 2013). The ability in case studies to make use of significant qualitative

data, such as from interviews, supports in-depth analyses (Myers & Newman, 2007). Moreover, a motivation for using case study research is that it very much matches the typical characteristics of the construction industry: a project-based functioning with the involvement of many different firms and disciplines for a limited time frame (Dubois & Gadde, 2002; Sydow & Braun, 2018). The involvement of so many specialties in projects very much contributes to the complexity of construction (Baccarini, 1996). Case studies are especially appropriate when seeking to study complex processes at multiple levels of analysis: different levels within a single organization, in discipline-specific subsectors, and in inter-organizational project contexts (Pettigrew, 1990; Yin, 2003). A more detailed description of the methodology used is presented below for each chapter and its accompanying research questions. In addition, Table 1 gives an overview of the research approach, techniques employed, and data gathered for this thesis.

The approach for Chapter 2 reflects its nature as an explorative case study, aiming to implement and evaluate a developed BIM maturity model in the contemporary context of the Dutch construction industry. Strong elements taken from existing BIM maturity models are adapted to design a BIM maturity model that is appropriate for all disciplines and construction phases. In doing so, the study covers all stages used in the design cycle approach of Wieringa (2014), including problem analysis, design, validation, implementation, and evaluation. The data collection for the sectoral study involved 53 in-depth interviews, mostly with representatives of firms that are leading in terms of BIM. In addition to determining the BIM maturity score of individual organizations, an averaging on the subsector level provides an understanding of differences and similarities between subsectors. The identified multidisciplinary appropriateness of the model forms an important starting point for its use in the context of inter-organizational projects in Chapters 4 and 5. The feedback from interviewed respondents is used to gain knowledge of the appropriateness of the model and then to refine the BIM maturity model for further application.

Chapter 3, aiming to increase our understanding of barriers to the implementation of BIM at different levels within an organization, follows the methodological steps advanced by Gioia et al. (2013) for analyzing case studies. This method is appropriate for an in-depth analysis on the level of the organization and has an inductive approach starting with information extracted from quotes by the interviewees: a first-order analysis. These concepts are then grouped as themes in a second-order analysis, a process requiring further interpretation of the data. By means of further grouping and interpretation of the data, overarching dimensions

are defined in the third step. These dimensions are then used in developing a grounded model of implementation barriers that organizations could typically face given a particular degree of BIM maturity.

Chapter 4 uses a multiple case study approach (Eisenhardt, 1989) to gather empirical evidence of variations in BIM maturity present within project organizations. As such, this study focusses on the project level of analysis, but specifically addresses variations across collaborating organizations. To enhance the empirical evidence, data triangulation is used involving the interviews with project managers, surveys conducted with a broader group of project employees, and archival project documentation. Within-case insights from four projects provide improved understanding of variations in BIM maturity among the partnering organizations and the experienced impact of these variations in the particular context of the projects. In addition, a cross-case analysis is conducted to grasp differences and similarities among the investigated projects, thereby beginning to generalize patterns across the investigated projects. Of most practical relevance, this study of multiple cases provides an opportunity to identify patterns in the strategies that project organizations employ to deal with variations among partner organizations' BIM maturity levels.

A multiple case study approach is also adopted in Chapter 5 to explore Team Mental Models (TMMs) in a still rather unexplored context: inter-organizational BIM use in construction projects. Compared to Chapters 2 to 4, this chapter therefore uses a novel lens to investigate BIM maturity. A combination of qualitative interview data and quantitative survey data is used to capture Team Mental Models of four variables in the developed research model: a shared understanding of project-level BIM maturity, a shared understanding of BIM goals, a shared understanding of conditions for success, as well as the consensus on project-level BIM use. Adopting methodologies from previous TMM studies, the similarities within the team members' mental models are analyzed by calculating summed standard deviations of team member ratings of various items. Results indicate the extent to which project team members are on the same page regarding various aspects of BIM use. Further, the study captures data on four project outcome variables in order to explore whether these are positively related to the sharedness of mental models within a project. Here, project outcome variables including the BIM maturity of the project, team performance, team satisfaction, and the extent of experienced barriers to BIM use are considered. Overall, this study adds theory to the existent body of knowledge on team mental models and their effects on project performance in diverse contexts.

Table 1. Overview of research approaches and data collection per research question.

	Research questions	Research approach	Employed techniques	Data collection
Ch. 2	RQ1	Explorative case study	Interviews:	53 interviews with BIM representatives of companies that can be regarded as leading in the field of BIM
Ch. 3	RQ2a & RQ2b	Multiple case study of nine organizational units within one large contracting firm	Interviews: Archival data: Observational data:	17 interviews with BIM experts and managers responsible for implementation of BIM on the organizational level Strategic plans, operational plans for BIM implementation guidance, steering group meeting minutes 11 BIM steering group meetings
Ch. 4	RQ3a & RQ3b	Multiple case study of four inter-organizational projects	Interviews: Surveys: Archival data:	22 interviews with representatives of participating organizations to assess project BIM maturity and adopted strategies 41 online surveys to assess organizational BIM maturity General project information, organization charts, contractual arrangements, BIM execution plans, project responsibilities, schedules, procedures
Ch. 5	RQ4a & RQ4b	Multiple case study of four inter-organizational projects (Data collection extended from RQ3a and RQ3b)	Interviews and accompanying questionnaires: Archival data	22 interviews with representatives of participating organizations to assess Team Mental Model and project outcome variables General project information, organization charts, contractual arrangements, BIM execution plans, project responsibilities, schedules, procedures

1.5 Thesis outline

Chapter 2 presents an explorative case study that evaluates the status of BIM in the different subsectors of the Dutch construction industry. Based on an evaluation of existing BIM maturity models, an adapted BIM maturity model is developed that takes account of both technological and organizational aspects of BIM and is applicable for the various subsectors of the construction industry. The developed model is tested through making use of in-depth interviews at 53 organizations from various subsectors. Results of this study provide insights into the implementation status of BIM in individual firms. By aggregating the results to the subsector level, similarities and differences between the various subsectors are explored and the findings can be used by sectoral associations to define sector-specific or industry-wide policies. An evaluation of this implementation of the BIM maturity model forms the basis for further applications in the following chapters of this thesis.

Chapter 3 presents a multiple-case study that aims to add understanding of the barriers that hinder organizations implementing BIM by first mapping those barriers on to different organizational levels, i.e., from top management down to the level of project teams. Subsequently the study identifies the relationship between the implementation barriers and different degrees of BIM maturity. In doing so, the study provides an understanding of the barriers that organizations typically face in various stages of implementation with either low or high levels of BIM maturity. By making use of information gleaned from interviews with BIM department managers and experts, the chapter helps to further understand the BIM implementation process within organizations and where one should focus BIM implementation measures.

Chapter 4 is based on a multiple-case study of four construction projects located in the Netherlands and Belgium. The study set out to provide insights into how project-level BIM maturity is related to the BIM maturities of the partnering organizations involved. The motivation for this study originates in the fragmented nature of the construction industry. For example, organizations from different subsectors could attribute different levels of relevance to using BIM or improving its level of maturity. As a consequence of this, inter-organizational collaboration with BIM could be challenging because the maturities of the project partners vary. For this reason, this chapter also explores strategies that project managers employ to deal with variations in organizational BIM maturity among collaborating parties.

As such, the results of this study are of practical relevance for BIM use in real-world projects.

In Chapter 5, the same four projects as used in the previous chapter are examined to explore project outcomes in multidisciplinary projects in relation to the extent to which team members share a mental model of BIM use (a Team Mental Model). This novel perspective on BIM collaboration adds to previous research in non-construction contexts that shows that collective images of, for example, tools, work procedures, work strategy, member responsibilities and knowledge are likely to improve the performance of teams. The variations in the BIM-related mental models and project outcomes identified in the studied inter-organizational projects serve to unravel whether investing in developing Team Mental Models of BIM use in a project could be a route to project success.

In bringing this thesis to a close, conclusions are presented that combine the findings from the above individual studies. The answers to the main research questions are presented along with the main theoretical and managerial contributions. Finally, the research methodologies are reflected upon and avenues for further research identified.

CHAPTER 2

DEVELOPING AND TESTING A TOOL TO EVALUATE BIM MATURITY: A SECTORAL ANALYSIS IN THE DUTCH CONSTRUCTION INDUSTRY

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Abstract

This study's objective was to evaluate the status of Building Information Modelling (BIM) implementation within the Dutch construction industry by means of a developed BIM maturity tool that could be applied within the construction industry's various disciplines. Existing BIM maturity models tend to focus on technological aspects and have often been developed for specific disciplines. This paper first describes the development of a maturity model that enables the assessment of both technological and organizational aspects of BIM and enables comparison of all the disciplines in the construction supply chain. Second, the applicability of the proposed BIM maturity model is explored by using the model in in-depth interviews at 53 Dutch firms that represent the various disciplines within the construction industry. The output of the testing of the BIM maturity model shed light on the current implementation status of individual companies and, when aggregated, of the subsectors present. The latter information is valuable for sectoral associations because it identifies differences and similarities in BIM implementation across subsectors. The main finding is of strong strategic support for BIM among the leading companies evaluated. However, the formalization of BIM-related processes, tasks, and responsibilities is lagging behind BIM developments. Notably, respondents emphasized aspects related to people and culture when it came to implementing BIM, with awareness, education, and training regarded as essential elements in stimulating BIM maturity growth. Based on these findings, priorities have been identified to stimulate the BIM implementation process that can be included in sector-specific or industry-wide policies.

2.1 Introduction

Building Information Modelling (BIM) has progressively received more and more attention since the beginning of this century because of its many promises including increased productivity, reduced failure costs, and new ways of collaboration (e.g. Bryde et al., 2013; Eadie et al., 2013; Eastman et al., 2011; Miettinen & Paavola, 2014; Porwal & Hewage, 2013). However, practice shows that projects cannot always take full advantage of these promised benefits (e.g. Dainty et al., 2017; Neff et al., 2010). It appears that the inconsistent BIM maturity levels across collaborating parties in a project limit the degree to which BIM goals and accompanying expectations can be realized, especially regarding BIM uses with extensive data exchange between parties. Previous research has shown that an important factor in successful BIM use in a collaboration of multiple parties is the capabilities of the parties in terms of the desired or required BIM working methods (Adriaanse et al., 2010a). The readiness of an organization, in terms of both soft and technical aspects, has a great influence on the extent to which it is able to leverage the potential of information technology (IT) (Alshawhi, 2007). In this regard, Dutch sectoral associations have also recognized that differing levels of BIM readiness within organizations representing the various disciplines within the Dutch construction industry is a serious implementation barrier to BIM supported collaboration between parties. Given this situation, they have called for a tool that could help them identify differences in BIM maturity levels, the uses, drivers and barriers among the subsectors. Using such a tool, the sectoral associations aim to receive inputs that could be directive in defining policies and measures to stimulate BIM from the sector's perspective. In addition, the BIM maturity tool could support individual organizations in identifying priorities for improving their BIM implementation process.

An initial observation is that the literature points toward a lack of a uniform BIM definition. Based on a literature review of BIM definitions, this study distinguishes the following elements as essential in describing BIM:

- An object-based definition of a construction and its elements (Eastman et al., 2011).
- A cooperation between multiple disciplines across the different phases of a project (Miettinen & Paavola, 2014).
- A life cycle perspective on a construction object (Eastman et al., 2011; Gu & London, 2010; Miettinen & Paavola, 2014).

- An IT supported and consistent digital representation (in 3D) of a construction object (Eastman et al., 2011; Gu & London, 2010).
- A centralized consistent repository for all data related to a project or asset (Gu & London, 2010; Succar, 2009).

So, to sum up, BIM should be seen as an object-based and multidisciplinary approach aimed at facilitating collaboration between parties and the integration of object-related information over the entire life cycle of an asset. This function is supported by IT, through which building objects are often captured in 3D representations.

The objective of this explorative study is to develop a BIM maturity model that is able to assess BIM maturity of organizations in the various subsectors of the construction industry while, in doing so, addressing all life cycle phases of a building object. The practical applicability of the developed BIM maturity model is tested by evaluating the BIM maturity of primarily leading firms that are active in the various subsectors of the Dutch construction industry. This research focuses on BIM maturity at the organizational level. Aggregating the results to the sector level provides insight into the current BIM maturity of organizations in the various subsectors and their similarities and differences. This reveals the current opportunities for and barriers to BIM cooperation between parties of these different subsectors. The results of this explorative BIM maturity sectoral study provide the construction industry and its specific subsectors with recommendations on how to increase and improve BIM use.

This article starts with a review of existing maturity models on BIM implementation and use. Based on this review, a generic model for assessing the BIM maturity level of a firm in the construction industry is developed. Following this, a methodological justification and a design for the empirical research is provided. In the next section, the developed BIM maturity model is assessed in 53 in-depth interviews of firms in the Dutch construction industry. Based on the development and testing of the BIM maturity model, the main findings are discussed, followed by conclusions and managerial implications.

2.2 Assessment of existing maturity models

Several existing maturity models were assessed to determine their applicability for the proposed BIM maturity research. In this assessment, four categories of requirements for design-oriented research have been applied (Verschuren & Doorewaard, 2007):

- Functional requirements comprising the features that the artifact has to fulfill. These requirements have been matched with the scope of the BIM maturity research, including the evaluation of collaboration along the entire supply chain, appropriateness to all the disciplines in the construction industry, appropriateness to the Dutch construction industry as well as evidence of a life cycle perspective.
- Contextual requirements covering political, economic, social, and transactional requirements from the environment. These requirements take account of the individual organization being part of a chain of collaborating parties in a dynamic context. The requirements are based on the adopted BIM definition, the intended added value of the model in the assessment, and mutually comparing results across disciplines.
- User requirements comprising requirements from current and future users of the model. These requirements are based on a stakeholder analysis and use scenario, including primarily the perspective of individual organizations.
- Structural requirements covering the tangible and intangible characteristics necessary to fulfill the requirements of the other three categories. These requirements originate in the starting points of BIM maturity research, building on the existing scientific knowledge with a strong emphasis on the usability for the target users.

The evaluated maturity models are the BIM Capability Stages and the BIM Maturity matrix (Succar, 2009), the BIM Quick scan (Berlo van, Dijkmans, Hendriks, & Spekkink, 2012) of the Netherlands Organization for Applied Scientific Research (TNO), the National BIM Standard (NBIMS) Capability Maturity Model (National Institute of Building Sciences, 2012), iBIM maturity (Bew et al., 2008), Penn State BIM assessment (Computer Integrated Construction Research Program, 2013), the BIM proficiency matrix (Indiana University, 2009), the Supply Chain Management Process Maturity Model (Lockamy & McCormack, 2004), and the Capability Maturity Model integration (CMMi) (Software Engineering Institute, 2010).

A multi-criteria analysis indicated that none of the existing maturity models fully satisfied the objectives of our BIM maturity research (see the outcomes of the qualitative assessment in Table 2). The rationale behind the multi-criteria analysis is based on the requirement categories for design-oriented research of Verschuren and Doorewaard (2007) as explained above. The following findings illustrate the need for a new BIM maturity model:

1. Collaborative aspects receive little attention in the models assessed, especially in terms of collaboration within the construction supply chain. This is despite organizations with different BIM maturity levels collaborating intensively in a project. Only the Supply Chain Management Process Maturity Model (Lockamy & McCormack, 2004) fully addressed this criterion, with that model especially developed to evaluate inter-firm processes.
2. Complex frameworks are often applied and maturity assessment results are unclear or not transparent, i.e. interpretation and mutual comparison of maturity results is hindered by ambiguous scores or lacking foundations. Consequently, the outcomes of the various maturity analyses are not mutually comparable. This reduces the usability of the BIM maturity models as supportive tools for organizations and sectoral associations.
3. The meaning and requirements for the various maturity levels are often poorly defined and ill-founded in the related literature. In general, the development and design choices made have been poorly explained, a failing which was also identified by Liang et al. (2016). As such, the background required for appropriate measurement is lacking, and ranking an organization according to a maturity model, such as when determining whether maturity has increased, is challenging.
4. Existing models pay insufficient attention to organizational processes and instead tend to focus on technological characteristics of BIM.
5. Many of the maturity models focus on the evaluation of specific disciplines (e.g., clients) and this limits their applicability by different disciplines within the construction industry.

Based on the above-mentioned shortcomings and limitations of existing maturity models, the potential benefit of a new BIM maturity model was evident. Although none of the assessed maturity models fully satisfied the requirements, many contained strong elements that were brought together in the new BIM maturity model. Based on the assessment in Table 2, the CMMi framework was chosen as the general framework for the new BIM maturity model. The major reason for this

is that the CMMi focusses on process areas that can constitute best practices, and which can be tailored to appropriate BIM criteria and BIM uses for the construction industry. Moreover, the CMMi aims to cover all the life cycle phases, which fits very well with the adopted BIM perspective and the different subsectors involved in the construction industry. Additionally, the CMMi structure makes it possible to include aspects of other maturity models such as the collaborative aspects of the Supply Chain Maturity model and the clear presentation of both maturity model descriptions and outcomes found in the Penn State Maturity model.

Table 2. Assessment of existing BIM maturity models.

	Requirements		Maturity models								
Requirement category			BIM Capability stages	BIM Maturity matrix	BIM Quicksan	NBIMS Capability Maturity Model	iBIM Maturity	Penn State BIM assessment	BIM proficiency matrix	SCM Process Maturity Model	Capability Maturity Model integration
	+	Requirement satisfied									
	o	Requirement partly satisfied									
	-	Requirement not satisfied									
Functional	The model was developed or is suitable for the Dutch construction sector		o	o	+	o	o	o	o	-	-
	The model has been developed in order to measure BIM maturity level		-	+	+	+	+	+	-	-	-
	The model can be used at sector, corporate, and project levels		-	+	-	-	-	o	-	o	+
	The model can be applied in organizations of different sizes		+	+	+	+	o	o	+	+	+
	The different BIM maturity levels are construction-specific and distinctly defined		-	-	-	o	o	o	-	-	-
	The model covers different phases in the life cycle of a construction work and the parties involved		-	-	-	-	-	-	-	-	o
	The model is able to test the maturity level of BIM applications		-	-	-	-	-	o	-	-	+
Contextual	The model covers BIM-supported cooperation between parties		o	o	-	-	-	-	-	+	-
	The results of the model offer insight into the appropriateness of possible project partners and can be communicated		-	-	o	o	-	-	-	-	o
	The model can be adapted to future BIM applications (best practices) and other relevant developments		-	-	-	+	-	o	-	-	+
User	The maturity audit is complete and clearly described; the results are not heavily reliant on the auditor's interpretation		-	-	+	+	-	+	+	-	+
	The maturity audit can be carried out within the limited interview/survey time		-	-	+	+	o	o	-	o	o
	The results of the maturity audit are transparent and understandable		+	-	+	-	-	+	+	o	+
	The outcome of the maturity audit provides sufficient understanding of the current phase of BIM implementation		-	o	-	+	o	o	-	-	-
	The maturity model provides a clear path from a lower to a higher maturity level		-	+	-	+	+	+	-	+	o
Structural	The maturity model has a sound scientific basis		+	+	-	o	+	o	o	+	+
	Software for execution or visualization of the maturity analysis is generally available		-	-	+	+	-	+	+	-	o

2.3 Developing a new BIM maturity model

In this section, the two basic dimensions of the maturity model developed are discussed. First, the general descriptions of the maturity levels are provided. Second, the six main criteria in the maturity model are explained.

2.3.1 Description of maturity levels

In order to further detail the generic maturity definitions contained in the CMMi, the findings of the SPICE project (Standardised Process Improvement for Construction Enterprises) were considered. This project examined the applicability of the CMMi methods for the construction industry, and concluded that construction supply chain relationships are insufficiently covered (Sarshar, Finnemore, Haigh, & Goulding, 1999). Furthermore, it was concluded that improvements were required in the maturity definitions if they are to serve the vast diversity of organizations within the construction industry in terms of organizational size, focus, and financial position. In addition, it has been argued that a maturity model cannot be operationalized unless criteria are defined that reflect the context of the specific sector (Vaidyanathan & Howell, 2007). Considering the above-mentioned aspects, the definitions of Siriwardena, Kagioglou, Jeong, Haigh, and Amaratunga (2005) and of Lockamy and McCormack (2004) have been employed in further specifying the five maturity levels of the CMMi. Here, one should also note that although Vaidyanathan and Howell (2007) described four specific levels for a construction supply chain maturity model, these can, for the most part, be matched with the definitions of Lockamy and McCormack (2004). The contribution from these various publications is combined to come to the descriptions of the five maturity levels used in the newly developed BIM maturity model as shown in Table 3. A distinction is made between internal and external processes in order to make supply chain aspects more explicit.

The general descriptions of maturity levels in Table 3 have been further specified for the context of the criteria used in the BIM maturity model. Explanations for the developed criteria and subcriteria can be found in the following.

Table 3. Definition BIM maturity levels.

Level	Internal definition	External definition
0	Processes related to the criterion are not present in the organization and no related goals are formulated.	
1	Internal BIM processes are not defined or limited and ad hoc. Good practices are not shared or laid down in procedures (no multi-project integration). Performance of BIM-related processes and projects is unpredictable and completely dependent on skills in the project team.	Cooperation between companies within a project is ad hoc, and reactive rather than proactive. The organizational structure and functions are not geared to collaboration within the supply chain (no multi-firm integration). Performance of BIM-related external processes and projects is unpredictable and targets are often not met.
2	BIM policies and procedures have been established for the management of major project-specific BIM processes, whereby good practices can be repeated and processes become more predictable. The structure of the organization is traditional and has not adapted to the BIM process. BIM processes are followed, adjusted, and evaluated to a limited extent during the project.	The importance of cooperation in the supply chain is recognized through the definition of objectives and external fundamental processes. However, the organization has changed insufficiently to reflect supply chain processes. Although external BIM processes are better able to predict, objectives are often still not met.
3	BIM goals are formulated by management with strategic intention and there is a good overview of the performance and progress of BIM projects. Organizational structures, job profiles, and working methods are defined in accordance with BIM-related tasks, providing greater understanding of the delivered quality of projects. Good BIM practices are documented and applied as standard processes throughout the organization. Based on trust and motivation, there is increasing unity regarding joint BIM targets, which outweigh possible frustrations.	At this level, a breakthrough takes place with regard to cooperation in the supply chain: organizational structures and functions are partly focused on supply chain management, whereby joint supply chain goals and activities can be set. Clients/partners in the chain are involved in efforts to process improvements, leading also to greater mutual satisfaction.

4	<p>Measurable quality targets (quality programs) are made with regard to the outcome and progress of processes. BIM processes are controlled objectively, enabling adjustment, and helping to keep targeted performance within acceptable limits. Risks associated with new, more advanced BIM applications can be controlled due to the strong process discipline and the acquired skills. Both the internal culture (in which confidence in the BIM approach and method is present) and the satisfaction of the project partners strengthen the competitive position/authority of the organization.</p>	<p>Cooperation with chain partners is part of the business strategy and takes place on the process level, including joint efforts on process improvement. Traditional functions disappear at the expense of functions and procedures focusing on external processes in the supply chain. This enables more-advanced applications to be set up together with supply chain partners, such as joint planning for both the short and the longer term. This cooperation, with shared confidence in the objectives, becomes a competitive advantage.</p>
5	<p>Effective evaluation of processes and projects contributes to continuous learning and improvement. Internal processes are aligned with the collaboration within the supply chain. Data on the effectiveness of processes are used to analyze new technologies and proposed changes in organizational processes. Through this increased understanding of the processes, organizations are able to assess and implement large-scale process changes. The corporate culture stands for openness and transparency for the sake of intensive collaboration.</p>	<p>An organization operates as part of a 'multi-firm' supply chain. This is characterized by intensive cooperation with supply chain partners in which BIM processes are continually improved. This cooperation is ensured by the strong mutual trust and financial dependence. The exchange of performance data makes it possible to anticipate problems and to implement new BIM applications/technologies. Evaluation of processes and projects contributes to coordinated learning across projects.</p>

2.3.2 Criteria and subcriteria used in the BIM maturity model

A Building Information Model can be thought of as an information system, and as part of the organizational context. It is not an isolated system, but forms part of a larger whole. The information system is characterized by a number of subsystems: hardware, software, data, people, and procedures (Silver, Markus, & Beath, 1995). These subsystems are closely related with each other and jointly determine the functioning of the information system. However, as part of the organizational context, the information system is not self-contained but is a part of a larger whole. Silver et al. (1995) describe other aspects of the organization that interact with the information system, such as business processes, strategies, culture, organizational structure, and IT infrastructure. Note that new or existing information systems, for example in the area of planning, calculation, Enterprise Resource Planning (ERP), asset management or Geographical Information Systems (GIS), can either be integrated with BIM or can be used as a separate IT system. In addition to the information system and the organization, influential factors from the external environment can be distinguished. The external environment affects the motivation to develop and use information systems, which can originate from contractual agreements (Adriaanse, 2007). The information system, with its internal and external interactions, is shown in Figure 2.

Since aspects of the information system, of the surrounding organization, and of the external environment represent the interactions and determine the performance of that information system, they are seen as appropriate criteria for inclusion in a BIM maturity model. Below, the criteria included in the maturity model are explained further.

Figure 2. Information system and its interaction with the organization and the environment. (Adapted from Silver et al., 1995.)

Based on the elements of the information system, a framework has been constructed with criteria that are used to define "BIM maturity" (the domain). Some criteria overlap and can be merged into a single criterion. In doing so, aspects related to people and to culture are included as a single criterion, and aspects of the IT infrastructure and information and communications technology (ICT) are similarly combined. The data and documents that are part of the IT infrastructure constitute an important BIM aspect, and these are therefore separated out as a distinctive criterion. Most criteria are broken down into several subcriteria to distinguish and assess the specific aspects within each criterion. These subcriteria are based on the descriptions of criteria in the literature (Silver et al., 1995) and criteria used in existing maturity models, with significant contributions from the Penn State BIM Assessment (Computer Integrated Construction Research Program, 2013) and the Supply Chain Management Maturity Model (Lockamy & McCormack, 2004).

The BIM maturity model is divided into six main criteria, namely strategy, organizational structure, people and culture, processes and procedures, IT (infrastructure), and data (structure). Most criteria include several subcriteria (see Figure 3). No particular weights are allocated to the criteria, which allows a uniform comparison of the criteria scores. Considering organizations with varying focus areas or BIM use scenarios, this uniform model structure allows organizations to set priorities afterwards.

Figure 3. Criteria and subcriteria of the BIM maturity model.

Below, the criteria included in the BIM maturity model are explained in the context of BIM. In doing so, justifications for the chosen subcriteria are presented (see also Figure 3).

Strategy: BIM is often included in an organization's strategy. It can be a key element in a marketing or production strategy, or even the core of a strategy. If the intentions of the digital information model do not align with the organization's strategy, the implementation and use of BIM can fail. The strategy should be based on the mission and goals of the organization. More specifically, specific *BIM vision* and associated *goals* should be aligned with the organizational strategy and vice versa. The implementation of the strategy, however, requires sufficient *management support*, both in spoken words and by management committing financial and other resources for short- and long-term planning. Further, dedicated time and expertise from a *BIM expert/working group* are indispensable elements when it comes to the operationalization of the BIM strategy.

Organizational structure: the formal structure of the organization, such as the division of labor and associated power. These aspects are formalized in job profiles, which contain the *tasks and responsibilities* of the employees. Due to new BIM-related processes, new working methods, new roles within the organization and the project, new competences with regard to the use of, for example, BIM software, a revision is required of the traditional tasks and responsibilities. To what extent an organization has adopted new, or updated, tasks and responsibilities, for example by means of changed job profiles, reflects the ability of its staff to support the BIM processes. Further, the authors recognize a strong relationship with softer aspects in the field of organizational change, and these are explained below as part of the *people and culture* criterion.

People and culture: a set of basic assumptions and habits that are anchored in an organization, and which will be transferred to new employees. These facets determine the *personal motivation* for working with BIM and expanding its use into new areas. Such motivation can spring from the many benefits that BIM offers an organization, although these will generally not directly affect the entire organization. Therefore, it is important to have a BIM champion for the implementation process, one who functions as an internal *requesting actor* for the application of BIM. In addition to being motivated to work with BIM, the functioning of BIM is also determined by having the *competence* required to be able to work with it. An organization should therefore provide intensive *education and training* to all those who are part of the BIM process. The culture of the organization also affects the openness (to external partners) and the *degree of collaborative attitude* or orientation towards the supply chain. Achieving an integrated and multidisciplinary BIM approach requires a setting and an attitude that is aimed at cooperation. To this end, the organization needs to show a *willingness to change* its traditional culture, structure, and processes.

Processes and procedures: a process can be defined as a collection of related activities aimed at a specific result or output. It is important, in this context, that the processes contribute to the desired functioning of BIM and vice versa. The consistency and the performance of processes depend on the extent to which these processes are formalized in *job instructions and procedures* (e.g., with regard to various BIM uses). Job instructions are seen as detailed step-by-step acts or practices, compared with procedures that provide a set of guidelines for streamlining processes.

IT infrastructure: the technical means within the information system, initially consisting of the (BIM) *software*. In addition, the IT infrastructure includes the

hardware and network environment that support a smooth use of the software as well as the sharing of data. The quality of the network environment determines the extent to which project disciplines can work in an integrated way and in real time. Another component is the *BIM facilities*, such as spaces where the models can be visualized. These facilities enable interactive coordination sessions with project partners, for example to detect clashes.

Data (structure): the management, structuring, (re-)use, and exchange of project-related information. First, it is important to store project data in a structured way and for other people/parties to be able to access these data. This *information structure* can be facilitated by a document management system. Next, an object-oriented approach constitutes the core of the BIM definition. The basis of this is formed by drafting an *object structure and decomposition* (possibly in combination with Systems Engineering) and using unique codes for all the objects in the model/project. Depending on the intended uses of BIM, *object libraries* can be helpful in standardizing and easing the BIM model design processes. Specifications and characteristics of objects can be linked by means of attributes, possibly included in object libraries, or otherwise added to objects in the model. Integration with models of supply chain partners is determined by *data exchange* regarding object information, discipline-specific models, or merged models.

2.4 Method and data collection

A BIM maturity model has been developed, which is visualized as a matrix, that enables the measurement of organizational BIM maturity. The horizontal axis of this matrix consists of the maturity levels, while the vertical axis consists of the criteria and subcriteria outlined in the previous section (an illustrative example of maturity level definitions is shown in Table 4). Subsequently, this matrix was translated into an interview format to enable data to be collected through in-depth interviews. More than 50 interviews were conducted in 2014 and 2015. Interviews were held with representatives of organizations drawn from seven subsectors: clients and owners; architectural firms; engineering firms; commercial and industrial building contractors; civil structure contractors; mechanical, electrical, and plumbing (MEP) contractors; and suppliers.

Table 4. Illustrative example of the BIM maturity model: subcriterion BIM vision and goals.

Maturity level	Description maturity levels of subcriterion BIM vision and goals (part of strategy criterion)
0 Not present	No vision or goals for BIM formulated.
1 Initial	A basic vision for BIM is defined, but there are no concrete goals associated with it.
2 Managed	There are general BIM goals, but a BIM vision is lacking or not kept in line with the broader strategy.
3 Defined	The BIM vision fits within the broader organizational vision/strategy and is aligned with partners.
4 Quantitatively managed	'SMART' BIM goals are defined.
5 Optimized	The BIM vision and goals are actively monitored (e.g., by means of periodic reporting) and, if necessary, updated.

The measurement tool uses a 'strict step' principle when determining the maturity level of each criterion, i.e., all the elements of a certain maturity level description must be met before moving on to the subsequent level. For example, a company will be evaluated as having a maturity level of 2 on a given construct if not every aspect of level 3 is met, even if all the criteria for levels 4 and 5 are met. This approach highlights to a company those actions that should be taken and, as such, offers them a gradual path to growth.

The research project included a supervisory group, consisting of representatives from all distinguished subsectors, that was able to provide a list of firms that were appropriate and could be approached to participate in the research. Besides the willingness to participate in the research, no specific criteria were used to select the firms and their respondents. Factors like organizational size of the firm or age and experience of the respondent have not been evaluated in the selection process, nor in the evaluation of the outcomes. However, the initial approaches to respondents found that organizations with limited focus and experience of BIM were often unwilling to participate in the research. As such, the interviews that did take place tend to provide insight into the BIM maturity of those companies that are leaders in the industry. Therefore, the results of the research should not be seen as providing a general representation of the construction industry as a whole.

Nevertheless, interviewing leading firms could still show the trend in the development and adoption of BIM. In addition, they can highlight drivers and barriers they experienced in earlier phases of the BIM implementation process. This information can be very helpful for companies that are at these lower BIM maturity levels and may be struggling with certain barriers.

Table 5 provides an overview of the number of companies interviewed in each subsector. The selected companies varied in size, with both small and medium enterprises (SMEs) as well as large companies included in order to reflect the wide diversity of companies in the construction industry. Moreover, companies from the two main divisions of the construction industry, commercial and industrial buildings, as well as the infrastructure subsectors were included. Using a standard interview format, a total of 53 interviews were conducted. Given the commercial value and confidentiality of the information provided during the interviews, the results are presented anonymously. The participating organizations were either interviewed 'face-to-face' (55%), through Skype (15%), or by phone (30%). The respondents consisted of employees and executives who held a broad overview of the BIM developments within their organization and who often also had a clear picture of BIM developments at other parties in the construction supply chain.

Table 5. Number of interviewed organizations per subsector.

Subsectors	Number of interviews
Clients and owners: (semi-)governmental organizations and housing associations	7
Architectural firms	6
Engineering firms	9
Contractors of commercial and industrial buildings	8
Contractors of civil structures	8
MEP contractors	7
Suppliers	8
Total	53

Generally, each interview required approximately two hours although the duration varied depending on the knowledge, experience, and comprehensiveness of the answers provided by the respondents. To assess the BIM maturity level for the various criteria, the interview format was partly open-ended, allowing the interviewer to explore areas that were revealed during the discussion. Where required, the researchers would ask the interviewees to provide additional documentation to support the given answers. Following the round of interviews, data analysis was performed in three steps. First, after a visit, a researcher would prepare a BIM maturity report for that company. Second, to achieve construct validity, these draft reports were submitted to the respondents for verification. After the verification and integration of comments, the final BIM maturity report of each organizational assessment was compiled. Finally, when all 53 assessments were completed, the overall results were analyzed. The data were first analyzed by subsector so that trends, and similarities and differences, between subsectors could be revealed. Next, aspects of BIM were analyzed for the entire dataset to investigate the development of BIM within the Dutch construction industry as a whole. These results are presented in the next section.

2.5 Results of the BIM maturity assessment interviews

This section describes the results of the sectoral BIM maturity analysis in the Dutch construction industry, which involved assessments at 53 primarily leading companies in the field of BIM. The results of the BIM maturity sectoral assessment are presented in terms of the six main criteria of the maturity model: strategy, organizational structure, people and culture, processes and procedures, IT (infrastructure), and data (structure). Indications of the BIM maturity level for each subsector are provided. From these results, the adoption characteristics and priorities for further implementation of BIM in a front-running country can be identified.

2.5.1 Strategy

The main criterion strategy is made up of three subcriteria: *BIM vision and goals*, *management support* (both financial support and promoting the importance of BIM), and *BIM expert/working group/department*. The scores on the strategy criterion and its subcriteria are relatively high in all the subsectors (see Figure 4).

The lowest maturity score was found for the suppliers' subsector (an average maturity level of about 2). This is reflected in the drivers of BIM implementation

that were mentioned by the suppliers. Indeed, the interviewed suppliers experienced little intrinsic motivation and indicated that BIM had largely been adopted because of requests from their clients (particularly construction companies as the main contractor in a project).

On the other hand, the highest scores were obtained by the commercial and industrial building companies and engineering firms with a BIM maturity score of around 4. These organizations generally had a management that recognized the importance of BIM and that took initiatives to stimulate awareness of the value by BIM. Moreover, these companies have specified a BIM vision, and accompanying goals, for both short- and longer-term strategic planning, and progress is monitored and measured over time.

Figure 4. BIM maturity scores of subsectors on strategy. (CIB = commercial and industrial building).

2.5.2 Organizational structure

The organizational structure criterion consists of *tasks and responsibilities* and does not include further subcriteria. This criterion is assessed by asking the organizations' representatives about the extent to which tasks and responsibilities in the organization have been aligned with BIM use. In general, the scores on this criterion were relatively low when compared to the average maturity over all criteria. The majority of the interviewed organizations did not formalize changes in tasks, responsibilities or job profiles as a consequence of modified BIM procedures. Rather, they tended to see BIM as an additional tool within existing roles and responsibilities, for example to support the design process (Eastman et al., 2011).

Of all the subsectors, architectural firms were clearest in the use of BIM as a supplementary tool. From their perspective, further adoption of BIM would not affect their designing processes considerably. As such, the implementation of BIM does not require a considerable revision of their formalized task descriptions. Conversely, many of the contractors did view BIM as a new way of working that should be streamlined using appropriate job profiles. They also recognized the value of role descriptions, which can be used to formalize tasks and responsibilities between different individuals, disciplines, and parties in a project. However, BIM-related roles had yet to be directly linked to the internal job descriptions of the employees concerned.

Despite the general awareness of this need, the formalization of tasks and responsibilities seems to lag behind the actual adoption of BIM. It should be noted, however, that many organizations are still in the early stages of BIM implementation and, therefore, BIM may only be being applied in parts of some projects. The need to formalize modified tasks and responsibilities may have been recognized, but it was not being prioritized. Rather, the respondents tended to put their emphasis on BIM operationalization and put their effort into extending BIM use into new areas.

As can be seen in Figure 5, the highest scores for the organizational structure criterion were found for contractors of commercial and industrial buildings and of civil structures, whereas the lowest scores were found for MEP contractors, suppliers, and clients/owners.

Figure 5. BIM maturity scores of subsectors on organizational structure.

2.5.3 People and culture

The people and culture criterion is made up of four subcriteria: *personal motivation and willingness to change*; *requesting (internal) actor*; *education, training, and support*; and *collaborative attitude*. Those organizations that had an above average overall BIM maturity score often emphasized that this criterion was the most challenging in their BIM implementation process – that technical aspects can often be solved, but changing people is a complicated and gradual process. They saw it as important to work on boosting awareness and making clear how BIM can help facilitate, speed up, or professionalize people’s work.

As shown in Figure 6, the interviewed suppliers and MEP contractors scored relatively lowly for the people and culture criterion. They saw too few benefits of BIM for their own work. In their experience, the efforts and investments they would have to make in order to join the desired BIM working method within a project often outweighed the expected benefits.

Clients and owners also scored below average for the people and culture criterion. It appeared that, besides cultural aspects, their organization’s limited education and training with regard to 3D-oriented BIM applications also depressed their scores. Indeed, interviewed clients and owners stressed that they do not need to work with the 3D component of BIM. On the other hand, their focus within BIM is more on its uses related to maintenance during the operation phase of an asset, making the information attached to objects in the building model particularly important.

Figure 6. BIM maturity scores of subsectors on people and culture.

Figure 7. BIM maturity scores of subsectors on processes and procedures.

2.5.4 Processes and procedures

The main processes and procedures criterion consists of *working instructions and procedures*, and does not include further subcriteria. The results on processes and procedures match those for the roles and responsibilities (organizational structure) criterion. Indeed, in terms of processes, there is a similar lack of formalization in terms of working instructions or procedures. The results (see Figure 7) indicated that the interviewed construction companies, both contractors of commercial and industrial building as well as contractors of civil structures, obtained the highest maturity scores (average just above maturity level 3), followed by engineering companies and architectural firms.

2.5.5 IT (infrastructure)

The IT (infrastructure) main criterion is made up of three subcriteria: *hardware and network environment, software, and BIM facilities* (such as projection screens or rooms equipped for BIM cooperation). The results of this criterion are shown in Figure 8. Despite their often-lengthier experiences with 3D design software and a strong dependence on 3D software packages in their design work, architectural firms did not have the highest maturity scores for the IT (infrastructure) criterion. This seems to be partly due to their tendency to judge the IT (infrastructure) maturity against higher standards or envisioned state-of-the-art usage. As a consequence, requirements and expectations regarding BIM software increases. In addition, architectural firms were very able to identify shortcomings regarding software. Some of the interviewed architectural firms stated that they stay in regular contact with software vendors to discuss certain defects in functionalities. This information can be used in software updates.

In addition, the software aspect was generally given a reduced score due to limitations in the area of information exchange using open standards, such as the Industry Foundation Classes (IFC). Respondents who had experience with IFC indicated that IFC exports sometimes lose building model data and therefore have limited reliability. The data exchange aspect is investigated in more detail within the data (structure) criterion.

Figure 8. BIM maturity scores of subsectors on IT infrastructure.

With regard to the hardware and network environment, respondents indicated that initial investments, for example for the purchase of new laptops, are generally not a problem since the purchase of suitable hardware usually coincides with the decision to invest in BIM. Most parties are happy to make these initial investments in order to kick-start and accelerate the implementation of BIM. Management recognizes that the initial investment can be significant, but that it does not result in structurally higher costs. Moreover, the expected positive return on investments in the longer term is seen as a sound basis for justifying the initial investments. However, respondents did mention that the IT infrastructure, the data lines and servers, were often insufficient to handle rapidly the very large (and increasing) volume of data. Many of the contractors noted that this issue was particularly problematic at remote project locations with temporary facilities.

Most parties felt they were able to facilitate meeting/coordination sessions with BIM screens using beamers or smart boards. The parties earning an above-average maturity score had often invested in specific changes to workspaces and meeting rooms, for example by creating rooms where several project parties can cooperate. Commercial and industrial construction companies scored highly on this aspect: they attach considerable importance to 3D coordination (especially clash detection and coordination of disciplines) and have equipped meeting rooms and project rooms to meet these requirements.

2.5.6 Data (structure)

The main data (structure) criterion is made up of four subcriteria: *information structure*, *object structure and decomposition*, *object libraries and attributes*, and *data exchange*. In general, the maturity scores of the various subsectors are similar; mostly with levels between 2 and 3 (see Figure 9). First, considering information structure, it emerged from the interviews that many parties do not use a document management system for storage and accessibility of project information or, if they do, use it inconsistently. Respondents acknowledge that this aspect should be higher on their priority list, recognizing that a structured document management system can be linked more efficiently to objects in the building model. Such a link between the BIM environment and the document management system has been realized by more than half of the civil structure contractors whereas, in other subsectors, this seems very sporadic.

In terms of object structure and decomposition, it appeared that many organizations do not have a unified approach in place. From the interviews, the impression gained was that contractors of civil structures had taken a leading role in the employment of a uniform structure/decomposition of objects, often originating from an adopted Systems Engineering approach. As seen earlier when it came to the formalization of tasks and responsibilities, suppliers again clearly had reservations: they often just follow the structure and methodology used and provided by their principal (main contractor). They see this as reflecting their position in the construction supply chain and a desire to act as flexibly as possible.

Addressing the next subcriteria, some of the interviewed parties stated that they had chosen not to have a uniform library of 3D objects, but to develop separate libraries on a project-by-project basis for the various software packages used. Transferring developed object libraries from project to project is mostly done on an ad hoc basis. Some organizations do create and maintain an object library at the organization level, but aligning or exchanging these libraries with supply chain partners is still rare. Explanations offered in the interviews included the diversity of software packages and the lack of well-implemented standards.

Finally, further addressing the object libraries, the respondents from the architectural firms explicitly mentioned the lack of available online object libraries of prefabricated or standard products from producers and suppliers. They see such libraries as being an important step toward further increasing automation and efficiency in the design and engineering processes. Moreover, this could enable detailed information on the manufacturing processes to be included during the early stages of the design, reducing the number of later change orders and clashes.

Figure 9. BIM maturity scores of subsectors on data (structure).

2.6 Discussion

In this section, the results from the BIM maturity sectoral analysis will first be discussed. Second, the BIM maturity model, including the interview instrument, will be evaluated. This will reveal directions for further research and, specifically, potential refinements to the BIM maturity model.

2.6.1 Evaluation of BIM maturity results

The BIM maturity of organizations is evaluated on the basis of several criteria. Figure 10 shows the BIM maturity of the interviewed organizations by subsector on each of the main criteria. Some of the most notable outcomes are then discussed. Organizations in the construction industry as well as sector associations can use these outcomes to set priorities for further adoption and implementation of BIM. When interpreting the findings, one should not forget that only a limited number of organizational representatives were interviewed.

Almost all of the subsectors distinguished scored highly on the strategy criterion. This implies that the management of organizations attaches value to BIM development by setting an organizational BIM vision, BIM goals, and specific BIM

implementation plans. In addition, this criterion involves the allocation of financial resources as well as the establishment of BIM experts who support the implementation process. This result is underlined by the strong representation of leaders within this explorative BIM maturity study. One notable exception was seen with suppliers, where many adopt a wait-and-see position since they are dealing with multiple clients, often with different needs.

Second, in terms of both the organizational structure criterion as well as the processes and procedures criterion, the results show that organizations have not given this significant attention. There is still a lot to gain from progressing the formalization of tasks and responsibilities and of processes and procedures related to BIM. The findings indicate that these aspects have often lagged behind the rapid BIM development in other areas over recent years. A consequence is that BIM processes become highly dependent on individual competences, which could lead to divergent BIM performances between projects or between internal departments. Froese (2010) similarly argued that the full potential of BIM can only be achieved if changes are instituted in the organization structures, work practices, and skills of project members. Based on the research findings, it would seem that developments in the field of BIM typically run ahead of its institutionalization.

Figure 10. BIM maturity scores of subsectors per BIM maturity criterion.

In addition, there were several interviewees who felt that only limited changes to tasks and responsibilities needed to be implemented. In their organizations, BIM is considered more as a supportive tool for other important organization activities. As such, the research shows that organizations have different expectations and perspectives regarding the use and consequences of BIM, and this presents a challenge to the implementation process (Davies & Harty, 2013). Nevertheless, there is a general recognition that (inter)organizational business processes have to evolve and adapt to technological changes (Taylor & Bernstein, 2009).

Further, many respondents emphasized the importance of our third criterion, people and culture, with respect to a successful BIM implementation. Indeed, early adaptors identified aspects related to people and culture as the most challenging ones in the entire BIM implementation process. A majority of the respondents recognized that, if employees were not motivated to move on from existing practices, organization-wide adoption was difficult. This justifies the inclusion of people and culture as a main criterion in the BIM maturity model.

Our analysis of the people and culture maturity scores showed that these were generally relatively high. It appears that these aspects already receive considerable attention in the front-runner organizations in our sample, especially at the interviewed construction companies, architectural firms, and engineering companies. That is, they put effort into providing clear BIM information to employees, demonstrating the advantages of BIM for people's own work, and stressing the advantages that it may offer for the work of project partners or other disciplines. In addition, respondents emphasized that appropriate training and active guidance for employees, including the presentation of case studies, in the practical context are essential. The above mentioned aspects can help motivate employees to adapt to the BIM method of working, including its various roles and responsibilities (Gu & London, 2010). It is particularly important that people become aware of the benefits of using BIM for their own work, their organization, and their projects.

When interpreting the outcomes of a BIM maturity analysis, one should not forget that an organization does not need to be at the highest maturity level on all the BIM criteria in order to work or cooperate in a BIM project. Depending on, for example, a comparative assessment of estimated costs and benefits or a limited clients' mandate for BIM, organizations can decide to set a target level below the maximum. Nevertheless, the maturity scores do provide valuable insights into those aspects that an organization should focus on to professionalize its use of BIM.

2.6.2 Evaluation of the BIM maturity tool

The content and suitability of the BIM maturity tool, comprising the maturity model and the interview format, were first appraised by submitting the model to all members of the supervisory group. After processing their feedback, the model was reviewed through some test interviews at organizations in various subsectors. The comments by the respondents were then processed in reaching the final maturity model and interview format for wider testing.

To ensure and evaluate the accuracy of the maturity model and interview format during the interview round, the interviewer also asked questions about any aspects that play a role in BIM that were missing. In this way, the sectoral analysis functioned both as a practical usage and as extensive testing of the maturity model and the interview format. In general, the respondents believed that all relevant aspects of BIM were covered in the interview. From this, it can be concluded that the contents of the maturity model and the accompanying interview questions sufficiently address the meaning of BIM. However, some respondents advocated a stronger anchoring of contractual aspects. Porwal and Hewage (2013) similarly emphasized the importance of contractual arrangements in improving productivity and project coordination. Moreover, Miettinen and Paavola (2014) concluded that the adoption of BIM in projects requires new contractual arrangements because of the changed collaboration between parties. One way to make contractual aspects more explicit in the maturity model would be to add this aspect in the context of the project structure for BIM. Here one could address the formalization of BIM-related processes between organizations, thereby complementing the within organization arrangements already covered by the organizational structure criterion.

In addition, from the overall exercise, the research team came to the conclusion that extra attention should be paid to the trust-related aspects of openness and transparency between parties in respect of BIM during any further development of the BIM maturity model. The temporary nature of collaboration between organizations in construction projects hampers the process of building trust because trust is influenced positively by past experiences and future expectations of collaborating partners (Laan, Voordijk, Noorderhaven, & Dewulf, 2012). The research team further believes that BIM can be a driver of change and improvements in processes. This effect on process change could be included in the further development of the BIM maturity model within the “processes and procedures” criterion.

Once these enhancements have been incorporated in the assessment tool, the next step in the BIM maturity research will be to focus on further implementation of the BIM maturity model and in particular to develop a survey tool as a data collection method. Using such a tool will enable a more generic picture of BIM maturity to be obtained from a wider sample enabling the BIM maturity model to be further tested and refined once again.

In addition, tools such as the Virtual Design & Construction (VDC) scorecard (Kam et al., 2014) could be evaluated to extend the use of the BIM maturity model to the project level. Investigating the potential of the developed BIM maturity model on the project level is particularly relevant since collaborative aspects are expected to be particularly beneficial within a project context.

2.7 Conclusions

The objective of this research was to provide insights into BIM developments within the various subsectors of the Dutch construction industry by developing and employing a BIM maturity model and accompanying data collection methods. Unlike existing BIM maturity tools, the development of the presented BIM maturity model focused on both technical and organizational aspects of BIM, incorporating collaborative aspects between parties. In addition, the developed model aimed to support clear and mutually comparable BIM maturity assessments for making comparisons across the various disciplines within the construction industry. Based on the strengths of several existing maturity models, the structure and components of the proposed model were described. The model broke BIM down into six main criteria and sixteen subcriteria, whose maturity levels were to be classified on a scale from 0 to 5. Once the basic BIM maturity model was established, it was translated into an interview format that was used to collect data from 53 firms in the Dutch construction industry. This implementation of the model also served to validate the BIM maturity tool. The in-depth interviews provided insights into differences and similarities among the subsectors. The main findings from the sectoral analysis can be summarized by three core elements:

- First, the evaluated leading companies demonstrated strong strategic support for BIM by setting goals, making BIM plans, and providing sufficient resources for BIM implementation.

- Second, the maturity scores for the formalization of BIM-related processes, tasks, and responsibilities were lower than for other criteria despite their relevance being acknowledged by the respondents.
- Third, respondents emphasized the importance of people and culture in the BIM implementation process. Influencing personal motivation and improving BIM-related competences were identified as essential means for supporting change of people and culture.

The BIM maturity assessment identified differences between subsectors that could be utilized by subsector-specific associations to develop industry-wide policies and diminish the gaps in BIM maturity and perspectives among the industry's subsectors.

The responses to the invitations to be part of our interviews indicated that the extent to which organizations were engaged in BIM implementation influenced their willingness to take part. Organizations that believed they were lagging behind in implementation often indicated that participation in the research was not relevant for them. Conversely, leading companies often saw benefits in gaining a sense of their own BIM progress in relation to developments in their subsector and in the construction industry in general. Further, these organizations have already encountered several barriers that have hindered implementation and often found ways to overcome them. As such, the interviews with those leading the way were especially valuable, not only providing more extensive information on the BIM maturity criteria, but also on presenting attention points of BIM implementation. Nevertheless, when interpreting the results, one should be aware that the sample used does not allow generalization to the entire construction industry.

Based on this study, the following directions for further research are proposed:

- First, it would be useful to further explore the applicability of the developed BIM maturity model by incorporating the aspects from the evaluation in its design and, subsequently, by conducting more extensive sectoral analyses. A related research topic would be to analyze to what extent the findings here on BIM maturity, at primarily leading companies in this field, are representative of the Dutch or European construction industries as a whole. Further, is the maturity model developed here also valuable for organizations that are lagging behind?
- Second, it would be relevant to analyze whether an increase in BIM maturity corresponds with an increase in BIM performance on the firm and project level. A related issue would be to explore how the BIM

maturity model can be applied to support effective collaboration on the project level.

Based on this study, the following recommendations can be made for practice:

- First, focusing on organizations, there is a need for BIM education and training. According to many of the interviewed BIM managers, learning could be accelerated by linking more general education and training with specific BIM-related support in projects (on-the-job training).
- Second, sectoral associations need to further clarify BIM definitions within subsectors to enable mutual understanding of one another's BIM uses. Linking these perspectives would help close the gap between subsectors and thereby foster multidisciplinary BIM use in projects.
- Third, although many standards are already used by the various disciplines, the maturity and fragmentation of standards is regarded as a point needing attention. A sectoral priority for encouraging collaboration between subsectors is therefore the further development and adoption of standards that transcend subsectors.
- The final recommendation to organizations in the construction industry is to formally standardize tasks, responsibilities, processes, and procedures with regard to adopted BIM methods. Doing so, will encourage the reliability and consistency of BIM processes and accelerate organizational learning.

CHAPTER 3

UNDERSTANDING BARRIERS TO BIM IMPLEMENTATION: THEIR IMPACT ACROSS ORGANIZATIONAL LEVELS IN RELATION TO BIM MATURITY

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Abstract

This multiple case study at a contracting firm contributes to understanding the barriers that organizations face during the implementation of Building Information Modelling (BIM) by providing insights into the impact of barriers on different organizational levels (i.e., from top management to the level of project teams) and by relating barriers to different degrees of BIM maturity. First, we saw the dominance of barriers related to people's motivation, competence, and time capacity across all levels of the organization. Second, the cluster of barriers on the middle-management level indicates that this level is key when attempting to reduce barriers. Third, it was only cases with a low level of BIM maturity that struggled with a lack of top management support, showing this support's importance in achieving BIM maturity growth. High BIM maturity situations are more prone to externally oriented barriers in attempting to further leverage the benefits of BIM. Our study provides insights on where to focus BIM implementation measures and, as such, build organizational BIM maturity.

3.1 Introduction

Recognized as one of the least digitalized sectors (McKinsey Global Institute, 2017), the construction industry is now catching up by, over the last decade, widely adopting Building Information Modelling (BIM). This is expected to significantly increase productivity as well as to significantly reduce costs (McGraw Hill Construction, 2014; The Boston Consulting Group, 2016). Several maturity models have been developed to gain insight into an organization's progress in BIM adoption that can be used as tools to assess an organization's BIM maturity level in terms of various technological and organizational criteria (Bew et al., 2008; Computer Integrated Construction Research Program, 2013; National Institute of Building Sciences, 2015; Siebelink, Voordijk, & Adriaanse, 2018; Succar, 2009). However, to support organizations in their further BIM development, more is needed than merely assessing their current BIM maturity level. To better understand what is stopping organizations maturing in their BIM use, more insights are needed into the barriers that organizations face in their efforts to implement BIM and increase its maturity.

Previous research has stressed many of the barriers that organizations encounter in their efforts to implement BIM, involving aspects such as a lack of motivation to change to BIM practices (e.g. Adriaanse, Voordijk, & Dewulf, 2010b; Chien et al., 2014; Eastman et al., 2011; Gu & London, 2010), insufficient knowledge and competence in BIM (e.g. Adriaanse et al., 2010a; Arayici et al., 2011; Liu et al., 2015), insufficient technological means, Information Technology (IT) support or interoperability issues with different software and data exchange (e.g. Chien et al., 2014; Li et al., 2009; Miettinen & Paavola, 2014).

Since the construction industry is striving to gradually mature its use of BIM, we wonder whether this development is accompanied by a decrease, or change, in the barriers to BIM implementation experienced. Put differently, it is unclear what kind of barriers an organization can expect to face given a particular degree of maturity in BIM. Existing literature mainly focused on providing an overview of barriers, regardless of the influence of BIM maturity on the occurrence of specific barriers. Moreover, existing literature is also lacking a more in-depth understanding of how these barriers can manifest themselves on different levels within the organization (e.g., strategic level, operational level) and, accordingly, what actions have to be taken to overcome these barriers. Based on the research gaps identified, the goal of our research is to gain increased understanding of the extent and type of barriers to BIM implementation and use in relation to the

current level of organizational BIM maturity. We will use organizational levels as a framework to classify the characteristic barriers, providing insights into the impact of barriers on the implementation process from the strategic top management level down to the operational level of projects. In so doing, our study provides valuable insights that managers can use to remove or influence the characteristic barriers.

In order to meet this research objective, we conducted a multiple case study in which we examined the BIM maturity level and implementation barriers in a large contracting firm participating in many complex and multidisciplinary projects, mainly in the western European market. The contracting firm provided access to cases that showed variations regarding BIM maturity and barriers to BIM. Data were collected through interviews with BIM department representatives, analysis of BIM strategic documents, and participation in BIM steering group meetings.

Compared to previous studies, this case study approach provides a novel perspective on BIM implementation barriers in three different ways. First, the adopted approach allowed us to map barriers on different organizational levels and, in so doing, find relationships with the implementation processes of strategic BIM initiatives across different levels of analysis. Second, the link between BIM maturity and barriers to BIM implementation and use allowed us to gain increased understanding of the occurrences and types of hindering factors that organizations typically face in their pathway to increased maturity. Third, the interviews with BIM department managers and experts helped us to gain a comprehensive understanding from the point of view of representatives responsible for implementing the BIM strategy in their firm. This differs from previous research which has not explicitly distinguished respondents on different organizational levels, (i.e., from strategic or operational levels), leaving room for multi-interpretable findings.

The approach introduced above enables us to extend theoretical insights on barriers to BIM implementation and use as elaborated below.

3.2 Theoretical background

Existing theories have increased our insights into many of the barriers that hinder the implementation and use of BIM. We can describe factors as found in the literature in terms of (1) management support, (2) people and culture, (3)

technology, and (4) the use of defined processes and standards. Based on the following explanation of these factors, we will derive our main research questions.

3.2.1 Management support to boost BIM initiatives

An important barrier to BIM implementation, leading to poor BIM performance, has been identified as insufficient commitment or leadership by senior management in support of BIM implementation in their company (Chien et al., 2014; Won, Lee, Dossick, & Messner, 2013). In addition to the lack of managerial support, traditional management approaches also seem not to fit well with BIM implementation, and nor does a traditional organizational structure with the associated distribution of tasks and responsibilities (Chien et al., 2014; Won et al., 2013).

Furthermore, a lack of management support is often expressed in insufficient financial resources. This can first be seen with the high initial costs and high costs of the implementation process (Liu et al., 2015). Beyond these short-term investments, also a lack of long-term financial support is considered as a significant barrier due to the lack of continuous investment to support BIM implementation (Won et al., 2013). On the more operational level, the high costs of software and hardware have been identified as barriers (Chien et al., 2014). Also related to operations, the costs associated with education and training of personnel, as well as the costs of setting up modified BIM processes are seen as barriers (Liu et al., 2015).

Another barrier to BIM implementation on the management and strategic level is the lack of evidence for BIM success in terms of quantifiable benefits. Since management is looking to legitimize allocating resources to BIM implementation, this lack of clear benefits for the various project participants and project phases limits the management's conviction to focus on BIM implementation (Li et al., 2009; Lu, Fung, Peng, Liang, & Rowlinson, 2014; Miettinen & Paavola, 2014). Furthermore, when there is a clear focus on BIM and expectations are high, the promises tend to exaggerate the real impact of BIM, leading to misconceptions and disappointment (Miettinen & Paavola, 2014).

3.2.2 Willingness and competence of people to use BIM

A second factor identified in the literature can be summarized as the influence of people's motivation, knowledge, and skills, and the organizational culture, on the implementation and use of BIM. In general, a non-supportive organizational culture has been found in the construction sector that hinders the change process

to BIM. Where there is an unsupportive organizational culture, essential elements such as goal setting and team orientation are often absent (Cheung, Wong, & Wu, 2011). Moreover, also on the individual level, a lack of intrinsic motivation caused by perceived complexity, perceived disadvantages, time pressures, and a lack of trust in technology are significant barriers to the use of BIM, resulting in persistent use of traditional approaches (Adriaanse et al., 2010a; Chien et al., 2014; Eastman et al., 2011; Gu & London, 2010).

If we turn to external motivation, the lack of a client's requirement to use BIM is one of the main impediments (Eastman et al., 2011). If there is no clear mandate in the form of a contract or enforced (inter)national standards, organizations feel they do not need to implement BIM (Adriaanse et al., 2010a; Volk, Stengel, & Schultmann, 2014). Another external factor is the lack of motivation for BIM in supply chain collaborations. These collaborations are characterized by conflicting organizational interests and differing organizational backgrounds (Gal, Lyytinen, & Yoo, 2008). As a result, supply chain partners are often unwilling to take part in the proposed BIM approach of the general contractor (Eastman et al., 2011). Within the context of projects, the lack of willingness to share information among project participants is also recognized as a barrier to BIM implementation (Won et al., 2013).

When considering knowledge and skills, many researchers have stressed their importance for implementing and using BIM. Generally speaking, a lack of trained personnel hinders organizations in making the transition to BIM (Chien et al., 2014; Eastman et al., 2011; Underwood, 2009), which is particularly linked to insufficient skills to work with the new technology or to operate the applications (Adriaanse et al., 2010a; Arayici et al., 2011; Liu et al., 2015). Insufficient training on BIM applications, which even applies to young, recently graduated, employees, is regarded as an important reason for these lacking skills (Gu & London, 2010). However, simply increasing the amount of training appears not to be very effective in current practice because organizations struggle to define who and to what extent people in the organization should be skilled in using BIM (Underwood, 2009). Also the incentives to invest in BIM training are limited since there's no clear understanding of the added value of BIM or how BIM should be used to gain the most benefit (Arayici et al., 2011; Gu & London, 2010; Li et al., 2009; Miettinen & Paavola, 2014). It seems that organizations have insufficient knowledge about how BIM could contribute to people's everyday work (Underwood, 2009). Further, the literature also comments negatively on the capabilities of supply chain partners. It often turns out that project partners are incapable of adopting the intended project approach to BIM (Eastman et al., 2011). Where it is intended to

use BIM in collaboration with project partners, their lack of BIM capabilities constitute a risk to the reliability and credibility of the model as the main source of information (Miettinen & Paavola, 2014).

3.2.3 Technology to facilitate the digitization of processes

Less prominent, but still seen as important barriers are technological aspects. From a technological perspective, the limited interoperability of different software packages is particularly recognized as a barrier, mainly due to the dispersed landscape of BIM software, other related software, and tools (Gu & London, 2010; Li et al., 2009; Miettinen & Paavola, 2014). The data to be exchanged could be incompatible with other software packages when other parties or disciplines work with native data formats (Chien et al., 2014). Furthermore, the organizational IT infrastructure often insufficiently supports the implementation and use of BIM (Eastman et al., 2011), which can lead to misalignment between the technology and the working practices, and may also restrict the use of the technology in the intended way (Adriaanse et al., 2010a).

3.2.4 The need to define processes and standards

Another set of barriers to BIM implementation relate to change and the institutionalization of procedures and aspects related to contracts, standards, and legislation. In terms of change, organizations often struggle with BIM implementation because of the absence of standardized work procedures for BIM, or a lack of clarity in these procedures (Adriaanse et al., 2010a; Won et al., 2013). Organizations struggle to transform and integrate new BIM practices with their currently used traditional processes (Arayici et al., 2011; Chien et al., 2014). Turning to legal and contractual aspects, organizations face issues regarding the definition of contracts in a BIM context, including the ownership of intellectual property, protection of copyright, and dispute-settlement mechanisms (Chien et al., 2014; Eastman et al., 2011; Gu & London, 2010; Miettinen & Paavola, 2014). With regard to standards, literature shows that sectoral standards for the exchange of information are insufficiently available or not well-defined (Eastman et al., 2011; Grilo & Jardim-Goncalves, 2010).

3.2.5 Towards linking barriers to BIM maturity and organizational levels

As shown above, organizations can face a wide variety of barriers to BIM implementation and use. However, the lengthy list gathered from the literature fails to provide an advanced understanding of barriers that would provide guidance on appropriate measures to overcome them. The first step we identified

to build on the existing knowledge is to gain greater insight into in what situations we can expect certain barriers in order to develop ways to act upon them. Previous studies have already informed us about the varying BIM maturity levels seen in organizations (Siebelink et al., 2018). We would expect that organizations with a strong focus on BIM, and well-structured BIM use, to encounter different barriers than organizations that have only recently taken the first steps towards BIM implementation. Therefore, in this study we investigate the barriers to BIM implementation in relation to BIM maturity.

Second, although we have identified that barriers to BIM implementation affect various organizational levels, from top management down to the operational level, and also the external environment of the organization, a comprehensive understanding is lacking. To provide better insight into at what level interventions could most effectively be made, we will analyze the barriers with respect to the organizational level where they appear. In so doing, we will generate actionable knowledge on how organizations could achieve a greater BIM maturity.

Concluding, our study aims to better understand the relationship between BIM implementation barriers and an organization's BIM maturity, supported by advanced insights into the organizational levels on which these barriers occur. To this end, we defined the following two research questions:

Research Question 1. How can the barriers an organization encounters with respect to BIM implementation and use be mapped on the particularly affected organizational levels?

Research Question 2. To what extent are the barriers to BIM implementation and use that occur related to organizational BIM maturity?

3.3 Methodology

The aim of this study was to increase understanding of barriers to BIM implementation and use, particularly regarding the organizational levels on which these barriers occur and how these barriers relate to BIM maturity. This objective requires insights into the complex interaction between the BIM implementation process, the initiatives undertaken on different organizational levels, and the occurring barriers. Following the arguments put forward by Eisenhardt (1989) and Yin (2003), we adopted a multiple case study approach as this provides methods that we can use to understand the complex BIM implementation barriers

in their specific, natural context. In contrast to other research methods that involve large samples, our study of a relatively small number of cases provides a wealth of detail which we can leverage to extract cause–effect relationships from our theoretical constructs (Hall, 2006).

We conducted an in-depth multiple case study of BIM maturity and BIM implementation barriers in a large contracting firm employing more than 20,000 people spread over nine distinct organizational units, which form our cases. These nine organizational units are operating mainly from offices in different western European markets. They vary in terms of their size, as well as in their focus on either civil structures or buildings disciplines. Nevertheless, they share the overall firm's strong common strategic BIM intent to develop a leading position in the construction industry. Given the defined BIM strategy, BIM departments within the individual units have to set up and guide the BIM implementation process for their own specific firm. The choice of a general contractor was based on their central position in projects, which allowed a broad view of experienced barriers, crossing both phases and disciplines. As such, the selected firm served as a representative of the diversity of firms in the construction industry. The particular contracting firm was selected based on the aims of our research, which led to the choice of a large, but fragmented, firm with sufficient potential to show diversity in BIM maturity. This enabled us to link the case study outcomes to the identified BIM maturity levels.

3.3.1 Data collection and analysis

We interviewed BIM department heads, BIM managers, technical BIM specialists and information managers from these departments in a face-to-face setting to assess BIM maturity and gather insights into BIM implementation barriers. The first author had been involved in various meetings with managers and experts from the BIM departments and, by doing so, was in a good position to better understand the organizational setting and context before conducting the series of interviews. The interviewees possessed a broad and comprehensive view of the status of BIM in their firm and could, from their positions, also reflect critically on the barriers encountered during the implementation of BIM in departments and projects. Each semi-structured interview generally took between 1.5 and 2 hours. This allowed an interview setting in which we could deal with key questions on aspects of BIM maturity and implementation barriers, but also could leave room for follow-up discussion on interesting or surprising topics that arose during the conversation (Myers & Newman, 2007). The interviews were recorded, transcribed and results were shared with the interviewee before being discussed

in the steering group to verify whether both the respondent and the other BIM representatives recognized the outcomes. Representatives from each of the cases participated in these steering group meetings which aimed to share and align BIM goals and initiatives. Moreover, the outcomes were intended to contribute to steering the BIM policies in the firm.

The initial interview questions were general introductory questions about the interviewee's function in the company and about how, from their department's perspective, they had organized BIM implementation. Next, we extensively asked the interviewee about the barriers the organization had encountered in the implementation and use of BIM. Besides information on the barriers themselves, the questions also aimed to reveal the causes, consequences, and actions taken with regard to these barriers. Additionally, this interview gathered some information about the organizational level mainly affected by the barriers. In order to define the organizational levels, we adopted the perspective of BIM implementation as an organizational change process that propagates through the organization (Whelan-Berry, Gordon, & Hinings, 2003) and is affected by many different internal and external factors (Duncan, 1972). We then integrated these definitions with appropriate levels in the construction industry (Kamara, Augenbroe, Anumba, & Carrillo, 2002) and the organizational structure within the studied units. In doing so, we identified a top management level, below which there was a layer consisting of the IT department and the BIM department, and finally a project level consisting of all the operational project teams. In addition, we specified an external environment consisting of factors related to clients, partners, and sectoral regulations.

The subsequent part of the interview was more structured and contained a set of questions related to the 18 criteria for a BIM maturity model previously developed and validated in a sectoral analysis of the Dutch construction industry (Siebelink et al., 2018). Following this model and the corresponding method, we assessed aspects related to strategy, organizational and project structures, people and culture, BIM-related processes, IT infrastructure, and data structure. We asked several questions related to each of the 18 criteria to verify whether all conditions for a particular maturity level were met. Only then, could the BIM maturity level increase incrementally to the next level, introducing a new corresponding set of questions. In doing so, interviewee's answers could be translated into a BIM maturity score for each criterion. The closing interview questions turned attention to aspects the interviewee either missed during the interview or wanted to elaborate upon. Figure 11 summarizes the main parts of the described interview structure.

We improved the validity of our study through triangulation during our data collection and analysis (Scandura & Williams, 2000). This was achieved by studying BIM strategic documents and analyzing field notes from participating in BIM steering group meetings alongside the interviews. The minutes and discussed documents from these steering group meetings were also available. By using multiple data collection sources, we could check whether interview data were consistent with documentation and meetings. Next, we further improved the validity of our study by adding a reflexive member check (Cho & Trent, 2006). This enabled all interviewees and other steering group members to reflect and comment on study outcomes, which contributed to final refinements made to this article. Table 6 provides an overview of the main case characteristics and the data sources.

Figure 11. Graphical representation of the interview structure, which covers the two main theoretical constructs. Part 1 includes questions on barriers to BIM implementation and use, including their characteristics. Part 2 has questions related to the 18 BIM maturity criteria (Siebelink et al., 2018).

Table 6. Data collection and case characteristics.

Cases	Interview data	Archival data	Observational data
Case 1 Sector: buildings and civil	2 interviews: - Head of BIM department - Technical BIM specialist	- Overarching organizational strategy - Strategic plans of individual units - Work package plans to structure and guide specific BIM implementation and use	- Two-day steering group meetings attended (11 in total)
Case 2 Sector: buildings and civil	2 interviews: - BIM manager - Lead BIM engineer	- Steering group meeting minutes	
Case 3 Sector: buildings	2 interviews: - Head of BIM department - BIM advisor		
Case 4 Sector: buildings	1 interview: - Head of BIM department		
Case 5 Sector: buildings and civil	2 interviews: - BIM manager - BIM implementation manager		
Case 6 Sector: civil	2 interviews: - Head of BIM department - Digital systems manager		
Case 7 Sector: buildings	2 interviews: - BIM manager - BIM specialist		
Case 8 Sector: civil	2 interviews: - Head of BIM department - BIM specialist		
Case 9 Sector: buildings	2 interviews: - Information manager - BIM coordinator		

Our data analysis approach involved three main stages. The first involved the analysis of the data related to barriers to BIM implementation and use and the second then positioned the identified barriers on the affected organizational levels. In the third stage, we analyzed data related to BIM maturity, which enabled us to map barriers to BIM implementation and use onto characteristic degrees of BIM maturity. The data analysis stages are now described in more detail (see also Figure 12).

In the first stage, our data analysis process followed the approach of Gioia et al. (2013), which involves first- and second-order analyses of the interview data. We started by creating first order codes on the basis of interviewee quotes that were related to barriers to the implementation and use of BIM. This aimed at identifying the barriers in each case as literally described by the interviewees. During this process, we also identified several characteristics related to each of the barriers linked to their causes, consequences and, if mentioned by the interviewee, actions taken to act upon the particular barrier. Further, still following the inductive approach of Gioia et al. (2013), a second-order analysis of the data was completed, resulting in themes for the first-order barriers. This stage involved interpreting the quotes from the interviewees to arrive at commonalities in meanings and opinions on a more abstract level. The review of existing literature provided a useful reference for defining these second-order codes, but we did not limit ourselves to this existing theory. We then distilled the second-order themes into overarching categories to construct a framework that provided an understanding of the barriers. At this stage, the created data structure was useful in discussing the interpretations of the data among the authors, and this way of triangulation contributed to an agreed understanding of the case data. In addition, we consulted archival data to validate our notion of the interview data.

In the second stage, we allotted the barrier themes and overarching dimensions to the organizational levels we could identify in our interview data. This resulted in a mapping from which we could distinguish whether individual barriers occur on one or more levels of the organization, for example only the top management level or middle management level.

In the third and final stage, the BIM maturity data were added to the analysis. Based on the BIM maturity assessments we did as part of the interview analyses, we determined the BIM maturity level for each of the cases. As shown in Figure 11, this involved 18 criteria related to both technical and non-technical aspects of BIM. Next, we defined whether a case could be assigned to a relatively low, relatively high, or average BIM maturity group. In this, we calculated the average BIM

maturity score for each case as well as the overall average and standard deviation. These outcomes were used to select two low and two high scoring subcases for further in-depth analysis on the impact of BIM maturity on barriers encountered in BIM implementation and use. We used the in-depth interview data to understand the dominant barriers that appeared in these different BIM maturity groupings, which were then visualized in a BIM maturity-dependent mapping of barriers. In this way, we could build our theory on the extent and type of barriers faced by organizations with various degrees of BIM maturity. These insights then provided ideas when discussing ways to lower barriers that matched with the level of BIM maturity.

In order to validate the final outcomes, a feedback session with our key informants was organized, in which we presented our findings and asked for final feedback on the findings. We further interpreted our findings by embedding them in the existing literature, trying to explain both similarities and differences. We then summarized the research outcomes in the form of propositions that can be tested in future research.

Figure 12. Visualization of the data analysis stages.

3.4 Results

3.4.1 BIM barriers

The interview data on barriers to BIM implementation and use led to the identification of first-order codes which, after further analysis, could be grouped into second-order themes. Based on this, we were then able to draw up overarching barrier dimensions. Figure 13 shows the resulting data structure with, from left to right, first-order concepts, second-order themes, and overarching dimensions. Below, we, one by one, explain the overarching dimensions, their second-order themes, and provide representative first-order quotes.

In our explanation of the barrier themes, we will also consider their link to the organizational levels as identified during the interviews. From our data analysis and the predefinitions in the methodology section, we distinguished a top management level, an IT department and BIM department level, and a middle management and project management level, a project team level, and the external level. Figure 14 visually represents the barrier themes and overarching dimensions from the data structure in relation to the affected organizational levels.

Figure 13. Data structure.

Figure 14. Generic picture of BIM implementation barriers plotted against organizational levels, including data from all cases.

3.4.2 People who make it happen

Our data analysis revealed that the core structure of barriers can be related to people, their resistance to change, their BIM capability, and their lack of time for implementing or learning BIM.

Resistance to changing to BIM (a)

This aspect is important on all organizational levels, from top management through to and including the shop floor where projects are worked upon, and can be described by the following remark from one of the BIM department managers we spoke to:

“It is all about change management at the end of the day. So, my real function actually is managing change.”

Overall, our informants very firmly stressed that people are in principle resistant to change, especially when it concerns their own day-to-day activities. There is a strong tendency to stick to the traditional paper-based or less structured way of doing things when people can decide on this for themselves. As explained by one of our respondents, people have sometimes spent half of their life in these systems and working practices:

“People have their own way of doing it, that they are comfortable with. It’s also a way that the industry over many, many years has become quite successful, apparently. So, they don’t see the requirement for digitization as being that important. They will try and use an awful lot of excuses not to digitize.”

The only way people could be convinced about using BIM is by showing them what the benefits are or, as one of our informants said, “you have to create a need for using BIM, otherwise people won’t embrace it”. Often the resistance to change is also unintentionally strengthened by the BIM experts and managers who aim for a too rapid change to BIM. They have to be careful about what to change, why to change it, and how to roll that out in the business. Since overly rapid change could lead to misconceptions and disappointments, people might lose belief in BIM. Therefore, there should be a good fit between people’s capability of change and the proposed pace of change.

Another important resistance mechanism comes into play when a key person’s, such as from a project manager, resistance to change is easily adopted by others who are maybe not directly involved in all developments. Other project employees will not easily oppose these key people, as they have the greatest ownership and

responsibility in the project organization regarding the approach taken and the extent of BIM use. Most people do not have that level of ownership or the intrinsic motivation or drive to be able change working methods.

“You can’t just walk into an organization and say, “be digital, it’s good for you”. You have to show people. We have to earn their trust. They will only ever realize the benefits of being digital when being digital is a day-to-day thing for everybody. Not just having a department that is digital. It should be business as usual.”

Lacking knowledge and competence (b)

A very prominent barrier to BIM implementation and use we found in our study is a lack of knowledge and competence, which could be identified in many forms. First, the inadequate knowledge and competence of project teams hinder BIM performance, and the implementation of new BIM uses. This is not only a problem on the project level, but for the whole organization, including middle management who have to decide whether BIM is to be used and how BIM is applied.

Many respondents further explained the lack of knowledge and competence as due to both a shortage of good, qualified people and the difficulty in training people.

Further, when people are being hired, the importance of considering their BIM competences is sometimes overlooked. Preferably, people’s knowledge and competences should match the vision and future direction of BIM. This HR component is captured in the following quote:

“We, as technicians, tend to focus on technical aspects. However, we need to be aware of the huge human resource component of BIM implementation. That starts with educating the people we hire or currently have. It also involves taking into account the future directions of our business when selecting new people.”

Given the apparent difficulty in training people, the quality of available e-learning programs was criticized. If e-learning programs were better tailored to the needs of different disciplines in the company, and were more user friendly, they were seen as one of the key elements in overcoming the difficulties in getting people to learn and apply BIM in their daily activities. Notably, the competences in using the more basic tools and frequently used software were also limited:

“Some people think we have to buy software, but we have enough software that we just don’t make good use of. When you show people what they can do with the software, it kind of changes their

life. They say, wow, I've been doing this manually. So, are we getting the most out of our current software solutions? Most people's answer would be no."

As part of the lack of knowledge, our informants also stressed the limited knowledge on the tangible benefits of BIM to projects. Most of the time, the investments required for BIM are clear, whereas the return on investments remains a black box. The case study firm had started many initiatives to produce evidence of the advantages of using BIM in their projects but found it hard to distinguish the impact of BIM from other factors that influence project performance.

Time pressure and limited persistence (c)

The essence of time pressure as a barrier is that getting up to speed on using BIM is often an extra task on top of people's ongoing daily activities, and this could be demotivating. Although BIM is supposed to bring benefits in the longer term, sometimes investment is first required to learn about new tools, software, and working practices. Given the high pressure, particularly at the operational levels of project teams, project managers, and the BIM department, people do not always get the time or additional support they need to use BIM. We also see that time pressure is related to people's persistence to keep using BIM when they feel the additional time spent on implementing BIM is not sufficiently worthwhile. The following quote captures this field of tension between time and persistence:

"Say a project engineer still has to learn a lot about BIM, so he starts to get training and gains in-depth knowledge about BIM. This probably means he has to find an additional ten hours a week for learning, alongside his regular ongoing project activities. Although he might end up gaining the results from BIM he wished for, the question is whether this project engineer has become happier and more enthusiastic about BIM. I have experienced several cases in which such people said they would not go through this process again, because of the chaos and additional workload it caused. This is of course a missed opportunity in our effort to motivate people for BIM."

Given the time pressures present in projects, a switch cannot simply be turned to move over to BIM because people are operationally fully occupied and have only limited time left for development trajectories. Thus, patience is required because

the upscaling to more extensive BIM use can, in most cases, only be incorporated in a later project.

Time pressure can also be related to the role people traditionally have within the business. BIM means that people sometimes have to take up new responsibilities within their existing role, for example for more structured document management or for design coordination tasks. Even if people are keen to take on those responsibilities and they have the competences to do so, they might not always be able to because of time pressure.

Respondents also reflected on their own department, which was having to expand new BIM use in projects, provide on-the-job support to project teams, and convince people to use BIM. One of the respondents explained that the current capacity of the BIM department matched project needs from the perspective of the client's requirements. However, to further upscale BIM and more structurally work on innovation, it would require many more resources:

"If we really want to achieve what the firm's strategy requires, we would need a lot more. We probably would have to hire ten more people for our department."

3.4.3 Knowledge and competence building

The next overarching dimension is labelled knowledge and competence building, and involves transferring and upscaling knowledge on BIM across projects. This process aims at improving the institutionalization of BIM knowledge.

Ineffective knowledge transfer and upscaling (d)

One of the problems related to knowledge transfer and upscaling that we identified from the interviews is the project-based culture of the construction industry. There is a focus on first winning a project contract at the tender stage and then to execute the project before quickly pulling back and quickly moving on to the next project. One of the interviewees said the following about this project-level barrier:

"The project team, as a tight group of people, takes the lessons learnt from a project to another job. They can apply that knowledge and get progressively better, but the sharing of that knowledge to other parts of the business is not where it needs to be."

This lack of knowledge sharing and competence building also relates to the means or tools by which knowledge and competence building could be effective. A digital

platform for knowledge sharing has been found not to be very effective. This is illustrated by the following quote:

“Most of our people, even if you had a good platform, are not interested in sitting down in front of a web page and spending time learning.”

So, the question is how to bring knowledge to the very busy people working on projects in a way that they feel it is beneficial. A particular difficulty perceived at the level of the BIM department is to match the available technology and methods to the specific needs of various job profiles:

“We have had discussions about starting a campaign where we try to illuminate people’s awareness of the type of technology that is available to them on the site, and sell it to them on their level. Not on our level, because we see technology in a very different way to maybe what a foreman or a carpenter or a metal worker would. They all want different things. So, we need to be a bit more cognizant, a bit more aware of what people are looking for.”

Other initiatives on the middle-management level, such as meetings with project managers and design managers, have struggled with poor attendance and have not had the intended impact. This is because those who do not attend are mostly unaware of the importance of knowledge sharing. On the contrary, the people that are already trying their best to stimulate knowledge sharing on their projects are the ones who participate the most during such sessions.

3.4.4 Internal enablers and key decision-makers

This overarching dimension relates to key people in the firm that have a leading, steering role and could facilitate BIM implementation and use throughout the organization. This involves top management support, the autonomy of middle management in project organizations, and the impact of the age distribution in the company.

Lacking top management support (e)

Support from the level of top management was operationalized in the form of both providing resources for BIM implementation and supporting BIM in spoken pronouncements. Although most respondents agreed that verbal support was generally present, there could be a stronger focus from the organizational unit’s top management to speak out about their expectations regarding BIM to middle

management. In particular, this should include concrete targets through which middle management could contribute to the corporate strategy in the projects they are accountable for. With regard to this point, one respondent criticized the strong degree of freedom within people's jobs:

"Although I like freedom myself, top management currently allows too much freedom for project managers to decide the BIM approach on their projects. Why should I, given my role in the BIM department, convince a project team to use BIM? Why is it not the other way around, so that the project team has to explain to top management why they are not using BIM in accordance with the corporate strategy? Rules and boundaries for the BIM playing field are currently lacking."

Following a similar line of argument, one of our respondents identified the risks of top management not providing strong steering on BIM. If the BIM guidance from the top level is insufficient, he argued, "people will continue working on their project islands and will focus on their own uncoordinated developments". This means top management needs to facilitate internal boundary spanning to make sure people will share BIM developments not only within their own department or project, but throughout the whole organization.

From the interviews, it appeared that the risk-avoiding attitude of top management also had a restraining influence on BIM implementation. Nevertheless, the board had signed up to BIM and did truly appreciate what BIM could do for the business. However, their response to BIM implementation is measured because they fear the negative consequences of a too rapid change.

The older generation has most decision power, but the least innovation capacity (f)

The organization's age distribution also came across as a barrier in the investigated company. Generally speaking, our informants distinguished a younger generation, a gap in the middle, and an older generation of people. The "youngsters" are the ones with the brightest new ideas, the more innovative ones, but they lack the experience to implement those ideas. The older generation, with generally at least ten to fifteen years of experience, are mostly the ones in decision-making middle-management positions. These people are, however, less knowledgeable about innovative digital technologies and do not steer towards their introduction and use. In other words, the change capacity of the older generation is limited and, as explained by one of our respondents, the change process will only gradually take place:

“Time is a great issue as well. You could say, whether you like it or not, it could take ten years for the older people to leave and be replaced by a younger generation and also for people to get trained in the way of the business and apply a digital approach.”

We can also specify some personal characteristics that are related to the age distribution. For example, if we consider the project managers, the more structured ones more easily embrace the new technology whereas the more chaotic project managers find it difficult to conform to a more structured and formalized way of working.

Strong autonomy of project organizations (g)

As with the previous thematic barrier, the strong autonomy of project organizations mainly refers to the middle-management organizational level. Our respondents regard this level as the connecting link between top management and the BIM department on the one side and the project teams on the other. Project managers are accountable for both the success and the risks of a project and, as such, have considerable influence on deciding the approach for their project. The whole project team is more or less trapped within the BIM approach determined by the project manager. One informant illustrated this barrier at the organizational level of project managers as follows:

“The project managers have full responsibility for the project; they have decisive power. This means that, within our organization, these people have the power to decide to what extent to apply BIM in their project. Of course, in some cases, this turns out positively, but we also face many rather conventional approaches to projects.”

This barrier implies that the construction firm in practice consists of many separately steered and managed project organizations, all with their own specific extent of BIM use.

The widespread location of the projects is one of the factors that influences the autonomy of the project organizations. Given the distant functioning of project organizations, away from the head office, they have a large degree of independence:

“We expect project organizations to operate independently. They have to deal with their own problems. Consequently, these project organizations do not allow much steering from the head office either.”

Our respondents were aware of the differences between their perspectives on BIM, and those of a project manager, resulting in a gap between the desired BIM use and BIM use in practice. One of our respondents used a striking metaphor to explain these divergent perceptions of BIM:

“Imagine I need to be at a known destination in half an hour, I will take my car, as I always do. Now someone proposes to try something new, the Hyperloop, which will probably take me to my destination in 15 minutes. However, according to my contract I need to be there in 30 minutes. So, do I trust the other person sufficiently to join that experiment, to accept the risks and uncertainties? That’s exactly what we ask from project managers. We should not be surprised if they tend to rely on more traditional methods.”

3.4.5 Technological complexity

Technological complexity is a barrier that mainly involves the challenge of facilitating external collaboration with other parties or disciplines and the complexity stemming from the diversity and uniqueness of projects.

Facilitating external collaboration (h)

The exchange of data with external parties is primarily hindered by security precautions such as the use of firewalls. Consequently, the IT departments experience many challenges in making data accessible between parties. Workarounds are used in practice, but these undermine security. File-based approaches were also mentioned by our respondents as a way in which external data were exchanged, whereas they would rather opt for online services or cloud-based collaboration.

External collaboration at project locations is also dependent on the available internet connection. Since some projects are situated in very remote locations, the internet speed can also be a barrier to data exchange:

“We do have high-end laptops and we do have facilities such as double screens and high-resolution monitors. However, that’s no help if we have a slow internet cable attached to those devices.”

Respondents stressed that collaboration with other parties is also hindered by the limited interoperability of BIM software; a barrier in the external environment that is outside the organization. As such, it is a challenge to link the information from the various software packages used for design, calculation, and project control.

This can reduce the quality of the exchanged information, reducing its reliability, and requiring more extensive monitoring and checking of data.

Diversity of projects and disciplines hinder standardization (i)

The second technological challenge refers to the uniqueness and diversity of departments and projects. In principle, the efforts of the BIM department are aimed at ongoing application of BIM developments on the project level. However, only a few projects are able to benefit from the implementation of these new developments as it is difficult to apply BIM in all projects simultaneously and in a similar manner. BIM developments tend not to match the scope of some projects, and, in practical terms, implementation is limited by the supportive capacity of the BIM department.

Additionally, the specific process definitions for the various disciplines within the organization hinder standardization:

“Each division, each department has its own processes that work well for them, because they have optimized them for their own needs. As soon as you want to use standardized systems across the organization, it is a problem. So, the centralized standard for processes is not used in every project, at least not in detail.”

3.4.6 External facilitators

We also identified factors that posed a threat to BIM implementation and use, but could not be directly influenced by internal processes within the case study organizations. These factors can best be regarded as facilitators or conditions for internal BIM processes. From our analysis, we distinguished four main themes: the BIM maturity of supply chain partners, the BIM maturity of clients, the definition and implementation of open standards, and the appropriateness of available software to project goals and activities.

Insufficient supply chain maturity (j)

Our case study firm, as a general contractor, is very much dependent in their projects on both products and information from subcontractors and suppliers. However, not all supply chain partners have equal knowledge and experience with BIM, as explained by a respondent:

“We have to build on the information we get from supply chain partners. However, we can only do so if the quality of information is sufficient. This is a debatable point. We often get object libraries

from suppliers of poor quality. We cannot use these in our models. Although we give these suppliers feedback and try to train our most important suppliers on how to set up the object library, we do not always get the quality we need."

Some of our respondents admitted that supply chain maturity is also dependent on how supply chain partners are procured, illustrated by the following quote:

"We should make a decision. Is a cheap partner good or should we spend more money and have an easier time? Do we make more money out of that? That's a hard thing to figure out."

Insufficient maturity of clients (k)

Our case study firm was involved in many projects where clients did not request BIM usage. In such cases, the project was either carried out using a more traditional approach, or the project team had to convince the client of the added value of BIM for the particular project. An insufficient client maturity also refers to situations in which BIM is requested by clients, but the clients do not really know what the gains from BIM will be, or how they should use the information in the operation and maintenance phase. Given this perception, one of our interviewees therefore emphasized the need for a mature, well-educated client in terms of BIM:

"We need a well-educated client. We need someone on the client side who is coordinating BIM, including information management, coordination of the project, and the BIM capability of designers before they engage in the project. Too often, clients are not capable of doing that."

Not well-defined or poorly implemented open standards (l)

Information and data exchange standards have not been well-established in construction. The interviewees stressed that the construction sector association had only recently recognized the importance of such standards, whereas other branches, such as the mechanical, electrical, and plumbing sectors, had done so years earlier. As a result, different parties have different perceptions of object naming and the landscape of information standards is dispersed, hindering supply chain collaboration:

"There is an ongoing discussion with the supply chain to make sure that information is presented to us in the right format. There is no standard approach. Whether you are talking to environmental agencies, to rail infrastructure clients, or to road infrastructure

clients, they all have different ideas of what they actually want, the format they want it in, and the information that is contained in it. Even divisions within those organizations have yet to make firm agreements with each other on what they want. This is making it very hard for us to engage with the supply chain in the way we would like."

Even if sector standards are available, the inconsistent interpretation and use of them form a barrier. Setting up specific BIM arrangements for different clients slows progress in terms of standardization of processes and contracts. It also absorbs the capacity of the supportive BIM department that could otherwise have been used to implement more value-adding BIM use.

With regard to the existing Industry Foundation Classes (IFC) data exchange standard, the respondents saw the quality of this standard as a hindering factor. Some respondents stressed that the IFC quality should be better controlled. Additionally, the case study firm often receives discipline-specific models in an open standard format that are not well-checked by the suppliers before being exchanged. Since this could lead to serious errors propagating into the overarching BIM model, hard agreements need to be made on specific native data exchange formats. This hindered the more open exchange, use, and reuse of information in a BIM environment.

Software and tools are not appropriate for project goals and activities (m)

Our interviews revealed that BIM is gradually being increasingly used on construction sites. All kinds of digital technologies are finding their way onto the construction sites, such as the use of tablets for gaining insights into the design or capturing site inspections. However, the functionality of this technology was also criticized by our respondents from the supporting BIM departments. In terms of the software, they felt that the main packages being used did not sufficiently support onsite people in their construction activities. Only the final situation is shown, which limits the added value of the BIM software in the construction phase. Rather, interviewees like to have software that provides step-by-step instructions to guide the construction activity from start to end. This would also be beneficial in terms of a consistent and structured approach that better allows controlling of quality and status. Additionally, our respondents mentioned that user-friendliness is a problem with hardware such as tablets, specifically referring to situations where construction workers need to walk around with such devices and have to work precisely with touch screens.

Furthermore, respondents stressed that project teams and their BIM department experience challenges because of the misfit between software and project goals:

There is no one software package that provides a perfect or the desired BIM solution for each situation. Considering the goals and application in a specific project, a software package might not be favorable for, for instance, 4D modelling linking a 3D model to a construction plan. Therefore, we have to be careful when linking technology and software tools as well as possible to the goals and activities of a project. This requires flexibility in people, but also skills to work with different software packages.

3.4.7 Barriers related to BIM maturity

We added a further dimension to the data analysis of barriers to BIM implementation and use by evaluating the BIM maturity scores in our individual cases. This informs us whether differences can be expected concerning barriers to BIM implementation and use between companies with rather low and relatively high BIM maturity. In addition to the insight into the type of barriers that firms typically encounter, we also gained insight into the organizational levels on which these barriers influence outcomes in organizations with different BIM maturities.

Based on the average BIM maturity score across the main criteria – strategy, organization and project structure, people and culture, processes, IT infrastructure, and data structure – we identified two cases that scored significantly above average and two cases that scored significantly below average. We considered a case to be significantly higher or lower if its average BIM maturity differed by at least one standard deviation ($\sigma = 0.5$) from the overall average of all cases. In so doing, we grouped cases with a low maturity (Cases 6 and 9), as well as those with high maturity (Cases 2 and 7). The remaining cases were considered as of average BIM maturity. Table 7 shows the calculations and the resultant grouping of cases. We noted that Case 1 was borderline for being included in the low maturity group. We therefore analyzed how including Case 1 would affect the low maturity group, but as the outcomes matched with the findings of case 6 and 9 alone, we limited ourselves to these cases.

Table 7. Grouping of cases on the basis of their BIM maturity scores.

Case #	Average maturity	Average maturity - μ	Grouping
Case 1	2.7	-0.4	Average maturity
Case 2	4.0	0.9	High maturity
Case 3	3.4	0.3	Average maturity
Case 4	3.2	0.1	Average maturity
Case 5	2.8	-0.3	Average maturity
Case 6	2.6	-0.5	Low maturity
Case 7	3.8	0.7	High maturity
Case 8	3.4	0.3	Average maturity
Case 9	2.4	-0.7	Low maturity
Average all cases (μ)	3.1		
Standard deviation (σ)	0.5		

If we look in more detail at the BIM maturity level of the cases, we can also analyze the maturity of each in terms of the six main criteria. We illustrate this by plotting, in Figure 15, the maturity scores for each case for the six main criteria of the BIM maturity model. This further extends our understanding of how the average BIM maturity is built up and how much variance is present in our dataset with respect to cases and criteria. We can immediately see that the BIM maturity scores for IT infrastructure are relatively high in all our cases. This supports our respondents' view that IT is currently not their main concern in the organizational transition towards BIM. Furthermore, one can observe that the cases with the highest average BIM maturity levels (Table 7) did not score highest for IT infrastructure (Figure 15). Indeed, one of the low maturity cases scored highest for IT infrastructure. If, because of these observations, we were to leave IT infrastructure out of our overall BIM maturity scores, the classification of cases to the low or high maturity groups stands out even more clearly.

We then compared the barriers identified in the low maturity cases, the average maturity cases, and the high maturity cases. The comparative analysis of barriers among the different maturity groups revealed that ten of the thirteen identified barrier themes applied to cases from all three BIM maturity groups. Moreover, we found that the barrier themes plotted in Figure 14 reflect the cases with average BIM maturity. Only three barrier themes linked to a particular BIM maturity group: limited top management support, the inappropriateness of software and tools for project goals, and poorly defined or implemented open standards. The first of these, limited management support, was mentioned particularly by respondents

Figure 15. BIM maturity scores per case and per criterion of the BIM maturity model.

from the low and average BIM maturity groups (see Figure 16), but not by respondents from the high BIM maturity cases (see Figure 17). One of the respondents from the high BIM maturity cases illustrated their management support as follows:

“We do have a lot of support from top management with clear communication about why the company has to implement BIM. This

has made a huge difference for us. Due to their top-down support, and because of some good bottom-up BIM experiences from project sites, people have become increasingly aware of the benefits of BIM, which accelerates BIM implementation."

The external character of the two barriers that we did not identify in the low maturity cases, the inappropriateness of software and tools for project goals and poorly defined or implemented open standards, is notable, see Figure 17. Both these barriers relate to external parties and as such go beyond the sphere of influence of the interviewees. We noticed that respondents from the high BIM maturity cases referred to these external barriers because they often outperform other parties in multi-organizational projects or have to take a leading role in BIM. This reveals and expands the barriers that our high maturity cases experience in these contexts. In comparison, the cases with low maturity seem to focus first and foremost on improving their internal BIM maturity. Their representatives stated that their concerns are mainly related to the internal factors such as the knowledge and competences of people.

Considering the demands placed on software, these tend to be higher in the high maturity group with a more extensive and more professional use of BIM. These units have sometimes already reached the limits or the potential of current software solutions. Moreover, their respondents seemed to have reflected more and had insights to criticize software solutions and propose desirable future situations:

"We tend to see the availability of all information in a 3D model on a tablet as an advantage for a foreman, but it is not. Rather, the question is how to make sure such people get the right information for their tasks, at the right moment. Not that someone has to look at a tablet while standing on the scaffolding. Considering safety, this is something we don't want either."

As a result, the interviews also showed that respondents from the high maturity group more often engage in discussions with software vendors to further improve BIM software and achieve a better fit between software and construction activities.

Figure 16. BIM implementation barriers plotted against organizational levels for the low BIM maturity cases. Characteristic barrier themes are presented in bold.

Figure 17. BIM implementation barriers plotted against organizational levels for the high BIM maturity cases. Characteristic barrier themes are presented in bold.

3.5 Discussion

From previous research, we had identified a need to explore barriers to BIM implementation and use in relation to both the organizational levels affected and the level of organizational BIM maturity. The adopted multiple case study approach provided in-depth insights within the context of the selected construction firm, and was aimed at theory building by taking a new, fresh perspective on these barriers to BIM implementation and use (Eisenhardt, 1989). The results of this study contribute to the knowledge and understanding about barriers that organizations face during the complex process of BIM implementation and use. Practitioners can use these insights to focus measures they take against barriers on specific organizational levels, also taking into account their organization's BIM maturity. In doing so, these measures can be more effective and the implementation and use of BIM can be stimulated.

Based on our case study results, we now discuss the most interesting findings, resulting in testable hypotheses. First, the findings show that the most dominant type of barriers is related to people's motivation, competence, and capacity to implement BIM. Furthermore, this barrier theme was emphasized by informants from all our cases and was not limited to a particular organizational level. Rather, it crosses all organizational levels from top management, through organizational departments, to the middle-management level and is also prevalent at the project level. Based on these insights, we propose the following:

Proposition 1. The core group of barriers to BIM implementation and use, crossing all organizational levels, is formed by people-related aspects linked to their motivation, competence, and capacity to switch to BIM.

Although BIM has a rather technical connotation, we found its success is largely bounded by softer, people and organizational, aspects. Our proposition is consistent with existing theory describing the importance of people in the broader context of innovation adoption, use of IT, and organizational change processes. For instance, Jones, Jimmieson, and Griffiths (2005) found evidence of organization culture and change capability impacting on the success of change implementation and employees' perceived readiness for change. The identified importance of barrier themes related to motivation and capability is also supported by the research of Holt, Armenakis, Feild, and Harris (2007), who suggested that readiness for change is influenced by multiple factors including the capability to implement the change and the perceived value of the proposed change. Their

outcomes also indicated management support as an influential factor, here referring to their commitment to implementing the change. This resonates with our finding of limited management support being a crucial block to achieving higher levels of BIM implementation and maturity in the organization. In order to tackle the important barriers related to competence and motivation, we suggest to first make the required competences for BIM use more explicit. Specifically, by incorporating these competences in function descriptions and personal training programs, a structure is put in place that stimulates people to see BIM as part of their day-to-day job.

Although we found barriers across all organizational levels, one should note that the encountered barriers appeared predominantly on the level of middle management and at its boundary with the project level. Most of the barrier themes identified are clustered here, suggesting that this level is particularly relevant when trying to influence barriers to BIM implementation and use. This brings us to our next proposition:

Proposition 2. The middle-management level is key when aiming to influence the transition to BIM in projects and in the transfer of BIM knowledge and experience from one project to another.

Although research in the construction field has not especially considered the role of middle management in BIM implementation, broader management studies on strategy implementation have. Guth and MacMillan (1986) concluded that, when the self-interests of middle managers are at stake, they may redirect, delay, or worsen the implementation of a strategy. Contextualized to our multiple case study, we did observe similar behavior from middle management whose self-interest reflects their overall responsibility and accountability for a project's performance. As a critical reflection, seeing that many interviewees put middle management in a rather poor light, we would like to emphasize middle management's restrained behavior towards BIM implementation is understandable. Hence, the organizational structure of typical construction firms, with autonomous project organizations, can be considered as a driver of middle management's conservative attitude towards change. In line with Guth and MacMillan (1986), the recent study by Tarakci, Ateş, Floyd, Ahn, and Wooldridge (2018) found that middle managers' negative behavior towards strategic initiatives can be overcome by stimulating their identification with the organization which, as a result, can then outweigh their individual drivers. For our case study firm, this means they would have to build an organizational culture that matches with BIM implementation and use. Even more importantly, the firm has to

make sure middle management is willing to embrace this organizational mind-set. Given the importance of middle management in occupying the central position within organizational processes (e.g. Wooldridge, Schmid, & Floyd, 2008), we suggest that future studies on BIM implementation should focus more on this key level.

Next, our research focused on the relationship between BIM maturity and the extent and type of barriers experienced. The spread in BIM maturity found within our cases allowed us to select and compare two cases with rather low maturity and two cases with a rather high maturity. The case study results suggest that most of the barriers to BIM implementation and use occur irrespective of the level of BIM maturity, but that there are a few notable exceptions. First, limited management support was particularly mentioned as a barrier in the cases with a low BIM maturity. We saw that this limited management support hinders a directive voice that could stimulate the transition to BIM and is essential in the early stages of BIM implementation. Specifically, the directive voice can motivate the majority of the organization that is lacking intrinsic motivation to get to use BIM. Considering top management support, we therefore propose:

Proposition 3a. A lack of top management support is an indicator of a rather low BIM maturity in organizations, which emphasizes its importance as an essential condition for maturity growth.

Second, the high maturity cases emphasized barriers outside their own organization, such as the appropriateness of BIM software or tools for construction activities as well as the poor definition and adoption of standards. We express this outcome in the following proposition:

Proposition 3b. Organizations with more mature BIM levels have higher demands when working in collaborative project environments and, as such, experience more external barriers to BIM implementation from limited software capabilities as well as the poor availability and adoption of standards.

The interviews enabled us to see that organizations with higher maturity levels aim to work more closely with the supply chain to realize greater benefits from BIM. On the contrary, the low BIM maturity organizations seemed to position themselves more dependently on the maturity of supply chain partners, rather than to work on BIM together with the supply chain. Thus, we argue that greater maturity leads to an increased collaborative focus on BIM, in which organizations are more aware of their position in the supply chain and their dependence on

supply chain partners. This is supported by Lockamy and McCormack (2004) who, in their explanation of business process maturity, show a focus shift from internal to inter-company as the level of maturity increases. Our findings can also be understood by looking at the definition of organizational maturity. An organization that is more mature will more explicitly and consistently deploy its processes to effectively contribute to its business goals (International Organization for Standardisation, 2015; Software Engineering Institute, 2010). Being relatively mature in a multi-organizational project environment will therefore increase supply chain demands in order to satisfy goals and expectations, which in turn can be expected to lead to an increased supply chain orientation to align and improve processes with those partners. Moreover, we also acknowledge that, as the limitations or weaknesses of partners become more apparent, they will require more attention.

Furthermore, the comparative analysis of the BIM maturity results and experienced barriers also highlighted some remarkable outcomes in terms of the IT aspects. All the units scored relatively highly on IT aspects, even those with relatively low overall BIM maturity. This accords with the interviewees' opinions that, across the organization, the IT was sufficiently available and generally of an adequate standard. From this finding we argue that the IT infrastructure maturity does not necessarily correlate with overall BIM maturity. Elaborating on that insight, our data suggest that IT infrastructure is not a good predictor of the type or extent of barriers experienced. Rather than providing an impression of the overall BIM maturity, IT infrastructure could be seen as an organization-wide condition for IT-supported processes which include, but also go beyond, the scope of BIM. Furthermore, in practice, the IT infrastructure is traditionally considered to be an initial condition for BIM implementation, even before other aspects of BIM are taken care of.

However, as stressed by our respondents, aspects related to people and the organization are much more decisive in the current progress being made on BIM (Won et al., 2013). A previous study by Taylor and Levitt (2007) showed that it was important for an innovation to be aligned with the work practices of people in order to be successful. Broader studies on innovation have also emphasized the importance of the organizational context in which the technological innovation is supposed to take place. Rather than an innovation overloading and burdening people with demands, the organization should provide a context where individuals can connect, share ideas, and engage with each other in a creative innovation process (Arena, Cross, Sims, & Uhl-Bien, 2017; Cross, Rebele, & Grant, 2016). Our analysis of barriers support this notion given that the most important barriers also

relate to this non-technical area, including people's motivation to change and their competence in using BIM technology (Adriaanse et al., 2010a).

Our study also has some limitations. The first one is inherent to the case study approach and concerns the limited generalizability of the findings. Given the limited statistical evidence from this study, the findings should be considered primarily within the context of the investigated case. However, we strove for theoretical generalizability by embedding our findings in existing theories and, in so doing, tried to rule out alternative explanations. As such, the resultant propositions are designed to encourage future researchers to broaden the context of this study and search for more statistical evidence by using larger samples representing the vast diversity of organizations, disciplines, and country-specific conditions in the construction industry.

A second limitation is that we built our theory primarily from the perspective of people working in the department responsible for BIM. Although we highly appreciated the open, reflective, and critical attitudes of the respondents, we are aware that this single perspective could lead to an underestimation of barriers to BIM implementation and use related to their own BIM department and their own scope of work. However, we would justify our choice for this perspective by the richness of the information that respondents in this department could provide. These people also possess an overview of BIM implementation from the top management level through to and including the project level, which was a crucial aspect of our study's aim. Nevertheless, we suggest that future research tests and extends our theory by using informants from different organizational levels, thereby enabling critical reflections on the impact of the BIM department. Additionally, the perspective of people from the BIM department can be interpreted further by looking more closely at the relation between their perceived barriers and the actual implementation level of BIM in the firm. In this way, the impact barriers have on the implementation process becomes more tangible.

3.6 Conclusions

The contribution of this study is that it sheds new light on barriers to the implementation and use of BIM with respect to (1) affected organizational levels and (2) the BIM maturity of the organization. To this end, we carried out an in-depth multiple case study of nine cases from a large contracting firm. The interviews with representatives from the BIM-supporting department enable a

broad organizational perspective on experienced barriers from the level of top management down to and including the operational level of projects. In this way, we increase our understanding of both the causes and consequences of barriers as well as areas or organizational levels on which to focus in order to take effective actions.

Our results first show the dominance of those barrier themes that are related to people's motivation to change to BIM, people's competences in using BIM, and people's capacity to make and support the transition to BIM. These thematic barriers also stand out by their ubiquitous existence across all levels of the organization. Second, although barriers manifest themselves on all the different organizational levels, our study points particularly to the key role of the middle-management level in influencing both the transition to BIM in projects and the transfer of BIM knowledge from one project to another. Third, the analysis based on BIM maturity revealed that limited management support only appears as a barrier in the units with rather low BIM maturity levels, suggesting it is a significant block to maturity growth. In the units with above average maturity levels, greater prominence was attached to barriers related to the external environment as, in these cases, the focus was more on external collaboration as a way to enhance BIM benefits.

Extending the suggestion of Tarakci et al. (2018), our main recommendation for future research is to focus on how to effectively influence the key level of middle management in the specific context of the construction industry. Another key recommendation for future research is to use our insights on BIM implementation barriers to explore preventive and counteracting measures that can be specifically tailored to organizational levels and to the organizational BIM maturity level. Furthermore, we suggest more extensive research to support the impression gained from our data that, rather than IT aspects, it is non-technological aspects that can be used as indicators when determining an organization's overall BIM maturity.

Finally, we should not forget that our study covers only a limited period taken from years of dramatic change within the construction industry. We therefore hope that other researchers leverage our study's outcomes to continue research on future BIM progress and maybe new barriers encountered on this journey.

CHAPTER 4

EXPLORING STRATEGIES FOR MANAGING MATURITY VARIATIONS AMONG PROJECT PARTNERS: FROM UNDERPERFORMANCE AND CONTROLLING WEAK LINKS TO STRETCHING CAPABILITIES

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Abstract

Working with inter-organizational information systems, such as Building Information Modelling (BIM), in the construction industry can be challenging because the maturities of project partners vary. We have explored how these variations influence the maturity of the overall project. The results of our multiple-case study indicate that project maturity is not simply the result of averaging the maturity of project partners. Rather, project managers use strategies to influence project maturity: they tune ambitions, strategically limit the involvement of some parties, or support maturity development through structure and education. This enables partners to achieve a project maturity well above their individual levels.

4.1 Introduction

Over the past decade, digital transformations in the construction industry have been driven by the implementation of Building Information Modelling (BIM), which can be defined as a collaborative method for creating and maintaining a consistent digital representation of a building object over its entire life cycle (Turk, 2016). However, the uptake of BIM has evolved at different speeds in construction organizations (Vidalakis, Abanda, & Oti, 2020). As a result, we see large variations in the level of professionalism, or maturity, of organizations in their use of BIM (Siebelink et al., 2018). This is despite a characteristic feature of the construction industry being intensive collaboration both temporally and in multi-organizational projects (Briscoe & Dainty, 2005; Dubois & Gadde, 2002). As such, the success of these projects very much depends on effective collaboration between participating organizations such as contractors, suppliers, engineers, and architects (Humphreys, Matthews, & Kumaraswamy, 2003; Porwal & Hewage, 2013). Indeed, participating organizations have to recognize their interdependence in determining performance in a project collaboration (Fellows & Liu, 2012). This means that although firms to some extent adhere to their own perspectives and working practices, tuning the interfaces with other project participants is necessary for a satisfactory project performance. We hypothesize that this interdependence of project participants is also relevant in the context of BIM use in projects. Specifically, we discern individual project participants, each with their own organizational BIM maturity level, forming a project organization that also has a particular level of professionalism in BIM: the project-level BIM maturity. Although previous research has attempted to evaluate BIM maturity on the project level (e.g. Chen et al., 2014; Kam et al., 2014), many questions remain regarding how project-level BIM maturity is formed. In particular, research has yet to examine how variations in BIM maturity among participating organizations relate to the maturity of the project as a whole. For example, is a project's BIM maturity restrained by the least mature party in the project organization, or is it possible that parties draw on the most mature partners in the project? Further, does it matter whether parties are well-aligned in their maturity levels? In this paper, we will therefore explore how a project's level of BIM maturity is established.

The objectives of our study are twofold. First, we aim to further understand how the project-level BIM maturity is related to the BIM maturities of the participating organizations. Second, we aim to explore how project managers influence the aforementioned relationship between organization and project maturity. In this way, this study is distinct from previous research in exploring approaches that

project teams employ to manage variations in organizational BIM maturity among collaborating parties. As such, our findings should have a practical relevance for real world projects. In line with the explorative nature of the research, we have conducted a multiple-case study to gather in-depth insights from four construction projects located in the Netherlands and Belgium, collecting data through interviews, surveys, and archival searches.

In the next section, we provide relevant theoretical background on inter-organizational collaboration in construction contexts and BIM maturity. Next, in the methodology section, we explain the data collection methods employed and the approach adopted for within-case and cross-case analyses. After presenting the results, we discuss our findings in a cross-case comparison and further confront them with the existing literature leading to propositions.

4.2 Background

The construction industry is known for its project-based character, with the involvement of many different firms for a limited time frame (Dubois & Gadde, 2002; Sydow & Braun, 2018). Organizations vary in size, but most are small and are often regionally oriented (Lönngren et al., 2010; Poirier et al., 2015). The number of specialties involved in many projects very much contributes to the complexity of construction (Baccarini, 1996). Not only the number of parties but also their reciprocal interdependencies adds complexity and is very typical of the construction industry (Bankvall et al., 2010). In the first place, activities are sequentially interdependent. Second, the overlapping of stages in the construction process adds interdependencies (Dubois & Gadde, 2002). The consequence of this interdependence is that effective collaboration among these firms requires frequent and direct interaction in order to tune their resources, their practices, and to make necessary process adjustments (Bankvall et al., 2010; Bygballe & Jahre, 2009). The digitalization of project delivery has made this interdependence even more apparent (Whyte, 2019). The fragmentation between firms in the construction supply chain is higher than in any other industry (Howard, Levitt, Paulson, Pohl, & Tatum, 1989). Fulford and Standing (2014) concluded that this fragmentation, the resulting project management processes, and the failure to standardize processes impede achieving higher efficiency in projects. In addition, many small to medium size enterprises in the construction supply chain lack both the financial and human resources required to make new technology and innovation viable (Benjaoran, 2009; Lönngren et al., 2010). Given this

fragmentation, collaboration is considered key in enabling integration and automation of processes between project partners (Conneely & Mehrjerdi, 2009). Following Bankvall et al. (2010), we thus argue that, given the fragmented and complex collaboration in construction projects, a construction company should not be seen as a stand-alone entity.

BIM definitions have also recognized elements of the fragmented project structure by focusing on the cooperation between multiple disciplines across the different phases of a project (Miettinen & Paavola, 2014). However, the frameworks provided in the literature on BIM maturity mainly aim to evaluate single organizations (Bew et al., 2008; Computer Integrated Construction Research Program, 2013). Notable exceptions are the studies by Succar (2009), Liang et al. (2016), and Siebelink et al. (2018) who describe maturity measurement methods that can be applied on different levels of analysis. A few approaches explicitly focus on assessment at the project level (Chen et al., 2014; Kam et al., 2014). However, to date, all project-level studies on BIM maturity have presented maturity scores without specifically referring to the diversity within the parties that form the project organization. As such, empirical evidence is lacking about variations in organizational BIM maturity within the specific context of project organizations.

The existing literature tells us that variations between collaborating parties matter, particularly when working with inter-organizational information systems such as BIM where project delivery is digitized. The complexity of such inter-organizational systems is explained by partners having diverse interests, cultures, and strategic intentions (Ireland & Webb, 2007). In particular, partners are often not used to working together in the current formation and possess discipline-specific knowledge (Edmondson & Nembhard, 2009; Van Der Vegt & Bunderson, 2005). One of the core problems of these cross-functional teams is transforming their specialized knowledge into an integrated solution for the project as a whole (Carlile, 2004). To overcome these challenges, Rajaguru and Matanda (2013) argue that collaborating parties should offer compatibility in the fields of strategy, culture, and technology. For example, this could be in the technological infrastructure in terms of software and hardware, a cultural fit between collaborating parties, as well as alignment of objectives and intentions. If that compatibility is present, higher levels of integration in their work practices and information systems can be achieved. Consequently, it should be possible for supply chains to enhance performance and achieve synergy (Rajaguru & Matanda, 2013; Sarkar et al., 2001).

To summarize, in the fragmented construction industry, inter-organizational collaboration in fixed duration construction projects is critical and can be supported through BIM. However, the diverse partners have different levels of BIM expertise such that the collaborating parties may be incompatible in certain BIM domains. Within such a context, we question how the level of BIM maturity in a project is established. In particular, we aim to better understand how the organizational BIM maturities of the various project partners relate to the maturity of the project as a whole. In addition, we wonder how project managers deal with the variations in project partner maturity, and situations where the maturity of some of the partners may lag behind those of others and of the maturity level targeted for the project. To resolve these issues, we have developed the following research questions:

- (1) How is the BIM maturity of project partners related to the overall project maturity?*
- (2) What strategies do project managers use to deal with differences in organizational BIM maturity within a project organization?*

4.3 Methodology

4.3.1 Research design

In this study, we explore the relationship between two main variables: the BIM maturity of individual organizations and the BIM maturity of the project in which those organizations are jointly operating. In addition, as reflected in the second research question, we explore strategies that project managers use to deal with the variations in the maturity of individual organizations. Here, we view these strategies as a mediating factor, influencing the relation between the BIM maturity of the project partners and of the project. A visual representation of the relationship between the investigated variables and the mediating factor is shown in Figure 18.

Figure 18. Investigated variables representing the formation of project maturity.

We explored our research questions by following a multiple-case study approach in which we studied the relation between organizational and project BIM maturities in four projects in their natural settings (Eisenhardt, 1989). First, a within-case analysis allowed us to gain an understanding of the complex dynamics of multidisciplinary BIM collaboration within the setting of individual projects. Second, by including four projects, we were able to compare and contrast our findings through a cross-case analysis, which strengthens understanding and explanation (Miles, Huberman, & Saldana, 2019). Compared to studying single cases, this enhances generalizability and transferability to other contexts (Yin, 2003). In addition, we looked for theoretical generalization by confronting our findings with existing literature (Tsang, 2014).

We selected four cases in the Western European construction industry based on theoretical sampling (Eisenhardt & Graebner, 2007). In the selection process, we consulted the project managers of nine preselected cases to discuss their projects' BIM use and project organization. All the discussed cases used BIM in a multi-organizational setting. In addition, these projects were characterized by a core team of parties, consisting of the general contractor, architects, engineering firms, and the most important suppliers, collaborating intensively through BIM. Furthermore, we included projects that were in the design and/or construction phases as collaboration through BIM is essential in and across both phases. To strengthen the diversity of our cases with respect to BIM maturity, we selected

projects that, based on our first impressions, were expected to show different degrees of project maturity. As such, the BIM-related ambitions of project organizations varied. The main characteristics of the selected cases are shown in Table 8. The identification of relevant parties in the cases was decided upon in consultation with the project managers based on the various parties' involvement in the BIM use. As a result, we did not involve supply chain parties that were only marginally involved and, as such, less decisive in the collaborative BIM use. Each selected party provided one respondent for in-depth interview sessions. These respondents had responsibility for BIM as part of their functions and had job titles such as project manager, BIM coordinator, project engineer, designer, or consulting engineer.

Table 8. Main case characteristics.

Case	Residential Building	Road Infrastructure	Commercial Building	Civil and Hydraulic
Case characteristics	Design and build of five-floor apartment block	Design and build of public transport line and road works	Design and build of inner-city office building	Design, build and maintenance of dike and road infrastructure
BIM scope of the project	Low profile BIM, aiming to ease basic design coordination and data exchange processes	BIM mainly as a means to support collaboration with partners and particularly the integration of processes	BIM was essential to meet design complexity and client's mandate, but is not targeted as a collaborative approach	BIM is key, aiming high to have a well-coordinated digital model to support all phases of the project
Involved parties	N = 7 General contractor (coordinating party), Two MEP* subcontractors, HVAC** Subcontractor, Frames and façades supplier, Two concrete element suppliers	N = 6 General contractor (coordinator), Engineering firm, Structural engineer, Reinforcement engineer, Landscape architect, Supplier concrete elements	N = 4 Property developer (coordinator), Contractor, Architect firm, Structural engineer	N = 5 Engineering firm (coordinator), Contractor, Designer, Dredging company, Engineering firm

* MEP: Mechanical Engineering Plumbing ** HVAC: Heating, Ventilation and Air Conditioning

4.3.2 Data collection

BIM maturity on both the organization and the project levels was measured using an existing maturity model that had been developed to be applied on multiple levels (i.e. organization, project, and sector levels) of analysis (Siebelink et al., 2018). This model evaluates BIM in terms of 18 criteria covering the fields of strategy, organization, people and culture, processes, information technology, and data. It includes a mixture of both formal criteria (such as project organization and contractual agreements) and informal criteria (such as motivation and collaborative approach) which is seen as essential to gain insights into performance (Wang, Lu, Söderlund, & Chen, 2018). The maturity levels for all the criteria are given on a scale ranging from 0 to 5, where 0 is allocated to a criterion if it is not addressed and 5 for a criterion that is fully optimized. Maturity scores are assigned by following the model's incremental structure, meaning that all the conditions for a level, and for all lower levels, have to be met for a score to be awarded. An online multiple-choice survey was used to assess organizational BIM maturity and a semi-structured interview format for assessing BIM project maturity. The data collection procedure is specified below.

Organizational BIM maturity assessment

We assessed organizational BIM maturity of all the participating organizations in each case through an online survey. The survey contained multiple choice questions with answer categories that represent the characteristic conditions of a particular maturity level. In order to gain a reliable picture of organizational BIM maturity, we asked two to three people from each organization to complete the survey. We asked our contact person in each organization to propose alternative respondents in their organization in the event of non-response and to help in stimulating participants to complete surveys on time. In total, we received 41 survey responses on organizational BIM maturity, see Table 9. To determine an organization's BIM maturity score, we averaged the scores on the 0-5 scale of its respondents for each category.

BIM project maturity assessment

To assess BIM maturity at the project level, the first author and another researcher were involved in in-depth interviews with representatives of all the main participating firms (N = 22, see Table 9). Moreover, we triangulated data by consulting project documentation (Scandura & Williams, 2000). This documentation included general project information, organization charts, contractual arrangements, BIM execution plans, schedules, and additional procedures or defined project responsibilities. Two researchers were involved in

the video-conferenced interviews, which were held with respondents who could assess and reflect on BIM-related aspects of the project from their disciplinary perception. The prepared semi-structured interview format contained questions on all 18 criteria of the BIM maturity model. We tailored the format to match the project level of analysis adopted in this study. For this purpose, we slightly rephrased the questions. For example, for BIM vision and goals: “Has a BIM vision been defined within your organization?” was converted to “Has a BIM vision been defined within this project?” During the interviews, we took account of the model’s incremental structure given that questions referring to higher maturity levels might be irrelevant if the interviewee’s answers indicate that the score would not progress beyond a certain level of maturity. The semi-structured interview method allowed us to ask follow-up questions and focus on interesting or unexpected information (Myers & Newman, 2007). This method was also considered the most appropriate when wanting to compare and discuss explanations given by multiple respondents within and across projects. The interviews typically lasted about one hour of which about fifteen minutes was used by the interviewee to explain the project, their function, their particular scope of work, and their relation to other parties in the project organization. Based on the interviews with all the selected participants in a case, and the supplementary project documentation, an assessment of project maturity level was made.

Table 9. Data collection overview with respect to project BIM maturity and organizational BIM maturity.

Case	Interviews with representatives: project BIM maturity and strategies	Surveys: organizational BIM maturity
Project residential building	N = 7	N = 16
Project road infrastructure	N = 6	N = 11
Project commercial building	N = 4	N = 6
Project civil and hydraulic	N = 5	N = 8
Total	N = 22	N = 41

Strategies to deal with differences in the BIM maturity of project partners

Alongside the data related to BIM project maturity, we used the in-depth interviews with the representatives of each organization to collect qualitative data on strategies used to deal with differences in the organizations' maturities. We started with an introductory question on whether variations in organizational maturity were perceived and, if so, how it varied. This enriched the general picture of variation in BIM maturity after which we could move on to our two main questions: (1) how did variation in maturity or, for example, any shortcomings in the maturity of some partners have repercussions on the maturity of the overall project? and (2) how did project managers deal with these variations or shortcomings in project partner maturity? As a follow-up to the latter, we also enquired into how variations in project partner maturity, and any related strategies, helped to achieve the desired level of maturity for the project. The qualitative data from these questions supported evidence from the maturity scores in the previous data collection steps (Eisenhardt, 1989). Moreover, it provided explanations for the moderating factors that project managers could potentially use to influence the relation between organizational BIM maturity and project maturity.

4.3.3 Data analysis

We first carried out a within-case and then a cross-case analysis. In the first phase of the within-case analysis procedure, we compiled case histories of our four projects (Eisenhardt, 1989). These case histories all started with a general introduction to the project and a description of the relationships as well as the responsibilities of the core project partners. Next, in-depth within-case analyses were conducted based on the scores for both the organizational BIM maturities of the various project partners and the maturity of the project. Here, we calculated differences between the maturity of the individual parties and the maturity of the project, which we displayed in the form of heat maps. This enabled us to visualize variations in organizational BIM maturity among project partners. Moreover, the colors in the heat map show at a glance whether the organizational BIM maturity of a project partner was above, similar to, or below project maturity. After these quantitative steps, we searched for explanations in our qualitative interview data. In particular, we coded our interview data based on a few categories that we had identified as most relevant to answering our research questions. The first category captured interview data that provided details about the maturity of the project. In addition to archival project data, the richness of the respondents' interview data was a major contributor to understanding the maturity of a project. The second categorization focused on interview data that explained how organizational BIM

maturity influenced project maturity. This, for example, might refer to one or more parties that, due to organizational immaturity, hindered the overall maturity of the project. Third, we categorized interview data that explained how limitations or variations in organizational BIM maturity were dealt with. Here, it was primarily the interviews with representatives of the coordinating parties (also referred to as project managers) that provided insights into strategies for managing organizational BIM maturity. We improved the validity of our within-case analyses by conducting a final interview with the project manager of each case as a member check (Cho & Trent, 2006). We encouraged the project managers to reflect on our provisional results by asking whether they could provide explanations for variations in maturity between project participants. The feedback from these interviews contributed to further interpreting the case study outcomes.

Subsequently a cross-case analysis was carried out to grasp differences and similarities among the investigated projects, helping to generalize patterns across the projects. In an analogy with Eisenhardt (1989), we applied cross-case techniques to compare and contrast through multiple lenses. Within our research team, we extensively discussed possible lenses for use in the analysis as well as the results from the analysis in order to reach an agreed understanding. First, we looked for similarities and differences in pairs and groups of cases. Second, we looked at our data from the perspective of specific dimensions and made comparisons. For example, we used the organizational BIM maturity scores to gain insights into the impact of organizational limitations and weak links on the overall BIM project maturity. Furthermore, we compared the cases to look for patterns in how project managers dealt with differences in organizational BIM maturity within their project. When comparing the strategies used in the different cases, we linked them to the relationship between an organization's BIM maturity and the project BIM maturity. The aim was to reveal the strategies adopted in situations where organizational BIM maturity was above, similar to, or below project maturity.

4.4 Results

In our results section, for each project, we first describe the case background information (project purpose, project organization), followed by the project maturity and a comparison of this with the maturities of all its partner organizations. We then conclude with an analysis of the general strategies used to deal with the BIM maturity variations found across the projects.

4.4.1 The Residential Building Case

This housebuilding project involved the construction of 82 apartments, divided among three apartment blocks with up to five floors, accommodating both social and private housing. The land was owned by housing corporations who offered a design-bid-build contract for development and construction. The chosen general contractor, based on the architect's design, proceeded with the engineering and construction work, which took about one year for completion and handover. In total, about 15 parties were to various extents involved in the BIM process. In consultation with the general contractor's project manager, a core BIM team of seven parties was selected for interviews during the project's construction phase.

Figure 19 shows the selected parties in the project organization and their mutual relationships. The project adopted a somewhat segregated approach to collaboration, with the organizations working from their own offices on a demarcated part of the project. In this project, the general contractor took a strong leading role, meaning that most of the communications were through the general contractor, rather than directly between subcontractors or suppliers. Nevertheless, some communication and information exchange did take place between the mechanical engineering and plumbing (MEP) contractors and the heating, ventilation and air-conditioning (HVAC) contractor. Relatively, the suppliers of the concrete elements and of the frames and facades were more isolated.

Party	Responsibility
General contractor	Overall project responsibility, coordination
Subcontractor MEP 1	Plumbing, drainage, drinking-water, sanitary fittings
Subcontractor MEP 2	Electrical installation
Subcontractor HVAC	Air-conditioning of wet rooms, inflow fresh air
Supplier frames and façades	Window frames and façade elements
Supplier concrete elements	Elevator walls, landings, stairs, prefab walls
Supplier concrete floors	Prefab concrete floor elements

Figure 19. Responsibilities and mutual relationships among the core parties in the Residential Building project.

Our analysis determined the project as having a maturity level of 1.6, indicating a low level of maturity. Despite higher levels of maturity for some aspects such as personal motivation, software, data structure, and data exchange, the overview in Table 10 is dominated by criteria with maturity levels of 1 (an ad-hoc approach) and even 0 (not considered at all). The organizational BIM maturity of the collaborating parties range from 1.5 for the suppliers to 4.4 for the HVAC subcontractor. On average, the organizational BIM maturity of the partners is 2.4 and the standard deviation of 1.1 indicates quite large differences between partners. As can be seen from the positive values in Table 10, the majority of the project partners have BIM maturity levels above the average project maturity. This implies that the organizational maturity potential of these parties is not being fully leveraged for the benefit of the project. The maturity of the three least mature organizations is close to the overall project maturity. If we look at particular

maturity aspects, we observe that the maturity levels of all the organizations exceed that of the project in both strategy and some aspects of IT. In contrast, in terms of data exchange, information structure, and collaborative attitude, most partners have organizational maturity levels below the overall project maturity. Despite most partners having a low level of organizational BIM maturity in terms of a collaborative attitude, the overall project nevertheless achieved a reasonable maturity in this respect. However, the score also indicates lacking alignment of processes and interfaces. When reflecting on the data exchange and information structure, the supplier of concrete floors argued that there was no real need for them to become more mature because of the low maturity demands in the project: "The data exchange requirements are similar for all contractors we work with. We provide all relevant file formats, so all parties can work with our data at all times."

According to our respondents, the variations in organizational BIM maturity did not really have an impact on BIM use, and this was mainly because the project made only low maturity demands. A good example is the approach adopted regarding the use of the document management system in the project. While the general contractor set the standards, they did not insist on consistent use of the document management system: as long as the project information was provided, they would accept deviations in how it was provided. This was apparent in that the supplier of concrete floors delivered information only by e-mail. Only one respondent mentioned any negative impacts of the differences in organizational maturity levels, noting that some parties were not capable of delivering their models on time.

Concluding, the BIM maturity potential of the various organizations was not converted into an equivalent maturity of the project. This was enabled by the project structure, with the general contractor holding a central and dominant position and therefore able to set the BIM approach for the project, and establish accompanying guidelines for information exchange, modelling standards, and software usage. Other parties were expected to follow this approach and, since the BIM ambitions of the project were purposefully set rather low, all of the project parties were able to conform.

Table 10. Organizational maturity relative to project maturity for the residential building case. Positive/negative numbers on the heat map indicate the extent to which an organization's maturity is higher/lower than the maturity of the project.

Criteria	Project maturity	MEP plumbing	HVAC	prefab concrete elements	MEP electrical	general contractor	prefab concrete floors	frames and facades	Project partner average
STRATEGY									
BIM vision and goals	1	+0.5	+1.0	0.0	+4.0	+1.7	+0.3	0.0	+1.1
Management support	2	+0.5	+3.0	+1.0	+1.0	+1.7	+0.3	+2.0	+1.4
BIM expertise	1	+1.5	+4.0	0.0	+1.0	+1.7	0.0	-0.5	+1.1
ORGANIZATIONAL AND PROJECT STRUCTURE									
Tasks and responsibilities	1	0.0	+1.0	+1.5	0.0	+1.3	0.0	-0.5	+0.5
Contractual aspects	2	-1.0	+3.0	-1.0	-1.0	+0.3	-0.7	+1.0	+0.1
PEOPLE AND CULTURE									
Personal motivation and willingness to change	3	-0.5	+2.0	-1.0	+2.0	-0.7	-1.3	+0.5	+0.1
Requesting actor (internal)	1	+1.0	+4.0	+0.5	+4.0	+2.0	-0.7	-0.5	+1.5
Education, training, and support	0	+1.5	+5.0	+1.0	0.0	+1.7	+2.3	+0.5	+1.7
Collaborative attitude, openness, and transparency	2	-0.5	0.0	-0.5	+1.0	-0.7	-1.0	-0.5	-0.3
PROCESSES									
Procedures and job instructions	1	0.0	+4.0	-0.5	+4.0	+1.3	+1.3	-0.5	+1.4
Process change	2	-1.0	+3.0	-1.5	+3.0	-0.7	-1.3	-1.5	0.0
IT (INFRASTRUCTURE)									
Hardware and network environment	0	+2.5	+5.0	+2.0	+5.0	+3.3	+2.7	+1.5	+3.1
Software	3	+2.0	+2.0	-1.5	+2.0	-0.3	0.0	0.0	+0.6
BIM facilities	0	+1.0	+5.0	+2.5	0.0	+3.0	+1.3	+1.0	+2.0
DATA (STRUCTURE)									
Information structure	3	-2.0	+2.0	-2.0	-1.0	-0.7	-2.3	-0.5	-0.9
Object structure / object decomposition	1	0.0	+4.0	+1.0	+4.0	+1.7	+1.3	-0.5	+1.6
Object libraries and attributes	1	+2.5	+2.0	+1.0	0.0	+2.0	+1.0	0.0	+1.2
Data exchange	4	-1.0	+1.0	-3.5	-1.0	-1.0	-1.7	-3.0	-1.5
OVERALL AVERAGE maturity (absolute values)									
OVERALL AVERAGE maturity (relative to project maturity)	1.6	1.9	4.4	1.5	3.1	2.5	1.6	1.5	2.4
		+0.4	+2.8	-0.1	+1.6	+1.0	+0.1	-0.1	+0.8

4.4.2 The Road Infrastructure Case

This infrastructure project concerns the realization of a fast and reliable public transport connection. It involves multidisciplinary infrastructure works including a bus lane of about three kilometers length, a nature bridge, and a flyover for a road-railway intersection. Maintaining security and minimizing nuisance during construction are key project characteristics as well as the strong environmental goals of the project. The client, a regional government, awarded the design and build contract to a general contractor who then started to form a core team with engineering firms, a landscape architect, and a supplier for the concrete elements. From the perspective of the BIM collaboration, six parties were selected for this study, which took place during the final design and construction phases.

Figure 20 depicts the mutual relationships between these six core project parties. Reflected by the length of the arrows, there is a strong relation between the general contractor and the engineering firm for general design and coordination tasks. There is also close collaboration between the triad of structural engineers, reinforcement engineers, and the general contractor. The central position of the general contractor is based on its leading role in setting up the BIM approach and facilitating systems for data management and exchange. A bit more distant, but still part of the integrated collaboration in the shared project office, is the landscape architect. A more remote position is occupied by the supplier of the concrete elements. This party only communicated directly with the general contractor and took no part in design and construction-oriented collaboration at the on-site project office.

The overall average project maturity level was calculated as 2.4, with a fairly even distribution of scores across the main maturity categories (see Table 11). The maturity levels of the core organizations in the infrastructure project range from 0.6 to 2.4, with an average of 1.8 and a standard deviation of 0.8. Looking at particular aspects of organizational BIM maturity, most of the variation among parties is in management support and software. The presence of both low and high scores on management support show that some but not all parties value BIM as important from their organization's perspective. The lowest scores for the organizations' BIM maturity are found in the formalization of tasks, responsibilities, and processes, which corresponds well with the project-level scores.

Party	Responsibility
General contractor	Overall project responsibility, coordination
Engineering firm	Design and coordination
Structural engineer	Engineering structural works
Reinforcement engineer	Construction model reinforcement model
Landscape architect	Design public space / landscaping
Supplier concrete elements	Concrete elements, fly-over

Figure 20. Responsibilities and mutual relationships of core parties in the Road Infrastructure project.

If we compare the average project maturity with the average organization maturity, these maturity levels are similar for most parties as visualized in Table 11. This suggests that most parties are working close to their maximum BIM capability in this project. Table 11 also clearly shows the two weak links in the project's BIM organization: the supplier of concrete elements and the landscape architect. These two parties have BIM maturity levels that are well below those of the other project participants and also well below the maturity of the overall project. Most of the variation in organizational BIM maturity between the core team parties can also be attributed to these two low scoring parties.

Most of the interviewees indicated that they experienced some impact from the variation in BIM maturity between project partners. Here, the only exception was the more remote subcontractor for the concrete elements. The interviewees from the engineering firm thought maturity differences could be explained by discipline-specific skills: "It's mainly about modelling skills. Other aspects are rather unambiguous, like saving, sharing, and publishing files. You can sometimes see

parties struggling to handle a model well.” The reinforcement engineer added that some engineers are not sufficiently experienced in reviewing their models. Interviewees stressed that these engineers are cooperative and willing to learn, but still need to make a lot of progress. From the perspective of the general contractor, the models for concrete reinforcement are very mature and the process of reviewing and modifying models runs smoothly. Some of the other disciplines, like the landscaping architect, were less mature in their BIM abilities. For them, taking into account their lacking maturity, collaboration is primarily a matter of good consultation: “Some parties you have to guide a bit more than others. If you do so, maturity differences between parties won’t result in problems.” This collaborative approach was repeatedly emphasized by our interviewees: [Parties are] “very much involved and know what others are working on.” Although there is little standardization and formalization of processes, collaboration is perceived as effective due to the integrated way of working with the main project partners and the client based in the project office. Only the subcontractor for the concrete elements was left out of the integrated data environment established by the general contractor, and this was because they could not learn quickly how to use this system. In this way, the project management tried to circumvent the subcontractor becoming a hurdle to a higher level of BIM maturity.

Table 11. Organizational maturity relative to project maturity for the road infrastructure case. Positive/negative numbers on the heat map indicate to what extent an organization's maturity is higher/lower than the maturity of the project.

Criteria	Project maturity	Supplier concrete elements	Engineering firm	Structural Engineer	Reinforcement engineer	Landscape architect	General contractor	Project partner average
STRATEGY								
BIM vision and goals	2	-2.0	+3.0	0.0	0.0	0.0	-0.3	+0.1
Management support	3	-2.5	+2.0	+0.3	+1.3	-3.0	-2.0	-0.6
BIM expertise	3	-2.5	-2.0	-1.3	-0.7	-3.0	-1.0	-1.8
ORGANIZATIONAL AND PROJECT STRUCTURE								
Tasks and responsibilities	2	-2.0	-1.0	-0.3	-0.7	-2.0	-0.3	-1.1
Contractual aspects	2	-2.0	-1.0	-0.3	+0.3	-2.0	0.0	-0.8
PEOPLE AND CULTURE								
Personal motivation and willingness to change	3	-2.5	+2.0	-0.3	-1.0	-2.0	-2.0	-1.0
Requesting actor (internal)	1	-0.5	+1.0	+0.3	+1.0	-1.0	+1.0	+0.3
Education, training, and support	1	-1.0	0.0	+0.3	0.0	-1.0	+0.3	-0.2
Collaborative attitude, openness, and transparency	3	-2.5	-1.0	-1.3	-1.7	-2.0	-1.7	-1.7
PROCESSES								
Procedures and job instructions	2	-2.0	0.0	0.0	-1.0	-2.0	-0.3	-0.9
Process change	2	-2.0	-1.0	-0.3	-1.0	-2.0	-1.0	-1.2
IT (INFRASTRUCTURE)								
Hardware and network environment	3	-2.0	-2.0	+1.0	-1.0	-2.0	-1.0	-1.2
Software	3	-1.5	+2.0	+1.7	+2.0	-3.0	+1.3	+0.4
BIM facilities	2	-1.5	-1.0	+1.7	+2.0	-2.0	0.0	-0.1
DATA (STRUCTURE)								
Information structure	3	-1.5	+2.0	+0.7	-1.0	0.0	-0.7	-0.1
Object structure / object decomposition	4	-3.0	-3.0	-1.7	-0.3	+1.0	-1.0	-1.3
Object libraries and attributes	1	+1.0	0.0	+1.3	+1.7	+4.0	+1.7	+1.6
Data exchange	3	-2.5	0.0	-1.3	-1.7	-3.0	-0.7	-1.5
OVERALL AVERAGE maturity (absolute values)								
OVERALL AVERAGE maturity (relative to project maturity)	2.4	0.6	2.4	2.4	2.3	1.0	2.0	1.8
		-1.8	0.0	+0.0	-0.1	-1.4	-0.4	-0.6

4.4.3 The Commercial Building Case

The commercial building case involves an office development in the heart of a metropolitan area. Its location is known for excellent accessibility and visibility, but also for limited and expensive space. The appearance of the new building is one of the focus points of the project as well as creating maximum office space in a ten-floor building. As a consequence, the project developer aimed to keep the walls, floors, and facades as thin as possible. The property developer purchased the land, coordinated the preliminary design, and had sold the eventual office building to a large insurance company. At the time of our case study, four main parties were involved in the BIM process, coping with final design and engineering activities.

The main collaborating parties are shown in Figure 21, where the property developer and contractor take central positions. These two parties work closely together on managing the BIM process and linking the various disciplines, as represented by the core team area in Figure 21. From their central position, design and engineering-related tasks are coordinated with either the architect or the structural engineer as appropriate. The latter two parties particularly communicate through the project manager of the property developer. In this process, the contractor adds BIM expertise, BIM support, and construction knowledge. During the design and engineering phase, which took about a year longer than expected due to the suspension of building permits, all four parties worked from their own offices. Consequently, the degree of integration of the whole project organization was low. As such, the architect and the structural engineer were somewhat distant from both the core team and from each other.

Figure 21. Responsibilities and mutual relations of core parties in the Commercial Building project.

The average BIM project maturity in this commercial building project is 1.9, with highest maturity levels for IT, management support, and especially data exchange. The project had not considered BIM facilities, resulting in a project maturity level of 0: the least mature aspect. The BIM maturity of the selected organizations range between 1.3 and 2.8, with an average of 2.2 and a standard deviation of 0.7. Looking in more detail at individual maturity criteria, we see that BIM maturity within the individual organizations is especially lacking when it comes to data exchange, information structure, and process-related aspects, as highlighted by the calculated maturity differences between individual organizations and the project in Table 12. In terms of data exchange, few organizational standards existed, meaning that these are developed on project-by-project basis. If we look at the information structure and at procedures and job instructions, the leading role of the two coordination parties is visible with the organizational standards of the contractor and property developer being implemented in the project. These two parties, as well as the architect, have maturity levels that exceed the project's maturity. The structural engineer is a negative outlier with a considerably lower level of BIM maturity. The structural engineer's respondent explained that they are not very motivated to invest in upgrading their organizational BIM maturity due to insufficient confidence in BIM providing benefits in projects. Rather, they perceive BIM as creating additional work: "I think we had enough motivation for BIM in this project, but everybody has gradually become tired of it. A project that takes so long, isn't that great in the long run. You can be an idealist, but you also have to be able to pay your people at the end of the day." These contrary visions on the usefulness of BIM were also visible in differences in certain maturity aspects, such as education, training, and management support.

The interviews revealed that the two coordinating parties were disappointed in the maturity of the engineering firm as this had a deleterious effect on BIM use in the project. However, the property developer also described how the applied project structure helped in dealing with maturity differences between the parties: "We used experts from our side and from the contractor to combine disciplinary models and carry out the clash detection work. These experts also communicated the resultant action points to the parties involved." Nevertheless, the property developer would aim to take organizational BIM maturity into account in other projects, as he brought up later in the interview: "For future projects, it is essential to choose partners with a maturity level that is similar to ours. In this project, we really had issues achieving the required level of quality and we also had to increase the fees for the structural engineer." The contractor held a similar view in saying that all parties had to join the 3D modelling process, whereas some still used 2D

plans for their part of the work. The structural engineer had even had to hire in an additional external modeler to overcome their lack of BIM competences. However, according to the structural engineer, the issues that arose in the project did not stem from maturity variations but from all the changes made during the design process that required reconsideration of the whole building structure and led to frustrations in the whole process. Despite the experienced differences in maturity between the various parties, all the interviewees agreed that BIM was used more, and more effectively, as the project progressed. As such, they did not consider the delivery of the project to be at risk.

Table 12. Organizational maturity relative to project maturity for the commercial building case. Positive/negative numbers on the heat map indicate the extent to which an organization's maturity is higher/lower than the maturity of the project.

Criteria	Project maturity	Property developer	Architect	Structural engineer	Contractor	Project partner average
STRATEGY						
BIM vision and goals	1	+1.5	0.0	0.0	+2.0	+0.9
Management support	3	+1.0	+1.0	-2.0	-1.0	-0.3
BIM expertise	1	+3.0	0.0	0.0	+1.3	+1.1
ORGANIZATIONAL AND PROJECT STRUCTURE						
Tasks and responsibilities	2	+1.0	0.0	-2.0	+0.3	-0.2
Contractual aspects	1	+2.5	+1.0	0.0	+1.0	+1.1
PEOPLE AND CULTURE						
Personal motivation and willingness to change	2	+1.0	+1.0	-1.0	-1.0	0.0
Requesting actor (internal)	1	+1.0	0.0	-1.0	0.0	0.0
Education, training, and support	1	+2.0	0.0	0.0	+4.0	+1.5
Collaborative attitude, openness, and transparency	2	+1.5	-1.0	+1.0	+0.3	+0.5
PROCESSES						
Procedures and job instructions	2	+0.5	-2.0	-2.0	+1.0	-0.6
Process change	2	-1.0	+1.0	-1.0	-1.0	-0.5
IT (INFRASTRUCTURE)						
Hardware and network environment	3	+1.0	+2.0	0.0	+1.3	+1.1
Software	3	0.0	+1.0	+1.0	+1.0	+0.8
BIM facilities	0	+1.5	+1.0	+1.0	+2.3	+1.5
DATA (STRUCTURE)						
Information structure	3	-1.0	-2.0	-2.0	+0.7	-1.1
Object structure / object decomposition	3	0.0	-2.0	0.0	-0.7	-0.7
Object libraries and attributes	1	+3.0	0.0	+1.0	+3.7	+1.9
Data exchange	4	-3.0	+1.0	-2.0	-3.0	-1.8
OVERALL AVERAGE maturity (absolute values)	1.9	2.8	2.1	1.4	2.6	2.2
OVERALL AVERAGE maturity (relative to project maturity)		+0.9	+0.1	-0.5	+0.7	+0.3

4.4.4 The Civil and Hydraulic Case

The civil and hydraulic project involves large-scale dike reinforcements, the construction of new outlet sluices, and renewing highway infrastructure. The national government initiated this project to ensure inland protection against expected rises in sea level and more powerful storms. In addition to the design and construction activities, with a total duration of almost five years, the contract also includes responsibility for 25 years of maintenance. The project has been assigned to a consortium comprising a general contractor, a dredging company, and a finance company. We conducted our case study while some parts of the projects were under construction and other parts were in the final design phase.

Five parties were mainly involved in BIM use in the project, as presented in Figure 22. The engineering firm and the contractor held a central position in which they coordinate sub-teams that are responsible for various parts of the project. In doing so, the contractor and engineering firm function as a link between the sub-teams, and also provide them with access to experts who can offer support. All the parties radiated a strong identity with the project organization, which was reinforced by their shared project office close to the construction works and a strong focus on integrated collaboration from the start of the project. As a result, the dredging company, the designer, and the second engineering firm are all represented as parts of a cohesive project organization in Figure 22.

Party	Responsibility
Engineering firm	Design coordination and project management
Contractor	Construction and coordination
Designer	Design and engineering
Dredging company	Dike reinforcement, sluices
Engineering firm II	Modelling, engineering, advising

Figure 22. Responsibilities and mutual relations of core parties in the Civil and Hydraulic project.

The average project maturity in the civil and hydraulic project was determined as 3.5 (Table 13). None of the maturity aspects scored below 3, which highlights the well-structured and collaborative use of BIM in the project. The maximum score of 5 was achieved for information structure and for education, training, and support. The organizational BIM maturity levels of the core project parties varies between 1.4 for the dredging company and 2.7 for the engineering firm. On average the maturity of the collaborating parties is 2.2 with a standard deviation of 0.5. If we look at particular aspects, we see that the lowest maturity scores are for formalization of processes and for process change. High average levels of organizational BIM maturity are found for software and for hardware, but these aspects also have the highest variability. This reflects the vast maturity difference in terms of IT aspects between the engineers and the dredging firm.

Table 13 also clearly shows that the BIM maturity of each party is lower, and often significantly so, than the maturity of the project. For most organizations, the differences are well above one in terms of maturity score, indicated by the red-shaded cells in the heat map. This indicates that all the parties have managed to outperform their organizational competences, either by growing in maturity within the project or by synergies created through the collaboration with other parties. Indeed, we heard that education, training, and support received considerable attention in this project. Not only did everyone receive a general introduction course on BIM working methods before entering the project team, but many specialized training sessions were offered to particular target groups. The respondent from the engineering firm especially emphasized the mandatory introduction course: “Every person entering the project gets an introduction to explain the basics, the project information, and how we approach processes. Participation in this lecture is required to gain further access to project data.” Some respondents also emphasized the availability of on-the-job support: “We made up an organizational chart so that people knew who to contact for BIM-related questions. In addition, we also started holding Q&A sessions at fixed hours.” Thus, by means of structure, guidance, and support, the project organization achieved a high level of maturity among the core partners.

When asked about the variation in maturity among the partners, the engineering firm’s respondent explained this is not an issue within the core team: “I notice that all parties within the consortium have a certain level of working in BIM, allowing them to conform to the intended BIM use in the project.” The dredging firm’s respondent also did not consider there to be vast differences in maturity among parties. He did, however, observe the leap between the project and his own organization: “I notice that BIM has progressed far more on this project than in my

own organization.” All the respondents recognized the need to work in accordance with a detailed BIM execution plan that was anchored in the contractual terms. In addition, respondents agreed with the importance of information sheets for subcontractors that define how the project team works and what the requirements are for data exchange processes.

A maturity-related problem that persisted was that of managing freelancers. The contractor’s respondent commented on this saying: “Since we pick up a lot of people from the market, the extent to which people are already used to the digital way of working is enormously diverse. That makes it difficult.” He added that the differences in the compositions of the sub-teams meant that there were some maturity differences between teams. However, because of strong coordination, the maturity of the project as a whole was not seriously affected.

Table 13. Organizational maturity relative to project maturity for the civil and hydraulic case. Positive/negative numbers on the heat map indicate the extent to which an organization's maturity is higher/lower than the maturity of the project.

Criteria	Project maturity	Engineering firm	Designer	Dredging company	Engineering firm II	Contractor	Project partner average
STRATEGY							
BIM vision and goals	3	+1.0	+2.0	-2.0	0.0	-1.3	-0.1
Management support	4	-2.0	-1.0	-1.0	+1.0	-3.0	-1.2
BIM expertise	4	-3.0	-2.0	-3.0	-1.0	-2.0	-2.2
ORGANIZATIONAL AND PROJECT STRUCTURE							
Tasks and responsibilities	3	-2.0	-1.0	-0.5	-2.0	-1.3	-1.4
Contractual aspects	3	+2.0	-1.0	-2.5	-2.0	-1.0	-0.9
PEOPLE AND CULTURE							
Personal motivation and willingness to change	3	+2.0	-3.0	-1.5	-2.0	-2.0	-1.3
Requesting actor (internal)	3	+2.0	+2.0	-2.0	-0.5	-1.0	+0.1
Education, training, and support	5	-2.0	-4.0	-2.5	-2.0	-3.7	-2.8
Collaborative attitude, openness, and transparency	4	-3.0	+1.0	-2.5	-3.5	-2.7	-2.1
PROCESSES							
Procedures and job instructions	3	-2.0	-2.0	-2.0	-2.0	-1.3	-1.9
Process change	3	-2.0	-2.0	-2.5	-2.0	-2.0	-2.1
IT (INFRASTRUCTURE)							
Hardware and network environment	3	+2.0	+2.0	-2.0	-1.0	-1.0	0.0
Software	3	+2.0	+2.0	-2.0	-1.5	+1.3	+0.4
BIM facilities	4	0.0	-3.0	-4.0	-1.0	-2.0	-2.0
DATA (STRUCTURE)							
Information structure	5	-2.0	-4.0	-2.5	-3.0	-2.7	-2.8
Object structure / object decomposition	4	-1.0	-2.0	-2.0	-3.0	-1.0	-1.8
Object libraries and attributes	3	-2.0	+1.0	-1.0	0.0	-0.3	-0.5
Data exchange	3	-2.0	-2.0	-1.5	-2.0	-0.7	-1.6
OVERALL AVERAGE maturity (absolute values)							
OVERALL AVERAGE maturity (relative to project maturity)	3.5	2.8	2.6	1.4	2.0	2.0	2.2
		-0.7	-0.9	-2.1	-1.5	-1.5	-1.3

4.5 Cross-case analysis

Table 14 presents a cross-case comparison with insights related to both organizational BIM maturity and project BIM maturity, allowing us to compare and contrast the four investigated projects. The average organizational BIM maturity is lowest for the road infrastructure project, which is primarily due to two very low scoring parties: the supplier of concrete elements and the landscape architect. The other three cases have a similar average level of organizational BIM maturity.

If we compare relationships between organizational BIM maturity and project BIM maturity, the picture is quite varied. First, the residential building project's BIM maturity is significantly lower than the average maturity of the parties in the project team. One could therefore argue that this project fails to utilize its abilities and could therefore be characterized as 'underperforming'. Indeed, the interview data also showed that while the residential building project had the potential for higher maturity that they had purposefully set low BIM ambitions for the project to reflect the limited anticipated complexity and expected benefits. As a consequence, all the parties could work within their capabilities. This observation was confirmed in how respondents talked about the impact on the project of organizational maturity variations. Although there were relatively high organizational maturity variations in the residential building case compared to the other cases, respondents experienced little impact from these variations.

The road infrastructure and the commercial building cases resemble each other on many dimensions, i.e., their project maturity is moderate, both have similar maturity variations among partners, and both have respondents that evaluate the impact of the uneven organizational BIM maturity differently (Table 14). Both projects also have one or two parties within their core team that we identified as weak links in the project organization in the sense that their maturity is well below that of the project. In the commercial building case, the weak link is the structural engineer, while in the infrastructure project it is the supplier of concrete elements and the landscape architect. There was one aspect that made these two cases significantly different: the level of integration of the project team. In the infrastructure project, the project team worked closely together in a project office. The landscape architect was involved in this integrated approach, but the supplier for concrete elements was purposefully positioned outside the integrated team. We characterize this strategy as 'weak link control'. In the commercial building project, all the parties worked apart, from their own offices. In this case, we found

a large degree of misunderstanding about the approach and the relevance of BIM. Interviewees stressed that collaborative issues persisted with BIM. Hence, we characterize this case as ‘problem solving’, rather than aiming to avoid problems upfront.

The case we have not yet addressed is the civil and hydraulic project. Perhaps surprisingly, and distinct from the other cases, this case had a project maturity that was significantly higher than that of all the individual organizations within the core team. At the same time, none of the respondents felt that the other parties lacked maturity such that this would affect the project negatively. On the contrary, participants valued the project’s cohesive structure and collaboration at the project office, allowing them to continuously manage interfaces with other disciplines. Furthermore, this project was unique in our analysis in that it attached particular importance to BIM training sessions for project team members. Our respondents emphasized that these education activities were an essential element in building higher project maturity levels during the course of the project. Indeed, all the project partners were very much aware of the need to invest in maturity development. We therefore characterize this case as the ‘stretching case’.

Table 14. Cross-case comparison matrix.

Case	Residential Building	Road Infrastructure	Commercial Building	Civil and Hydraulic
Case characteristics	Design and build of a five-floor apartment block	Design and build of public transport line and road works	Design and build of inner-city office building	Design, build, and maintenance of dike and road infrastructure
Team integration	Low	High	Low	High
BIM ambitions	Low	Moderate	Moderate	High
Project average maturity	1.6	2.4	1.9	3.5
Average organizational BIM maturity (range, variation) of core team parties	2.4 (1.5-4.4; $\sigma = 1.1$)	1.8 (0.6-2.4; $\sigma = 0.8$)	2.2 (1.3-2.8; $\sigma = 0.7$)	2.2 (1.4-2.7; $\sigma = 0.5$)
Parties with organizational maturity levels below project maturity	0	2 (Concrete supplier, landscape architect)	1 (Structural engineer)	5 (All parties)
Experienced impact of maturity variation and/or partner shortcomings	Low	Mixed	Mixed	Low
Strategies for dealing with maturity variations between project partners	Tuning BIM ambitions to match the least mature partners	Minimize BIM interactions with immature partners	Ad-hoc approach, try to solve maturity-related issues during the course of the project	Increase organizations' maturity through structure and education
Case characterization	Underperforming	Weak link control	Problem solving	Stretching maturity

4.6 Discussion

Our multiple case study aimed to explore the relationship between the BIM maturities of the individual organizations involved and the overall maturity of a construction project. The cross-case analysis showed that there is no consistent relationship between the maturity of collaborating parties and the maturity of the project. Rather, we identified several strategies adopted by project managers to mitigate risks arising from maturity shortcomings and variations among the participating parties. We have structured this section according to the three types of relationships we identified between organizational BIM maturity and project BIM maturity: (1) project maturity equals the level of the partners with the lowest maturity, (2) project maturity is about the average of the project partners, with some partners having maturity levels below project maturity, (3) project maturity is higher than that of all (or most of) the project partners. For these relationships, we have revealed characteristic ways of dealing with the varied maturity of the project partners.

Considering the first type of relationship, we observed that the ambitions set for BIM use in a project play an important role. Those ambitions could be set such that none of the project participants need to exceed their current BIM maturity, as was seen in the residential building project. For parties with higher organizational maturity levels, the project could then be labelled “easy” in terms of maturity requirements. Given the low ambitions, no further strategies are required to develop the BIM maturity of any of the project partners.

The second type of relationship revealed in our study between organizational BIM maturity and project BIM maturity describes cases where one or two parties' maturity was well below that of other parties and also that of the project. The presence of such ‘weak’ links, which was evident in two of our cases, had different consequences. We concluded that the commercial building project could have achieved the initial ambitions for a higher overall maturity but some persistent issues in obtaining building permits and the resultant delays or changes dampened the enthusiasm for BIM within the project team, especially that of the engineer. Given the engineering contractor's initially low BIM maturity level and intrinsic reluctance to use BIM, their obstructive attitude had a deleterious effect on the maturity of the project as a whole (Adriaanse et al., 2010a). Such behavior has been attributed to partners focusing on obtaining their own objectives and trying to avoid the additional costs that would come with meeting the requests of partners (Ligthart, Oerlemans, and Noorderhaven (2016). The interview with the

project manager revealed that in future projects they would give more attention to selecting capable and motivated partners, i.e., partners with sufficient BIM maturity. In this respect, Braun and Sydow (2019) highlight the importance and difficulty in searching for, evaluating, and selecting partners with organizational capabilities that match the requirements of a project. In the road infrastructure project, the weak links in terms of BIM were more deliberately addressed. The project management circumvented the very low maturity of the supplier of concrete elements by limiting their role within the BIM process. As such, this supplier was intentionally placed outside the core project structure and would only deliver and receive data for BIM models related to their specific discipline according to some simple agreements. The other weak link in this road infrastructure project, the landscape architect, was helped to upgrade their BIM maturity by intensive collaboration and support in the shared project office. From the interviews, we identified the positive effects of a high degree of mutual trust, commitment to the project goals, and open communication within the project team (Brinkhoff, Özer, & Sargut, 2015). With this support, the landscape architect came to appreciate the value of BIM for the project. As such, the road infrastructure and the commercial building projects took clearly distinct approaches in addressing weak links within their project organizations. We therefore conclude that a lack of BIM maturity within some partners need not have a dominant negative effect on overall project maturity provided that those potential weak links are identified early in the project and their lack of maturity is taken into account in the approach to BIM adopted in the project. This can include ensuring that the weak links are motivated to conform to the chosen approach and, if necessary, assisted in upgrading their BIM maturity level.

The third type of relationship we found was one where the project maturity was above that of all the participating organizations. In the civil and hydraulic project, the aim was to achieve a high level of BIM maturity. This meant that organizations within the project team would have to outperform their current organizational capabilities. Maybe surprisingly, the project organization achieved this ambition, and our data analysis reveals some explanations. Early in the project, the team increased the maturity level by instigating dedicated training programs and well-structured BIM support within the setting of the project. This collective learning process was empowered by a high level of awareness of the importance of developing skills together as well as sharing a mutual long-term orientation (Larsson, Bengtsson, Henriksson, & Sparks, 1998). The latter was supported by setting clear goals for the lengthy duration of the project that included design, construction, and maintenance obligations. Second, relative to the other three

cases, this project was larger and required an extensive organizational structure of sub-teams, with tens of subcontractors and suppliers involved. It also had a duration of five years plus longer-term maintenance obligations. Given this situation, the project management saw it as worthwhile to put considerable effort into the anchoring of tasks, responsibilities, and processes, which was also a necessity if BIM use was to be effectively coordinated (Porwal & Hewage, 2013; Sacks, Gurevich, & Shrestha, 2016). A third factor was the integrated collaboration that took place at the project location. Even more than in the road infrastructure case, we saw that bringing partners together in a shared project office led to the project team feeling dedicated to the project, which gradually changed their organization identity into a project-oriented identity. This mindset allowed them to set BIM targets and helped make the learning and maturity growth efforts effective during the course of the project. This somewhat goes against existing theory that argues that a project-based organization does not promote learning because of its temporary nature (Dubois & Gadde, 2002). However, it could be that the long-term nature of this project removed some of the drawbacks perceived in short-term project relationships. In addition, encouragement for this approach could come from the literature that shows a positive relation between integrated collaboration with supply chain partners and project performance (Leuschner, Rogers, & Charvet, 2013). As in the road infrastructure case, we saw that maturity growth in a project context is very much dependent on an integrated approach. The only issue frequently mentioned by our respondents was not with people within the integrated core team, but rather with freelancers who, by their nature, come and go, have varying practices, and are hard to steer. Here, the literature similarly shows that the type and duration of inter-organizational collaboration matters when it comes to project performance (Faems, Van Looy, & Debackere, 2005).

Taking a broader perspective on the outcomes of our study, we would propose adding variation in organizational BIM maturity as another characteristic of the complex heterogeneity of project team composition. Moreover, we acknowledge that the characteristics of individual project members are important. As Mathieu, Tannenbaum, Donsbach, and Alliger (2014) discuss, an ideal distribution of knowledge, skills, abilities, and other characteristics of team members adds to the dynamics of variation in organizational background. Here, we would also like to emphasize the dominating role of the general contractors and engineering firms in our case projects, who derived strong authority and strategic decision power from their BIM knowledge (Akintola, Venkatachalam, & Root, 2017). Given this position, these coordinating parties could inspire and steer other participants in the project

organization effectively. Coordinating parties can address many of the complexities resulting from the composition of project organizations by selecting partners who have similar value orientations in terms of BIM (Wu, Zhao, Zuo, & Zillante, 2019).

To summarize, we have been able to identify a few strategies that can be adopted to manage maturity variations within project organizations:

- a) Project managers can tune project maturity ambitions to match a maturity level that is achievable by all project partners.*
- b) Project managers can organize interaction separately with immature partners to enable collaboration on higher maturity levels with the remaining partners. This requires well thought-out and tailor-made agreements with immature partners.*
- c) Project managers can develop and increase the organizational BIM maturity levels of one or more parties by intensive and structured collaboration that is supported with dedicated training programs.*

4.7 Conclusions

The aim of this study was to increase our understanding of the effects of differences in organizational BIM maturity levels on the overall maturity of projects. Although previous studies have provided insights into BIM maturity using various methods to measure maturity in individual organizations and in projects, these did not clarify how differences in the maturities of individual project partners relate to the maturity of the project as a whole. Nor did these studies address approaches adopted by project managers to deal with such maturity variations. We therefore set up a multiple case study of four construction projects to further explore BIM maturity in the context of projects. The main research question we aimed to answer was: How is the BIM maturity of project partners related to the overall project maturity? Our findings suggest that the project maturity is not simply the average maturity of the individual parties in the project, nor that of the weakest partner. Rather, our cases showed patterns where project maturity was well-above, similar to, or well-below the average organizational BIM maturity. We have explained these different relationships through a number of manageable factors that played an important role in setting the maturity of a project.

The exploration of these strategies answered our second research question. First, the BIM ambitions set by the project management determine the impact that the weaker partners have within the project team. Here we recognize the strong coordinating role, mostly filled by general contractors or engineering firms, of weighing the requirements and the competences of the various parties in order to ensure the project is on the right track. One case showed that, if the ambition level is set similar to those of the weakest parties in the project organization, that maturity variations have no effect. Furthermore, two other cases showed that a project could circumvent its weakest links by strategically limiting the BIM interaction of the parties with low maturity. This approach was accompanied by specific agreements that eased the BIM-related tasks of the least mature parties. Last, and most surprisingly, one case showed that all parties could outperform their individual organizational maturity level if the project provided dedicated training programs and well-structured BIM support. In doing so, this project managed to build the maturity level within the setting of the project. We thus conclude that if project managers are sufficiently aware of partners' restrictions and ambitions, and act accordingly, the organizational maturity levels of the individual parties does not have to impede achieving a higher overall project maturity.

Given our varied findings from a very limited number of cases, we would recommend future research to further unravel BIM maturity at the project level. First, although we applied theoretical generalization to embed our findings in existing theory, the case study method limits the statistical reliability of the findings. Therefore, we would encourage future research that provides more statistical evidence on the influence of individual organizations' maturity on the maturity of the project as a whole. In particular, from both a scientific and practical perspective, it would be valuable to gain an increased understanding of approaches that project managers might adopt to deal with maturity variations and enhance maturity. Our study has already identified some possibilities that could be further unravelled, such as tuning ambitions, strategically restricting the BIM involvement of some parties, and intensively supporting some parties in developing their maturity. We would stress that we see great practical relevance in further revealing approaches that support the growth of maturity within the context of inter-organizational project collaborations.

CHAPTER 5

TEAM MENTAL MODELS FOR BIM USE IN CONSTRUCTION PROJECTS: EXPLORING THEIR VARIATIONS AND IMPACT ON PROJECT OUTCOMES

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Abstract

This study aims to explore Team Mental Models (TMMs), an organized shared understanding of the task at hand, for inter-organizational BIM use in construction projects. Getting all the project partners on the same page regarding the use of BIM is perceived as challenging due to the typically fragmented nature of construction. In this yet unexplored context, a multiple case study was conducted to first reveal variations in the shared understanding of BIM use in projects. The study revealed that most of the variations could be explained by one or two parties that operated more distantly from the core of the project team having less involvement with and therefore less knowledge of the BIM use and ambitions. Second, the study explored the positive relationship, widely assumed in the literature, between TMMs and project outcomes. Here the findings indicated that the level of consensus on BIM use was significantly correlated with the project's BIM maturity. However, there was no similar clear relationship with other investigated variables and the study identifies various factors that influenced these relationships.

5.1 Introduction

Daily business in construction projects involves inter-organizational collaboration in which multiple disciplines are represented and where mutual interdependencies are at stake (Bankvall et al., 2010; Dubois & Gadde, 2002; Sydow & Braun, 2018). While, for some projects, a cooperation model with a simple task division will suffice, for other projects a shared understanding of goals and how to reach these goals together is crucial for the project team to successfully collaborate (DeChurch & Mesmer-Magnus, 2010). In the construction sector, the use of BIM is associated with enhanced collaboration among the parties and disciplines involved (Bryde et al., 2013; Porwal & Hewage, 2013). However, despite technological advances, many projects suffer from barriers linked to the industry's fragmented nature, e.g. working in silos, lack of information sharing among disciplines, and unclear task divisions (Oraee et al., 2019). As a consequence, arriving on the same page regarding a project's use of BIM can prove challenging. It is for this reason that an inter-organizational use of BIM, at the project level, needs well-coordinated tasks and a shared understanding of the team's work.

This shared and organized understanding of the task, also referred to as a team mental model, (Converse et al., 1993; Klimoski & Mohammed, 1994) has been linked to effective collaboration and high team performance (Cooke et al., 2003; DeChurch & Mesmer-Magnus, 2010; Druskat & Pescosolido, 2002; Fisher et al., 2012; Van den Bossche et al., 2011). Team Mental Models (TMMs) entail how group members, as a collective, think or characterize phenomena. More specifically, TMMs can refer to tools, work procedures, work strategy, awareness of member responsibilities and interdependences, as well as of other members' knowledge and skills (Mohammed, Ferzandi, & Hamilton, 2010). Teams with a shared or collective understanding of these phenomena more effectively coordinate tasks and proactively act upon each other's competences and needs (Converse et al., 1993). Teams with more divergent mental models limit members' ability to bring together their ways of thinking and acting, such that they analyze and respond to situations differently (Senge, 1990). The aim of our study is to use the TMM lens to better understand how team members coordinate their use of BIM in the construction industry. More specifically, we adopt a multiple case study approach to explore whether project outcomes in multidisciplinary projects using BIM can be related to the degree of sharedness in the project partners' mental models of BIM use. In order to achieve these research aims, we defined the following research questions:

1. *What variations are present in project participants' mental models of BIM use within the cases studied?*
2. *How do Team Mental Models of BIM use in the cases relate to the project outcomes?*

This study contributes to the current body of knowledge in two ways. First, in adopting the Team Mental Model concept, this study provides a novel perspective on BIM collaboration that responds to the call by Mohammed et al. (2010) to investigate team mental models in various yet to be explored contexts. Indeed, we can observe that team mental models have mostly been investigated in relation to action teams, such as in flight simulations (e.g. Marks, Sabella, Burke, & Zaccaro, 2002; Mathieu, Heffner, Goodwin, Cannon-Bowers, & Salas, 2005; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000) or in military operations (e.g. Ellis, 2006; Espevik, Johnsen, & Eid, 2011; Lim & Klein, 2006), and often conducted in experimental settings with groups of undergraduates. Contextualizations of TMMs for the construction industry have been limited and captured only for certain disciplines, such as health and safety (Lingard et al., 2015), or in multidisciplinary design and construction courses (Forgues & Becerik-Gerber, 2013). The second contribution of this study is the understanding gained of variations in project team members' perceptions of BIM and how these relate to project outcomes. In this way, we start to answer whether investing in mental models of BIM use in projects could form a route to success. Such insights should be particularly supportive to construction practitioners in their ongoing efforts to enhance project outcomes.

To be able to answer these research questions, we develop a conceptual framework to capture both TMM-related and performance-related aspects in the selected construction projects. This conceptual framework is described in the next section.

5.2 Research model

In our multiple case study, we explore Team Mental Models of BIM use and their impact on project outcomes. Below we define both the project outcome variables (dependent variables) and the operationalization of TMM (independent variables) adopted in our study. Following this, we present the research model with the hypothesized relationship between the investigated variables.

5.2.1 Project outcomes

The expected benefits, as well as the challenges involved, in implementing BIM drove many scholars to focus on measuring the performance, or the degree of professionalism, in BIM use: or BIM maturity. To that end, BIM maturity models were developed to evaluate aspects of BIM that were considered key to reaping the benefits of BIM implementation (Bew et al., 2008; Liang et al., 2016; Siebelink et al., 2018; Succar, 2009). Maturity assessments give insights into performance, focus priorities, and aid communication of BIM-related strategies both internally and to stakeholders (Azzouz & Hill, 2017). Since a BIM maturity assessment can cover a broad range of aspects related to strategy, organization, people, process, and technology (Siebelink et al., 2018), it can reflect the functioning of an IT system as part of an organization and its environment (Silver et al., 1995). We therefore consider a comprehensive BIM project maturity measure to be an important project outcome variable.

The second project outcome variable is defined as the BIM issues or barriers that become apparent in a project. The recent literature has extensively described issues and barriers that are experienced with the use of BIM (Adriaanse et al., 2010b; Oesterreich & Teuteberg, 2019; Olawumi, Chan, Wong, & Chan, 2018; Oraee et al., 2019; Siebelink, Voordijk, Endendijk, & Adriaanse, 2021). In particular, on the level of projects, BIM is implemented for its premises of enhanced collaboration. However, several issues and barriers persistently hinder the implementation of BIM and the effective multidisciplinary use of BIM, and thus successful BIM use on the project level (Oraee et al., 2019). We therefore argue that the absence of BIM issues and barriers is indicative of successful project outcomes.

Alongside the specific BIM-related variables, we include two project outcome variables in our research model that relate to the perceived functioning and collaboration of the team. Indeed, the collaboration between project partners is considered a critical factor when measuring the success of BIM use in projects (Antwi-Afari, Li, Pärn, & Edwards, 2018; Matthews, Love, Mewburn, Stobaus, & Ramanayaka, 2018). To that end, we selected outcome variables that have been indicated in studies focusing specifically on assessing collaborative learning projects, i.e., perceived team performance and perceived team satisfaction (Détienne et al., 2012; Meier et al., 2007; Savelsbergh et al., 2009).

5.2.2 Team Mental Model of BIM use

Typical elements found in TMMs refer to work procedures, work strategy, awareness of member responsibilities and interdependences, as well as other members' knowledge and skills (Mohammed et al., 2010). In our conceptualization of TMM for BIM use in construction projects, we included variables related to shared understandings of why BIM is used, how BIM should be used to make the project successful, and perceptions of how (well) BIM is actually used in the project. The associated variables of the framework are explained in more detail below.

From the existing literature, we saw that the perspectives on a project, and on BIM use in particular, may vary among project participants. One of the main reasons for this is that the different parties or disciplines in a project organization tend to benefit in different ways from the implementation of collaborative information technologies such as BIM (Dainty et al., 2017). This non-equivalence in the value of BIM use is found to stem mainly from the divergent disciplines' roles, scopes, and thus obligations regarding BIM use in a project (Cao, Li, & Wang, 2017; Dossick & Neff, 2010). Moreover, the trust in BIM, as a beneficial approach to the project, seems to differ among different disciplines. Dainty et al. (2001) argued that the active involvement of many suppliers in integrated construction processes is hindered by a lack of belief in there being mutual benefits. As a result, the disciplines' motives, scopes, and expectations for BIM use may differ. From this, we derived two TMM variables. The first is a "shared understanding of BIM goals for the project" which previous studies identified with aspects such as improving efficiency, streamlining information exchange, or facilitating higher complexity (Bryde et al., 2013; Eastman et al., 2011; Ghaffarianhoseini et al., 2017). Second, we derived the "shared understanding of conditions for project success" as the other TMM variable. Given the potentially different perspectives on BIM use within a project, we posit that project participants may assign different values to BIM success factors such as the availability of technical means or procedural agreements (Adriaanse et al., 2010a). Different understandings of conditions for success could lead to partners deeming it relevant to focus on or invest in different aspects of BIM.

In response to the different understandings of BIM use in projects as described above, we would also add the need to account for different perceptions of BIM maturity in projects. However, previously developed methods for assessing BIM maturity on the project level (e.g. Chen et al., 2014; Kam et al., 2014) are based on the perspective of one or a few central individuals, mostly project managers, in the project organization. By adopting a multi-assessor method based on the

perspectives of the parties or disciplines involved, we can assess whether project participants have similar mental models of a wide range of relevant aspects incorporated in the BIM maturity model (Siebelink et al., 2018). Moreover, such a BIM maturity model, when used as a tool to capture mental models, makes it possible to address all kind of BIM aspects in a structured and traceable manner. On this basis, we add the “shared understanding of project BIM maturity” as a TMM variable.

Using the above-mentioned variables, we are able to map understandings of various BIM-related aspects in a project context and analyze the extent to which these understandings are shared. As a final measure, we also directly measure the sharedness of understandings from the perspectives of the project participants themselves. This very much addresses the essence of TMMs by capturing the team members’ degree of agreement over various important aspects of the work at hand (Mohammed, Klimoski, & Rentsch, 2000). The “perception of consensus on BIM use” is therefore added as a fourth TMM variable in the framework.

5.2.3 Drafting the research model

In essence, the research model in this study consists of two parts, a TMM component and the project outcome part, as visualized in Figure 23. A team mental model is typically conceptualized as the degree of similarity among the mental models of the team members (DeChurch & Mesmer-Magnus, 2010). In the context of BIM, we therefore address the shared understandings of: (1) project BIM maturity, (2) goals for BIM in the project, and (3) conditions for success. In addition, we directly measure perceived similarity in mental models through a fourth variable: (4) the perceived consensus on BIM use among project partners. The evaluation of project outcomes involves four variables: (i) project BIM maturity, (ii) absence of BIM-related barriers or issues, (iii) team performance, and (iv) team satisfaction. Based on the results of earlier research, we expect positive relationships between the degree of sharedness of the TMM and the project outcomes, indicated by the plus sign in Figure 23.

Research model for exploring Team Mental Models and project outcomes in the context of BIM use in construction

Figure 23. Research model including hypothesized relationship between TMM and project outcome variables.

5.3 Methodology

5.3.1 Research design

Given the explorative aim of this study, to better understand the relation between Team Mental Models and project outcomes in the context of BIM use in construction, we require an approach that fits with theory building. We therefore not only focus on the quantitative relationships between the variables but adopt a mixed-method multiple case study approach (Eisenhardt, 1989) that allows an understanding to also develop on the how and the why for the existence or absence of these relations. The subsequent rich and in-depth observations of TMM and project outcome variables from the cases studied are essential for extending theory on the specific context of BIM use in construction projects.

For our study, we selected four construction projects in western Europe that were all making use of BIM in a multidisciplinary setting. The cases were expected to show variations in terms of their maturity and uses of BIM. We explicitly selected cases that showed variations in their collaborative approach to increase the probability that we would also observe variations in team mental models. Two of the cases were based on an integrated, cohesive project organization, whereas the other two had a clear demarcation of responsibilities between the disciplines involved and worked in a more segregated manner. The first case, a residential building project, involves the design and build of a five-floor apartment block. In terms of BIM use, seven parties formed the core team, working mostly in a segregated way from their own offices.

Figure 24. Schematization of the scope for investigating project organizations.

In the second case, a road infrastructure project, six parties are engaged in an integrated collaboration to design and build a public transport line and surrounding road works. The third case, a commercial building project, involves a smaller core team of four parties working together on the design and build of an inner-city office building. The fourth case, a civil and hydraulic project, is a large infrastructure project with a core team of five parties that collaboratively share responsibility for the design, build, and maintenance of dike and road infrastructure.

Our case studies focus on the core parties collaborating in using BIM. In the schematic (Figure 24), this core team consists of the project consortium with parties A, B, C, D ... as well as the main subcontractors/suppliers E, F.... The subcontractors/suppliers that should be included with regard to BIM use were decided upon in consultation with the project manager in each case. The remaining supply chain parties, represented by the dotted lines, are less involved and less decisive in terms of BIM collaboration and have therefore not been taken into consideration.

5.3.2 Data collection and analysis

Across the four cases, we conducted a total of 22 interviews to provide data on the variables shown in the research model (Figure 23). These are the four TMM variables “understanding of BIM project maturity, understanding of BIM goals, understanding of BIM conditions for success, and perception of consensus on BIM use”; and the four project outcome variables “BIM project maturity, perceived team performance, perceived team satisfaction, and BIM-related issues and barriers”. For each included party in a project, we questioned one person as a main informant. The selected respondents held positions in which they dealt with BIM on a daily basis, for example as a project manager, BIM specialist/coordinator, or project engineer. Two researchers were involved in each of the interviews, which generally lasted about 1.5 hours. Alongside the semi-structured format used for the BIM project maturity element, we made use of a rating scale to capture similarities in the levels of understandings, meanings, priorities, and expectations (DeChurch & Mesmer-Magnus, 2010; Mohammed et al., 2010; Mohammed et al., 2000). Here, we particularly focused on the extent that perspectives on BIM were shared in the project organization (Dess, 1987). Respondents were asked to rate items and were also encouraged to elaborate on their scores. In addition to the analysis of quantitative ratings, we used the interviews to expand on the answers

given and seek explanations. We recorded and transcribed all the interviews so we were able to return to the raw data in the analysis process (Darke, Shanks, & Broadbent, 1998). This made it possible to find explanations for the variations among respondents in the assessed variables. Next, we triangulated the collected data by consulting archival project data (Scandura & Williams, 2000).

Furthermore, a final interview with the project manager was conducted to expand on the insights from the interviews with project participants, reflect on the results, and if required obtain further explanations. The data collection and analysis processes for the TMM and project outcome variables are further explained below.

Assessing the shared understanding of a project's BIM maturity (TMM)

To represent the degree of professionalism of projects and their parties in the use of BIM, a BIM maturity model was applied that involves 18 criteria covering strategy, organization and project structure, people and culture, processes, information technology (IT), and data (Siebelink et al., 2018). This was developed to provide insights into both organizational and technological aspects of BIM. Unlike many other assessment methods, it has proved to be appropriate for evaluating the various disciplines in the construction supply chain that are within the scope of our project analysis. We used the method's accompanying interview instruments to conduct BIM maturity assessments within the project organizations. In the BIM maturity interviews, we asked a few questions for each criterion to cover all the characteristics of the various maturity levels. If a respondent's answer was incomplete or inconsistent, we asked follow-up questions to enable the interviewee to expand or clarify the given answers. We emphasized that respondents should take the project's perspective when answering the questions. In determining the maturity level, we took account of the incremental structure of the BIM maturity model, meaning that a higher maturity level could only be achieved if all the conditions of lower maturity levels are satisfied. Each interview with project participants resulted in a score that represented their perception of BIM maturity. The resultant BIM maturity perception scores were used to unravel the variations among project members' understandings of BIM project maturity.

Assessing the shared understanding of a project's BIM goals (TMM)

We defined 10 items for assessing the shared understanding of BIM goals in a project. Statements were based on the goals and intentions of BIM as described in literature (Bryde et al., 2013; Eastman et al., 2011; Ghaffarianhoseini et al., 2017), such as "BIM is used to facilitate higher complexity in design and construction" and "BIM is used to ease data exchange among project partners". During the interviews,

we asked respondents to indicate whether the defined goals fit their project very well, to some extent, or not at all. In addition, respondents were given the opportunity to indicate goals for the project that had not been captured by the statements.

In considering these team mental model data, the data analysis procedure corresponds with methods described by Dess (1987) and by Knight et al. (1999). As such, we first calculated the standard deviation of the responses for the 10 items. Next, we summed these standard deviations for each variable, allowing us to categorize and compare the data based on the variables in the research model. Since we are looking for the degree of similarity in project team members' mental models, i.e., the extent to which they share a team mental model, we subtracted all the summed standard deviation values from a constant. By doing so, the numerical values acquire a positive relation with the measured variable: low values represent relatively high differences in understandings of BIM use in the project organization, whereas high scores imply a more shared understanding of BIM use. These quantitative scores proved particularly meaningful when comparing and contrasting cases in the cross-case analysis.

Assessing the shared understanding of conditions for project BIM success (TMM)

In defining statements for conditions for project BIM success, the BIM maturity model provided a useful framework since it contained all the relevant aspects of BIM use and implementation in practice (Silver et al., 1995). We therefore used and rephrased the criteria of the BIM maturity model (Siebelink et al., 2018) to convert them into items that represented conditions for BIM use to be successful in projects. For example, the BIM vision and goals and process descriptions criteria in the BIM maturity model were transformed into the statements "In order to be successful, the project needs a mutually aligned vision and concrete goals for BIM" and "In order to be successful, the project needs alignment of BIM-related process definitions from different parties in the project". All the 11 statements were scored on a five-point Likert scale ranging from 1 = "completely disagree" to 5 = "completely agree".

The data analysis procedure is similar to the one described for BIM goals in that we summed the standard deviations of the individual items in order to determine the sharedness of mental models of this variable. Since the resulting standard deviation value does not exclude outliers from one or a small number of respondents, we also checked the data for ratings that very much deviated from the mean.

Assessing the perceived consensus on BIM use (TMM)

As with the statements on conditions for project BIM success, the statements for determining the consensus on BIM use have also been based on criteria of the BIM maturity model (Siebelink et al., 2018). Given that aspects such as personal motivation or collaborative attitude could not be formulated as tangible statements, there were 10 statements for this variable such as “In this project, there is consensus on a mutual vision and concrete goals for BIM” and “In this project, there is consensus on task or role descriptions with regard to BIM use”.

The score for consensus in BIM use is considered a direct representation of the similarity of mental models in the project organization. As such, the score for consensus on BIM use is the average of the Likert scale scores (1-5) on the 10 items for this variable. In addition, we calculated the scores on BIM consensus to be able to take account of a strong similarity in perceptions combined with low scores for consensus. This reflects that if all project members have an equal perception of 1 for a particular item, they are agreed that there is no consensus on that item. The implication being that team members’ mental models could divert considerably. Next, we used the scores for consensus on BIM use to check for significant correlations with project outcome variables. In doing so, we analyzed the relationship between TMM and project outcomes quantitatively as an addition to the rich explanatory interview quotations we obtained for the other TMM variables.

Assessing BIM Project Maturity (project outcome)

The overall BIM project maturity was assessed by the two researchers using the same model and criteria as used to assess the partners’ understanding of BIM maturity. As such, we used the interviews to gather insights on project maturity as perceived by each of the respondents. Following this, the average score of all the respondents for each of the 18 criteria was calculated. Based on these insights and on an analysis of available project documentation, we made an overall judgement of BIM project maturity for all the criteria in the model.

Assessing perceived Team Performance (project outcome)

As in the approach used for most of the TMM variables, and similar to previous studies, a rating scale technique was used to capture the project outcomes for the team performance dimension (Détienne, Baker, & Burkhardt, 2012; Meier, Spada, & Rummel, 2007; Savelsbergh, van der Heijden, & Poell, 2009). Team performance is measured with a six-item scale (Bron, Endedijk, van Veelen, & Veldkamp, 2018; Zellmer-Bruhn & Gibson, 2006), with statements such as “In this team we perform well” and “This team meets its expectations”. As with the TMM variables,

respondents had to score these items on a five-point Likert scale ranging from 1 = “completely disagree” to 5 = “completely agree”. The reliability (Cronbach alpha coefficient) of the team performance measure was a satisfactory 0.88. In the data analysis, to help interpret the results, we calculated each respondent’s average score.

Assessing perceived Team Satisfaction (project outcome)

Team satisfaction is measured using a three-item scale adopted from Smith and Barclay (1997) with the statements “In this project, we are satisfied with our working relationship between parties”, “In this project, we are satisfied with each other’s contributions to the work to be delivered”, and “In this project, it is pleasant working together”. Again, respondents scored items on the five-point Likert scale ranging from 1 “completely disagree” to 5 “completely agree”. The Cronbach alpha coefficient for team satisfaction items was a satisfactory 0.81. In the data analysis procedure, we calculated the average score per item and for the measure as a whole.

Assessing BIM-related issues and barriers (project outcome)

A rating scale was also used to assess the apparent BIM issues and barriers in the project. We used a three-point Likert representing the possible answers, from “not a barrier at all”, “to some extent a barrier”, and “a serious barrier” in this project. We consulted the recent literature concerning project-level BIM issues and barriers to construct our statements (Adriaanse et al., 2010b; Oesterreich & Teuteberg, 2019; Olawumi et al., 2018; Oraee et al., 2019; Siebelink et al., 2021). In addition to the predefined 12 statements so developed, respondents could raise other BIM issues and barriers in the interview. The extent that BIM issues and barriers were experienced was calculated as the sum of the rating values. As such, a low total is indicative of few BIM issues and barriers in a project. In order to present the lack of barriers, we calculated a reversed score where a maximum value of 5 represents a complete absence of issues or barriers. In the analysis, we not only looked at the total barrier score but also looked into individual statements concerning what respondents rated as serious barriers.

5.4 Results

Table 15 presents an overview of the results for the Team Mental Model variables and Table 16 for the project outcome variables. We first note that the perceived consensus on BIM use, our direct measure for TMM, is highest for the Civil and Hydraulic project, with a score of 4.5. Moreover, the team members in the Civil and Hydraulic project have a relatively high degree of sharedness of mental models in terms of conditions for success. If we look at the project outcomes (Table 16), the Civil and Hydraulic project achieves a much higher BIM maturity level than the other cases. Further, the scores for team satisfaction, team performance, and an absence of BIM issues or barriers are also relatively high. Conversely, the project with the lowest score for consensus on BIM use (the residential building case with a score of 3.2) has the lowest BIM project maturity level. This points toward a positive relation between a team's sharedness of BIM-related mental models and the BIM-related project outcomes. This observation is supported by the significant positive correlation between the consensus on BIM use and the BIM project maturity ($r=0.74$, $p<0.001$). However, significant relationships were not found between consensus on BIM use and team satisfaction ($r=0.00$), team performance ($r=0.07$), and the absence of barriers ($r=0.14$).

Apart from the overall positive relationship between consensus on BIM use and BIM maturity, we also see, in some projects, other intriguing patterns. For example, in the commercial building case, relatively high scores for the TMM variables are accompanied with relatively low scores on team performance, team satisfaction, and experienced issues and barriers. We also see that not all outcome variables are positively correlated to each other. For example, although the BIM project maturity for the residential building project is relatively low, the other project outcome scores are among the highest. Moreover, we do not have an immediate explanation for the relatively large variation in perceptions of BIM project maturity in the Road Infrastructure project.

In order to better understand the relationship between TMM and project outcomes in the particular contexts of the four projects, we now consider the individual case results in turn below.

Table 15. Team Mental Model results from the four case projects.

Variable	Residential Building	Road Infrastructure	Commercial Building	Civil and Hydraulic
Case characteristics	Design and build of five-floor apartment block	Design and build of public transport line and road works	Design and build of inner-city office building	Design, build, and maintenance of dike and road infrastructure
Collaborative approach	Segregated	Integrated	Segregated	Integrated
Perceived project maturity	1.5 (1.0-1.8)	1.9 (0.8-2.3)	1.9 (1.7-2.3)	3.3 (3.0-3.8)
TMM: BIM project maturity ($\Sigma(\sigma^2)$ of items)	10.4	13.7	9.3	11.7
TMM: BIM goals ($\Sigma(\sigma^2)$ of items)	7.1	4.8	5.5	6.5
TMM: conditions for success ($\Sigma(\sigma^2)$ of items)	8.4	8.9	8.0	4.9
TMM: Consensus on BIM use (Scale 1-5)	3.2	3.7	3.9	4.5

Table 16. Project outcome results for the four case projects.

Variable	Residential Building	Road Infrastructure	Commercial Building	Civil and Hydraulic
Case characteristics	Design and build of five-floor apartment block	Design and build of public transport line and road works	Design and build of inner-city office building	Design, build, and maintenance of dike and road infrastructure
Project outcome: BIM project maturity	1.6	2.4	1.9	3.5
Project outcome: Team performance	3.6	3.7	3.0	3.6
Project outcome: Team satisfaction	4.3	4.5	3.1	4.3
Project outcome: Absence of BIM issues and barriers	4.0	4.3	3.8	4.3

5.4.1 Case I: Residential Building

Project relations

Figure 25 below shows the selected parties in the project organization and their mutual relationships. The project takes a distinctly segregated approach to collaboration, meaning that organizations work from their own offices on a demarcated part of the work. In this project, the general contractor takes a strong leading role such that most of the communication is through the general contractor, rather than directly between subcontractors or suppliers. Nevertheless, some communication and information exchanges take place between the MEP contractors and the HVAC contractor. In comparison, the position of the suppliers of concrete elements, frames, and facades is more isolated.

Results for the project outcome variables

The *BIM maturity* of the residential building project is low with an overall score of 1.6. For most of the maturity criteria, the score was 2 or lower, with the exceptions for software, information structure, data exchange, and personal motivation for

BIM. According to our informants, this rather low project maturity is mainly due to the low complexity of the project. As one of our respondents said: “This is quite a standard project. Everybody knows what to do, so we don’t need to make extensive agreements”. The low ambition was also reflected in the lack of a BIM vision and goals for the project such that mutual expectations were largely discussed only verbally. Strikingly, the interviewee from the general contractor, the coordinating party, was unaware of any vision or goals for BIM in the project. The way he described the protocol gives the impression that this is a formality on paper, rather than a document used in reality: “I have to admit I only looked at it once. Maybe there is something stated in that document, but I don’t know”. Despite the low BIM maturity of the project, the perceived *team performance* was fairly high, rated at 3.6 on average. Also, *team satisfaction* among the project partners was high, with a score of 4.3. The respondents generally seemed to prefer a more segregated way of working with limited interaction between the parties. They stated that this approach best matched the aims of the project.

Party	Responsibility
General contractor	Overall project responsibility, coordination
Subcontractor MEP 1	Plumbing, drainage, drinking-water, sanitary fittings
Subcontractor MEP 2	Electrical installation
Subcontractor HVAC	Air-conditioning of wet rooms, inflow fresh air
Supplier frames and façades	Window frames and façade elements
Supplier concrete elements	Elevator walls, landings, stairs, prefab walls
Supplier concrete floors	Prefab concrete floor elements

Figure 25. Responsibilities and mutual relations of core parties in the Residential Building project.

Most interviewees did not perceive there to be important *issues or barriers to BIM use* in the project. Only the contractor and the supplier of frames and facades mentioned a few important barriers. The most frequently mentioned barriers to BIM use in this project were a lack of knowledge and competence, ineffective knowledge transfer, and the lack of formalized work instructions. The low project maturities in terms of BIM expertise, training and education, as well as process-related criteria indicate potential failings on these aspects. Thus, we concluded that most of the problems that arise relate to specific immature aspects of BIM.

Results of TMM variables

The core TMM variable in this study, the *perceived project BIM maturity*, is displayed from the perspective of the various project partners in Table 17. For most of the 18 BIM maturity criteria, the variation among partners in perceived project BIM maturity is small. Most variations are within one maturity level of the average maturity scores across all interviewees. The criterion with the highest variation is contractual aspects. According to the general contractor, no hard agreements have been made, or at least these are not strictly maintained. Conversely, the MEP and HVAC contractors indicated that sound agreements on BIM have been made in the project, albeit agreeing with the general contractor that parties tended to diverge from prescribed methods. Further, the suppliers did not perceive the existence of clear agreements on BIM at all and indicated that their relationship with the general contractor was based on more of an ad hoc approach.

In our analysis of the variation in project maturity perceptions, we found scores well-above average for parties that were working closely together in the core project team. On the other hand, suppliers more distant from the core project organization perceived lower levels of project maturity, as is clear from the lower overall average maturity score for the project. The most striking differences were related to contractual aspects due to the lack of sound agreements on BIM collaboration with the supplying parties. Although we could verify the existence of defined agreements for BIM use from the studied project documentation, the BIM protocol had not been shared with the suppliers. This left room for a more individualistic approach to these suppliers from the general contractor's perspective. As such, only one-to-one, and often ad hoc, agreements related to a party's specific scope of work were made.

Considering our second TMM variable, important *goals for BIM* in the project, we saw a varying picture from the project partners involved. They did nevertheless mostly agree on the importance of BIM for improving information exchange between partners, working more efficiently, and reducing failure costs. Regarding

efficiency, the HVAC contractor disagreed with this view in saying that efficiency gains were limited in this project due to the basic BIM approach. The supplier of prefab elements disagreed on the data exchange aims of the project, which maybe reflects their exclusion from using the document management system.

When it came to the TMM variable, *conditions for success*, the two top-rated conditions were the delivery and exchange of information and the alignment of process definitions for the disciplines involved. These two items also showed the lowest variations in perceptions. In addition, there was a shared understanding of the relevance of task and role descriptions. We thus concluded that respondents recognized the relevance of anchored agreements on BIM-related task division and processes. However, perceptions of project maturity on these criteria were low.

An average score of 3.2 was calculated for the *consensus on BIM use* variable. We found the highest perceived consensus for data exchange, that is, who delivers what information, in what format, when and how. Furthermore, consensus was high on the software to be used and the system used to store and manage project data.

Relation between TMM and project outcomes

The project's focus on information exchange is particularly reflected in the high project maturity scores for the *information structure* and *data exchange* criteria. We also noted that these maturity criteria are among the top three in terms of where the project participants agreed the most. The lowest consensus was reported for how BIM training was arranged and on facilities at the construction site to support BIM collaboration. These aspects also received the lowest project maturity scores. The lack of consensus on these aspects was also captured well in the issues related to knowledge transfer between project partners. Overall, this case suggested that the greater the maturity of criteria, the lower the variation in maturity perceptions among partners. As such, the project partners had a high degree of consensus on the information structure and data exchange criteria. In general, the consensus on BIM use was moderate. The high perceptions of team performance and team satisfaction would seem to conflict with our supposition of a positive relation between TMM variables and project outcome variables. The interviews suggest that performance and satisfaction could score highly in this project because of the low BIM demands. As such, it seems that the project organization balanced effort and complexity.

Table 17. Perceptions of project BIM maturity by core parties in the Residential Building project.

Criteria	Assessed Project BIM maturity	MEP plumbing	HVAC	prefab concrete elements	MEP electrical	general contractor	prefab concrete floors	frames and facades	Average perception	Var. (σ)
STRATEGY										
BIM vision and goals	1	3	1	1	1	0	0	0	0.9	1.1
Management support	2	2	2	3	2	2	2	1	2.0	0.6
BIM expertise	1	0	1	0	1	1	1	0	0.6	0.5
ORGANIZATIONAL AND PROJECT STRUCTURE										
Tasks and responsibilities	1	1	0	0	0	1	0	0	0.3	0.5
Contractual aspects	2	3	4	2	4	2	0	1	2.3	1.5
PEOPLE AND CULTURE										
Personal motivation and willingness to change	3	3	3	3	3	3	3	2	2.9	0.4
Requesting actor (internal)	1	0	0	0	1	1	0	0	0.3	0.5
Education, training, and support	0	0	0	0	0	0	0	0	0.0	0.0
Collaborative attitude, openness, and transparency	2	4	3	3	2	1	2	2	2.4	1.0
PROCESSES										
Procedures and job instructions	1	1	1	0	1	2	0	0	0.7	0.8
Process change	2	3	0	2	1	2	1	1	1.4	1.0
IT (INFRASTRUCTURE)										
Hardware and network environment	0	0	0	0	0	0	0	0	0.0	0.0
Software	3	3	3	4	3	3	3	3	3.1	0.4
BIM facilities	0	0	0	0	0	0	0	0	0.0	0.0
DATA (STRUCTURE)										
Information structure	3	3	3	3	3	3	1	3	2.7	0.8
Object structure / object decomposition	1	1	3	3	1	1	1	0	1.4	1.1
Object libraries and attributes	1	1	1	1	1	2	1	1	1.1	0.4
Data exchange	4	4	4	4	4	4	4	4	4.0	0.0
OVERALL AVERAGE maturity	1.6	1.8	1.6	1.6	1.6	1.6	1.1	1.0	1.5	0.3

5.4.2 Case II: Road Infrastructure

Project relations

Figure 26 depicts the relationships among the core project parties. Represented by the length of the arrows, we show a strong relation between the general contractor and the engineering firm responsible for general design and coordination tasks. Further, we found close collaboration between the triad of structural engineers, reinforcement engineers, and the general contractor. The central position of the general contractor is explained by its leading role in setting up the BIM approach and facilitating systems for data management and exchange. The landscape architect is slightly more distant, but still part of the integrated collaboration in the shared project office. However, the supplier of concrete elements is an exception in taking no part in design and construction-oriented collaboration at the on-site project office.

Party	Responsibility
General contractor	Overall project responsibility, coordination
Engineering firm	Design and coordination
Structural engineer	Engineering structural works
Reinforcement engineer	Construction model reinforcement
Landscape architect	Design public space / landscaping
Supplier of concrete elements	Concrete elements, flyover

Figure 26. Responsibilities and mutual relationships of core parties in the Road Infrastructure project.

Results of project outcome variables

The *project BIM maturity* scores are, on average, 2.4 indicating a moderate level of maturity. On a few criteria, the project maturity is notably higher, most prominently for the definition and alignment of the object structure and the data exchange processes. Conversely, we observed low maturities, reflecting an ad hoc approach, for education, training, and support, object libraries, and the availability of a requesting actor. In terms of the last of these, most respondents felt there was no one in the project acting to inform and stimulate others regarding BIM. This was illustrated by the structural engineer in commenting: “The stimulating role should be with the general contractor, but that’s a trait I miss a bit in this project”. Nevertheless, the collaborative attitude in the project was reasonable, scoring a maturity level of 3. We found confirmation of this attitude in other project outcome variables. First, the *team satisfaction* rating stood out with a score of 4.5. This is explained by the high satisfaction with all the items included: working relations, each other’s contributions to the work, and the pleasant working in the team. Second, respondents on average scored *team performance* at 3.7 with respondents feeling that the team performed well and accomplished its objectives. When looking at barriers and issues to BIM use, none of the respondents experienced major *issues or barriers* in the project. Only two aspects, lacking knowledge and competence and a lack of clarity about tasks and responsibilities regarding BIM use, were considered “to some extent a barrier” by four of the six respondents. Moderate maturity perceptions of both tasks and responsibilities and education, training, and support indicate shortcomings of the project team in these areas.

Results of TMM variables

The *perceived project BIM maturity*, by project partners, is shown in Table 18. The variations in understanding of project maturity are small for most maturity criteria with the spread of maturity levels between respondents mostly no more than 1 from the average score. The scores of the supplier of concrete elements are most notable with large negative deviations from the average of all participating organizations. As such, most of the overall variation can be attributed to this single supplier. The interviews revealed that the poor perception of this supplier was mostly due to its unawareness of all kinds of BIM-related processes and agreements within the project team. Indeed, the supplier was only aware of some basic aspects that had been agreed upon such as the software they work with and the way they deliver their discipline’s models to the general contractor. On these aspects, its maturity perceptions were in line with the other parties. The supplier’s respondent illustrated their limited involvement in BIM use on the project as follows: “We actually haven’t spoken about BIM with the general contractor. I

haven't seen any protocol either. In my opinion, this project is quite similar to a traditional project without BIM." From the perspective of the other informants, further integration of this supplier is irrelevant. Excluding this supplier, most of the variations among the other parties' perceptions relate to process aspects. Here one can see the effect of differences between disciplines with the design and engineering of the reinforcement model deemed more mature than other aspects. The other parties also more strictly apply procedures as defined in the execution plan. Moreover, we saw the support that the landscape architect received during the project to adopt more advanced BIM use in that he valued the process change most highly.

The project participants have a similar *understanding of BIM goals* that are most relevant for the project, with the variation in ratings for BIM goals relatively low. According to the respondents, the most important BIM goal is streamlining collaboration with other parties. The collaborative approach with a lot of face-to-face communication at the shared project office is very much in line with this goal.

In terms of the *conditions for success*, project participants generally have a very similar understanding. First, they agree on the need for task or role descriptions with regard to BIM use. Second, the need for aligned process definitions and clear agreements about information exchange are widely supported. As such, the formalization of BIM use is seen as contributing to more successful BIM use.

The TMM *consensus on BIM use* variable scored an average of 3.7 out of 5. The strongest consensus was on what software to use to support BIM and on the delivery and exchange of data. Notably, the supplier here also scored much lower (1.7) than the general consensus about BIM use which reflects the above-mentioned divergent perception of project BIM maturity by the supplier. The least consensus among the project partners was found on the arrangement of on-the-job training and support for BIM.

Table 18. Perceptions of the project's BIM maturity by core parties in the Road Infrastructure project.

Criteria	Assessed Project BIM maturity	Supplier concrete elements	Engineering firm	Structural engineer	Reinforcement engineer	Landscapist architect	General contractor	Average perception	Var. (σ)
STRATEGY									
BIM vision and goals	2	0	1	2	1	1	2	1.2	0.8
Management support	3	1	3	2	2	2	3	2.2	0.8
BIM expertise	3	1	4	3	2	2	3	2.5	1.0
ORGANIZATIONAL AND PROJECT STRUCTURE									
Tasks and responsibilities	2	0	0	1	1	1	1	0.7	0.5
Contractual aspects	2	0	2	1	1	1	2	1.2	0.8
PEOPLE AND CULTURE									
Personal motivation and willingness to change	3	1	3	3	3	3	3	2.7	0.8
Requesting actor (internal)	1	0	1	1	1	2	1	1.0	0.6
Education, training, and support	1	0	0	1	0	1	1	0.5	0.5
Collaborative attitude, openness, and transparency	3	2	3	2	4	3	3	2.8	0.8
PROCESSES									
Procedures and job instructions	2	0	1	2	3	1	2	1.5	1.0
Process change	2	0	1	2	1	3	1	1.3	1.0
IT (INFRASTRUCTURE)									
Hardware and network environment	3	0	3	3	3	2	3	2.3	1.2
Software	3	3	3	3	3	2	3	2.8	0.4
BIM facilities	2	1	1	2	2	2	2	1.7	0.5
DATA (STRUCTURE)									
Information structure	3	0	3	3	3	3	3	2.5	1.2
Object structure / object decomposition	4	1	4	4	3	3	4	3.2	1.2
Object libraries and attributes	1	1	1	1	1	1	1	1.0	0.0
Data exchange	3	4	3	3	4	3	3	3.3	0.5
OVERALL AVERAGE maturity	2.4	0.8	2.1	2.2	2.1	2.0	2.3	1.9	0.5

Relation between TMM and project outcomes

When looking at individual BIM aspects, we could clearly identify that high scores for TMM emerged when high values were given to project outcomes and, similarly, low values for TMM emerged alongside low values for project outcomes. This supports our hypothesis of a positive relationship between TMM and project outcome variables. Alongside the lack of consensus on process descriptions and on education, training, and support, we found the lowest maturity perceptions for the criteria related to formalization of tasks and the availability of training and support. On the other hand, the widely shared collaborative aims of the project team (expressed in very similar understandings of BIM goals) seemed to be translated into higher maturity levels in areas where interfaces between partners exist: software use and alignment, sound data exchange arrangements as well as well-defined object structures and modelling conditions for the project team. Moreover, we also found an almost complete absence of BIM-related issues and barriers. Notably, we observed that the supplier of concrete elements scored much lower on both TMM and the project outcome variables than the other project participants. This reflects their somewhat excluded position, apart from not being part of the integrated collaboration with other project participants at the project office, the supplier also has a more divergent mental model than the other project participants and seems to operate largely alone at a lower maturity level than the other partners.

5.4.3 Case III: Commercial Building

Project relations

The main collaborating parties are shown in Figure 27, where the property developer and the contractor take central positions. These two parties work closely together on managing the BIM process and linking the various disciplines, as represented by the core team area in Figure 27. From their central position, design and engineering-related tasks are coordinated with either the architect or the structural engineer as appropriate. These two other parties particularly communicate through the project manager of the property developer. In this process, the contractor contributes BIM expertise, support, and construction knowledge. During the design and engineering phase, all four parties worked from their own offices such that the level of integration of the overall project organization was low.

Party	Responsibility
Property developer	Property development, project management
Architect	Architectural model
Structural Engineer	Structural model
Contractor	Construction, coordination

Figure 27. Responsibilities and mutual relations of core parties in the Commercial Building project.

Results of project outcome variables

The *project BIM maturity* in the commercial building project is low to moderate, with an overall average score of 1.9 (Table 19). The criteria with the highest project maturity levels are in the data and IT categories, i.e., data exchange, software, hardware, and information structure. The lowest scores are for the BIM project facilities, the lack of a functioning requesting actor, as well as the ad hoc education, training, and support. Respondents particularly emphasized the absence of a champion in the project: someone who could motivate other project members and ensure all efforts were directed to the same end goal. In terms of the functioning of the project team, several interviewees revealed some issues in the team as a result of project delays and discord about the right BIM approach for the project. Hence, respondents assigned only moderate scores to *team performance* (3.0) and *team satisfaction* (3.1).

Respondents also raised various *BIM-related issues and barriers*. The three barriers that respondents rated the most highly were: insufficient quality and detail in the BIM model, lack of knowledge and competence, and resistance to changing to BIM. There were, however, variations in the extent to which partners experienced issues or barriers to BIM use. On the one hand, the architect had not experienced significant barriers to BIM use. They found the design processes quite straightforward and were able to obtain all the information required to get their work going. On the other hand, the contractor had found many problems, with five items rated as major barriers. The contractor was responsible for most coordinating activities and had experienced many issues in the collaboration between partners: resistance to BIM use, insufficient knowledge of partners, and poor information sharing among partners. As a consequence, the contractor considered the team configuration to be inappropriate. Given all these issues, the contractor had decided to spend more time on the project.

Results of TMM variables

Respondents had a very similar *understanding of project BIM maturity*, reflected in a rather low variation in the scores for this variable. When it came to IT aspects, there was no variation at all. In terms of facilities for BIM, the project did not make use of a shared project office. The variations in the scores for many other aspects can largely be attributed to one interviewee, the property developer, scoring relatively highly compared to the other parties. Since their respondent had written most of the project's execution plan, he had the best knowledge of the content and aims of that plan. However, a lack of alignment and a poorer understanding by the other parties brought down the overall picture of the project.

Some aspects, especially those related to strategy and processes, drew our attention due to the large variations among respondents. An explanation for the differing perceptions concerning defined procedures and responsibilities was offered by the property developer: “We defined these at the very start of the project, but as the years pass it becomes more difficult to maintain those prescriptions.” Here we also recognize the impact of project delays on motivation, awareness of mutual agreements, and perceived efficiency of the BIM process. In terms of management support, we concluded that sufficient support was present in the form of spoken words as well as in allocated budgets, but especially the architect was unaware of such support for their discipline. The structural engineer considered the allocated budgets insufficient. Here, we see a link to the position of dedicated experts in the project, who were not visible from the very start of the project and also had a limited capacity. Although a budget was allocated for an expert and a BIM process manager, not all parties made use of these individuals. Notably, the engineers and the architect either did not know about these experts or did not know what tasks these persons could support. The contractor acknowledged that an expert was available but felt that capacity should be increased: “The expert is active on many different projects. Given that things are not yet running smoothly on this project, their availability is too little.” On process-related aspects, we saw that the respondents had mixed views concerning the presence of procedures and job instructions. These documents had been prepared by the property developer, explaining their maturity level of 3, but had not been well distributed among the partners. We also observed that, because of the lengthy design phase in this project, people tended to forget about the existence and proper use of such definitions.

In terms of *BIM goals*, all respondents rated reducing failure costs as an important goal in this project. Second, respondents agreed on the facilitating importance of BIM given the high complexity in the commercial building project. Conversely, we found the highest variation in terms of the “BIM is used to satisfy the client’s mandate” goal. Most respondents rated this goal as very important, whereas the contractor stated that BIM was primarily applied due to intrinsic motivation. Further differences in understandings of the BIM goals related to streamlining collaboration and using BIM for visualization purposes. From the interviews, we concluded that these different understandings stemmed mainly from the discipline-specific benefits of BIM use.

Many of the *conditions for success* were rated equally highly by the respondents. Given the issues experienced during this project, respondents were aware that many aspects could be done better in another project. This seemed to be reflected

in the high scores that respondents gave to many of the conditions for success. Interestingly, the structural engineer was most at odds with the other respondents. Their respondent perceived BIM to be a new tool that did not require many arrangements or technological provisions. However, unlike the structural engineer, the other respondents saw a need for a common data environment, uniform object coding and decomposition, as well as for BIM-related training and support. The structural engineer's aversion and distrust of BIM use was apparent in these ratings.

Consensus on BIM use was mostly apparent in terms of the software used for BIM in the project. An interesting finding is the strong agreement on the redundancy of a shared office for the project. All the partners preferred a segregated way of working, represented by the low score on this as a condition for success and the low maturity score for this aspect. The lowest consensus levels concerned task and role descriptions and process descriptions where agreements were lacking.

Relation between TMM and project outcomes

For certain maturity criteria, particularly on IT criteria and data exchange, there were similar maturity perceptions as well as a strong perceived consensus and high project maturity scores. These outcomes support the hypothesized positive relationship between the scores for TMM variables and project outcomes. However, if we look at the overall picture, we see that this project scored fairly highly on TMM variables but quite low on project outcomes, with a project BIM maturity below 2, only moderate team satisfaction and team performance, as well as a significant number of major issues and barriers. Here, the interviews provided explanations linked to factors outside the project team that strongly affected the project outcomes, most notably a delay in obtaining building permits. Furthermore, we saw that the structural engineer's resistant attitude and lack of BIM competences had a negative effect on the project outcomes. However, this is not clearly reflected in the scores for TMM variables such as consensus on BIM use and the understanding of BIM goals. The results from this case therefore suggest that project outcomes cannot be predicted on the basis of the similarity of mental models in the project team alone.

Table 19. Perceptions of project BIM maturity by core parties in the Commercial building project.

Criteria	Assessed project BIM maturity	Property developer	Architect	Structural engineer	Contractor	Average perception	Var. (σ)
STRATEGY							
BIM vision and goals	1	2	1	1	1	1.3	0.5
Management support	3	3	1	2	3	2.3	1.0
BIM expertise	1	4	2	2	1	2.3	1.3
ORGANIZATIONAL AND PROJECT STRUCTURE							
Tasks and responsibilities	2	2	1	1	2	1.5	0.6
Contractual aspects	1	1	1	1	2	1.3	0.5
PEOPLE AND CULTURE							
Personal motivation and willingness to change	2	2	3	2	2	2.3	0.5
Requesting actor (Internal)	1	1	0	1	2	1.0	0.8
Education, training, and support	1	1	0	1	2	1.0	0.8
Collaborative attitude, openness, and transparency	2	2	2	2	2	2.0	0.0
PROCESSES							
Procedures and job instructions	2	3	1	2	1	1.8	1.0
Process change	2	3	3	1	2	2.3	1.0
IT (INFRASTRUCTURE)							
Hardware and network environment	3	3	3	3	3	3.0	0.0
Software	3	3	3	3	3	3.0	0.0
BIM facilities	0	0	0	0	0	0.0	0.0
DATA (STRUCTURE)							
Information structure	3	3	3	2	3	2.8	0.5
Object structure / object decomposition	3	3	1	3	3	2.5	1.0
Object libraries and attributes	1	1	1	1	1	1.0	0.0
Data exchange	4	4	4	4	4	4.0	0.0
OVERALL AVERAGE maturity	1.9	2.3	1.7	1.8	2.1	1.9	0.3

5.4.4 Case IV: Civil and Hydraulic

Project relations

Five parties, as presented in Figure 28 were primarily involved with BIM use in this project. The engineering firm and the contractor held central positions from which they coordinate sub-teams that are responsible for different parts of the project. In doing so, the contractor and engineering firm function as a linking pin between the sub-teams and also provide them access to experts for support. All parties radiate the strong identity of the project organization, which was boosted by their shared project office close to the construction works and a strong focus on integrated collaboration from the start of the project. As such, the dredging company, designer, and the second engineering firm are also represented as a part of the cohesive project organization.

Results of project outcome variables

The *BIM project maturity* was scored as 3.5 on average with no criteria scoring less than 3. The highest scores were for the ‘education, training, and support’, and ‘information structure’ criteria which achieved the maximum maturity level of 5. This overall project maturity level indicates that none of the assessed criteria were absent or only applied on an ad hoc basis in the project. Indeed, BIM is perceived as spearheading the project, is well defined, and also agreed with by the partners.

Party	Responsibility
Engineering firm	Design coordination and project management
Contractor	Construction and coordination
Designer	Design and engineering
Dredging company	Dike reinforcement, sluices
Engineering firm II	Modelling, engineering, advising

Figure 28. Responsibilities and mutual relations of core parties in the Civil and Hydraulic project.

This well-thought-out characteristic was illustrated by one of the respondents: “we adopt a broad perspective on BIM, and we consciously thought about what to use BIM for in the project. That’s also because we do it mainly for ourselves, which means we have to be critical about the added value”. The second project outcome variable, *team performance*, scored 3.6. Notably, here, the scores for the ‘this project meets its expectations’ item were rather diverse. The lower scores given by the coordinating parties reflect their very high ambitions for the project. Furthermore, *team satisfaction* scored highly. According to our respondents, working collectively at the project office very much contributed to both collective performance and pleasant collaboration.

We could see the efforts undertaken by the project team to collaborate intensively and build the BIM maturity level reflected in the experienced *BIM-related issues and barriers*. None of the barriers on our list of predefined BIM-related barriers was rated as major in the project by our respondents. This aligns with the relatively high perceptions on all the project maturity criteria that ensure that BIM is used without serious issues. However, respondents from both the engineering firm and the contractor raised additional barriers. First, the contractor mentioned the challenge of changing personnel during the course of the project. New people had to get acquainted with all the BIM-related procedures and agreements in the project. This required resources in terms of training and on-the-job support. The high perceptions for project maturity in terms of the formalization of both tasks and processes underline the efforts that are required to ensure that all project members live up to these agreements. Second, given the contributions from many different disciplines, the engineering firm’s respondent raised the difficulty in maintaining consistency in model coordinates. To minimize this issue, the engineering firm focuses on strong coordination of the shared model.

Results of TMM variables

In terms of the *perception of BIM project maturity*, the lowest score was for process change (2.2) and the highest for information structure (4.6) as shown in Table 20. Considering the variations in partners’ perceptions, we observe a strong negative outlier by the designer on ‘tasks and responsibilities’ due to a lack of awareness of any definitions relating to this aspect. The results also show a high variation for collaborative attitude due to the different impressions on the extent to which the project functions as one cohesive team. The engineering firm was most convinced of the project’s single identity: “Being a representative of your own organization is no longer an issue. Everybody I speak to thinks alike, everybody is doing their job really for the project.” We often heard that this identity had a positive influence on openness and transparency between the core project team partners. In addition,

the efforts made in terms of shared office space and the detailed alignment of task interfaces contributed to the collaborative attitude. However, some respondents with less positive perceptions stressed the challenging dynamics that accompany such large projects, with the formation of smaller teams leading to more complicated communication between these teams.

Next, we observed variations between team members that stemmed from the extensive project documentation used to structure BIM support and expertise in the team. Since some respondents had only a limited scope in the project, they did not have detailed knowledge about these prescriptions for the full scope of the project. For example, the designer was not aware of all the BIM goals since his function was less strategically oriented. Similarly, the respondent from the dredging firm only referred to his superior for support and so was unaware of the support structure for the project as a whole. A third example relates to the perceived maturity of 'education, training, and support' where the respondent from the second engineering firm believed that only a limited group of people were targeted in the project's training program.

Turning to the *understanding of BIM goals* for the project, the project participants showed a high degree of consensus on 5 of the 10 predefined BIM goals which all received high ratings. The three most highly ranked were 'improving information management and information exchange', 'reducing failure costs', and 'streamlining collaboration'. However, the responses on the other five BIM goals were much more varied: some said these goals matched the project well, whereas others felt the opposite. According to the designer, the reason for this varied understanding of the goals lay in the project's focus on agreements over collaboration and information sharing, and that BIM goals had not been adequately communicated.

Informants rated on-the-job training and support for BIM as the most important *conditions for success* in this project. All the project partners agreed on the need for training and support to achieve a high level of maturity. Perhaps surprisingly, having the client insist on BIM use was, overall, rated as the least important condition for success, although this aspect had the largest variation in views. This outcome was largely due to the engineering firm's respondent believing that BIM success should originate from an intrinsic motivation to use BIM and reap its benefits, whereas others saw the importance of client demand.

Our respondents' ratings indicate a full consensus on BIM use concerning data management, software, the BIM lead, and the project facilities. The lowest score for other items was 3.8, on a scale of 1 to 5, and most items were rated well above 4. Thus, on all BIM-related matters, the respondents sensed a high level of agreement.

Table 20. Perceptions of project BIM maturity by core parties in the Civil and Hydraulic project.

Criteria	Assessed Project BIM maturity	Engineering firm	Designer	Dredging company	Engineering firm II	Contractor	Average perception	Var. (σ)
STRATEGY								
BIM vision and goals	3	3	1	3	3	3	2.6	0.9
Management support	4	4	4	4	3	4	3.8	0.4
BIM expertise	4	5	4	2	3	3	3.4	1.1
ORGANIZATIONAL AND PROJECT STRUCTURE								
Tasks and responsibilities	3	4	1	4	3	4	3.2	1.3
Contractual aspects	3	3	2	2	3	3	2.6	0.5
PEOPLE AND CULTURE								
Personal motivation and willingness to change	3	3	3	3	3	3	3.0	0.0
Requesting actor (internal)	3	3	3	2	3	3	2.8	0.4
Education, training, and support	5	5	4	4	3	4	4.0	0.7
Collaborative attitude, openness, and transparency	4	5	3	2	4	2	3.2	1.3
PROCESSES								
Procedures and job instructions	3	4	3	3	4	3	3.4	0.5
Process change	3	3	3	2	2	1	2.2	0.8
IT (INFRASTRUCTURE)								
Hardware and network environment	3	3	4	3	5	3	3.6	0.9
Software	3	3	3	3	3	3	3.0	0.0
BIM facilities	4	4	4	4	4	4	4.0	0.0
DATA (STRUCTURE)								
Information structure	5	5	5	5	3	5	4.6	0.9
Object structure / object decomposition	4	5	4	4	3	3	3.8	0.8
Object libraries and attributes	3	3	3	2	3	3	2.8	0.4
Data exchange	3	3	3	2	3	3	2.8	0.4
OVERALL AVERAGE maturity	3.5	3.8	3.2	3.0	3.2	3.2	3.3	0.3

Relation between TMM and project outcomes

Overall, the broad consensus on BIM use alongside very positive outcomes in terms of BIM project maturity, team satisfaction, and the absence of barriers supports our hypothesis of a positive relation between TMM and project outcome variables. We also noted that the goals with the most similar understandings and the highest scores could be linked to high scoring maturity criteria, such as for the information structure. The score for perceived team performance seems to be lagging slightly, which we attribute to the very high ambitions which open up new horizons in BIM use but are also challenging to fulfill. Nevertheless, given these ambitions and collective motivation, the project organization can be characterized as a cohesive team that has invested a lot in building a Team Mental Model. This is also reflected in the strong consensus on training and support and the high maturity level for this aspect. As such, we see that the team has put this condition for success into practice.

5.5 Discussion

Our multiple case study aimed to explore Team Mental Models (TMM) in the context of BIM use in construction projects. In doing so, we were particularly interested in variations in TMMs and in how TMMs influenced BIM-related project outcomes. The four within-case analyses provided in-depth insights that allowed us to further interpret the cross-case comparison shown in Table 15. Below we first discuss and explain outcomes regarding the variations in TMMs. Then, turning to the relationship between TMM and project outcomes, we expand on some of the influential factors in the projects studied.

5.5.1 Factors influencing the sharedness of mental models for BIM use

We gathered valuable insights into the sharedness of mental models within a single project organization. For some partners, mental models would be very similar, whereas, for one or a few project partners, the mental models for BIM use were often distinctly different. By taking a closer look at the variations and the absolute scores for the variables measured, we observed that in all four cases that it would be the lower scores of one or a few parties that pulled down the average. That is, our analysis indicated that most of the found variations in scores could be explained by one or two respondents rating much lower than the team's average. In the residential building project, the BIM project maturity perceptions of both the supplying firms were relatively low, as was that of the supplier of concrete

elements in the road infrastructure case. These parties also gave low ratings for the consensus on BIM use (1.5, 1.7, and 2.4). As such, both these projects clearly indicated that parties that are functioning at a greater distance from the core of the project team have lower perceptions of aspects of BIM use. Indeed, the involvement of these suppliers in the BIM process was limited to providing discipline-related BIM data, leading to a lack of understanding of many BIM-related aspects including procedures and systems for structured data management. The suppliers' interactions in both cases were only with the coordinating party, the general contractor.

Geographical, organizational, and technological proximity

Our findings are in line with the existing theory on the proximity concept. We saw that, indeed, not working together at a shared project office hampers face-to-face interactions and knowledge transfer (Knoben and Oerlemans, 2006) and particularly the exchange of tacit knowledge between project participants (Shaw & Gilly, 2000). In our cases, both geographical distance and limited interaction in meetings (both physical and virtual) led to gaps in project-related BIM knowledge. This in turn led to misalignments between the project partners in their mental models related to BIM use.

We found that this generally more distant functioning of the suppliers, and some of the less involved subcontractors, led to a lack of belief in the mutual benefits and contributions of BIM in improving shared processes (Dainty et al., 2001). This most strongly emerged in the commercial building project through the restraining attitude of the structural engineer. We also saw that lower ratings tended to be given by disciplines that had only a specific and limited scope in using BIM, notably by the architect in the commercial building project and the dredging company in the civil and hydraulic one. Since these organizations differ from the coordinating parties in terms of their standard practices and uses of BIM, they have a lower organizational and technological proximity to the project team (Knoben & Oerlemans, 2006). This is due to the differences in their standard routines and knowledge base regarding BIM. In addition, they are not fully aware, possibly because they have not been well informed, of various aspects such as the definitions of tasks, responsibilities, processes, and available training. Consequently, their understandings of the intentions and use of BIM in the project might differ from those of the coordinating parties (Dainty et al., 2017), a role usually filled by the general contractors and engineering firms.

Nevertheless, the civil and hydraulic project showed that it is possible to avoid parties feeling they have been marginalized. Here, even the dredging company

with its lower organizational and technological proximity did not feel they were not part of the BIM processes. This emphasized that the collaborative approach adopted, and the consequent close geographical proximity, was focused on integrating all parties that were relevant from the BIM perspective. Interviewees believed that the collaborative approach to BIM required them to adapt and learn quickly in order to form a collective and mature team. We observed this cohesiveness in the very similar understandings of BIM and a high score for consensus. Overall, ratings of TMM variables by the different parties in a project organization were generally negatively related to the distance, either geographical or organizational, of those parties from the core of the project organization.

Bias of coordinating parties

In contrast to the generally lower perception scores from parties that function more distantly the center, the coordinating parties' perceptions in most of the projects were above average. The only exception was the general contractor in the residential building project who was very self-reflective and more inclined to point out weaknesses in BIM maturity in practice than other coordinators. Consequently, his perception of BIM maturity was similar to the average of the other respondents. In all the other projects, the coordinating parties had more mature images of the project than their partners. In comparing interview transcripts with archival project data, we observed that coordinating parties' understanding of their project tended to resemble the original vision and the execution plans for the project. Further, the respondents from the coordinating parties were very much involved in drafting the plans and were also charged with ensuring other parties in the project followed the plan. From all the interviews and documentation, our evaluation suggests that those plans recorded on paper, and the accompanying intentions, did not fully match the reality in practice. In addition, we found that the coordinating parties' understanding of why and how BIM should be used had not been adequately communicated to subcontractors and suppliers. This further contributed to differing perceptions of BIM use among the project partners.

5.5.2 Factors influencing the relation between Team Mental Models and project outcomes

The results from our multiple case study to some extent support previous studies conducted in other contexts regarding the positive relationship between the extent of the sharedness in the mental models of a project's members and the outcomes of the project (e.g. Cooke et al., 2003; DeChurch & Mesmer-Magnus, 2010; Lim & Klein, 2006). In particular, the perceived consensus on BIM use was strongly correlated with BIM project maturity as a project outcome. Here, of our four cases,

the residential building case scored lowest on both TMM and BIM project maturity, the civil and hydraulic project scored highest on both, and the two other cases saw moderate scores for both TMM and BIM project maturity. Thus, where team members were agreed on what they were to achieve using BIM, and how to do so, this resulted in a higher BIM maturity in the project. A consensus on BIM use refers for example to agreements on design procedures, on how to share or store data, or how to clearly demarcate BIM responsibilities among the disciplines involved. However, for the other TMM and project outcome variables measured, the relationship between TMM variables and project outcome variables was less clear-cut. This was also reflected in non-significant correlation coefficients. The results from the four cases showed that these relationships were influenced by other factors, some beyond the influence of the project team itself. Below, we discuss the factors that we came across in the various projects.

Efforts versus project demands

Despite the low scores for TMM, the residential building case scored as highly as the civil and hydraulic case for both team performance and team satisfaction outcome variables. Based on the interviews, we concluded that the low BIM project maturity of the residential building case aligned with the needs of the project. The respondents were satisfied with the way they applied BIM and worked together with BIM in this particular project, which was reflected in good ratings for perceived team satisfaction and performance. From this, we should acknowledge that the perceived team performance and team satisfaction variables are influenced by a project's circumstances, whereas the BIM maturity measurement is more objective and less influenced by project-related characteristics. So, interestingly, because of the balance between efforts and demands for BIM, the lack of a shared mental model of BIM in this team did not prove an obstacle to achieving a satisfactory project.

Collaborative approach

Another factor that might influence the relationship between TMM and project outcomes is the manner of the collaboration, either integrated with physical interaction such as in a shared office or more segregated with primarily digital interaction. The shared BIM facilities in two of our cases made it easier to interact directly and see other team members at work, which is known to build trust and team effectiveness (Ford, Piccolo, & Ford, 2017). In the other two cases, the decision had been taken that partners would work in their own offices, and they were thus dependent on digital interactions using software output, the common data environment, or virtual meetings. Although participants in our study

emphasized that progress had been made using these virtual collaboration tools, they also indicated the difficulty of not having direct and more informal communications. The importance of communication was evident across all the cases and reflected in the sometimes inadequate distribution of, for example, goals and procedures for BIM use. Similarly, Aubert and Kelsey (2003) had concluded that good communication is a necessity in virtual teams to ensure satisfactory team performance by leading to mutual understanding among team members and a better aligned information base.

External factors

The commercial building project turned out to be a negative outlier in terms of the scores for the team performance, team satisfaction, and BIM-related issues and barriers project outcome variables. Despite its second highest score for the TMM variables, the project did not fully meet expectations and the progress was beset with difficulties. The within-case analysis showed that the latter was due to external factors in the form of delayed building permits. The resulting delays had repercussions on the atmosphere and on the belief that BIM could add value to the project. As such, this case shows that factors outside the project organization itself can influence project outcomes, which in turn affects the relationship between TMM and project outcomes.

Knowledge and skills

As described in the previous paragraph, despite the good score for the TMM variables, the commercial building case scored relatively poorly on the project outcome variables. One of the factors influencing the relation between TMM and project outcomes that became apparent from the interviews related to BIM knowledge and skills. Simply stated, the BIM capabilities of the structural engineer were insufficient for the task at hand. Consequently, meetings were not efficient, additional experts had to be hired, and the contractor had to take over some of the BIM responsibilities including some outside his own scope. This had an impact on perceived team performance, team satisfaction, and on experienced barriers in the project. Although the suppliers in the road infrastructure project were also lacking BIM skills, their role in the multi-organizational BIM process was less influential and their shortcomings less of a problem. As such, the project management had already anticipated this lack of skills and taken action to ensure the project outcomes were not seriously affected.

Based on these outcomes, a recommendation for future research is to ensure that the BIM knowledge base and competences are included in the TMM measurement. In our method, which is commonly used elsewhere, we focused on the similarity of

mental models in terms of goals, conditions for success, and various agreements and collaborative processes related to BIM use. However, the method did not incorporate the degree to which team members' mental models reflect the BIM domain and skills, a suggestion indeed made by Edwards, Day, Arthur Jr, and Bell (2006).

5.5.3 BIM project maturity assessment: accounting for perceptions

The findings from our multiple case study also suggest that methods based on project maturity evaluations by only the project manager or BIM coordinator could be overly positive. Such team members have a strong coordinating role and responsibility for the BIM approach and use in the project. As such, their project perception is somewhat a personal self-assessment. In line with our findings, the literature also associates self-assessments with a tendency towards a positive bias (John & Robins, 1994). We therefore propose that evaluations should include the perspectives of a variety of disciplines involved in a project, as well as archival project data, to reach a more thorough and maybe less biased understanding of a project's maturity.

5.5.4 Some general remarks on the case study approach

Given the limitations of our case study approach, we acknowledge the need to build evidence in future research by further exploring Team Mental Models and project outcomes in construction projects with BIM. Moreover, we recognize the limitations in gathering reliable and comparable measures of all a project's outcome variables. Although we were able to make a rather objective assessment of BIM project maturity, the team performance and team satisfaction variables were based on respondents' perceptions. If, for example, we consider the outcomes from the residential building case study, these outcome variables were considered satisfactory by the project members given the project's limited requirements and ambitions. However, the resulting low project BIM maturity led to contradictory indications for BIM-related performance. Thus, overall, because of the varying case contexts, it was hard to achieve an objective comparison of project outcomes. This emphasizes the importance of collecting ample qualitative case study data if one wants to fully understand and explain differences between projects.

5.6 Conclusions

In this study, we aimed to increase the understanding of Team Mental Models in the particular context of BIM use in construction. By adopting a multiple case study approach, we explored both variations in Team Mental Models that were apparent in the cases and how the sharedness of team members' mental models influenced project outcomes. In doing so, our study adds to existing theory showing a positive relationship between Team Mental Models and team performance. To this end, we developed a research model to investigate BIM-related TMMs and project outcome variables. The TMM variables included were understanding of BIM project maturity, understanding of BIM goals, understanding of BIM conditions, and consensus on BIM use. The project outcome variables were BIM project maturity, team performance, team satisfaction, and absence of issues or barriers.

In terms of variations in mental models within a team, the findings indicate that project partners generally had quite similar mental models of BIM use in their project. Any variations found in understanding BIM intentions and use were mostly attributed to one or a minority of project partners. An explanation for these results is offered by proximity theory: that the geographical, organizational, and technological distances to the core of the project team influence perceptions. Indeed, parties that operated further from the core of the project organization valued the project outcomes less. This was in general due to them having a limited and clearly demarcated component of the work, which was accompanied by an understandable unawareness of many inter-organizational, and for them irrelevant, procedures. The resultant low perceptions of project outcomes were accompanied by relatively low scores for the TMM variables. In the projects investigated, it was mostly supplying firms that belonged to this group giving low ratings for TMM and project outcome variables.

In comparison, parties with a central role in the project team, by coordinating BIM processes and setting up the BIM approach, scored the TMM and project outcome variables relatively highly. These respondents had the best overview of the entire project and BIM use within it. In many instances they had even been responsible for drafting the plans and procedures for BIM use in the project. A potential drawback linked to this broader knowledge was that the most knowledgeable respondents in most of our cases appeared to evaluate BIM based on the plans on paper rather than on how it was being implemented in reality. As such, respondents from the coordinating parties valued the project more highly than

other parties, and also more positively than the overall image we gained from project documentation and interviews.

Considering the relationship between TMM and project outcomes, the results of our multiple case-study particularly support the existing theory linking two of the investigated variables: a higher consensus on BIM use had a strong positive correlation with BIM project maturity. This implies that the more project teams have a consensus on what to use BIM for, and how to use it in practice, the higher the BIM maturity level for the project team will be. However, for other suggested relationships between TMM and project outcome variables, our findings were more mixed. The case study data suggested a number of factors that might influence these relationships. First, we saw that low project demands in terms of BIM could explain why a project with a low BIM project maturity level and a low shared understanding of BIM use could be considered satisfactory. Second, the form of the collaborative approach, either integrated at the project site or segregated from the parties' own offices, influenced partner interactions and communication, and thus team performance. Third we found that external factors, such as delays in obtaining building permits, could have a negative influence on project outcomes. Fourth, we saw that even when a shared understanding of BIM use was present, a lack of knowledge or required competences by a single project partner could prove seriously detrimental to project outcomes.

Based on our findings, we would encourage further research to find more evidence for the influence of TMMs on construction project outcomes. Although we applied theoretical generalization to embed our findings in existing theory, the case study method limits statistical reliability. Nevertheless, the ample qualitative data in the case study method has proven to be essential for gaining understanding of the relationship between variables and provided the opportunity to identify mediating factors. Furthermore, we especially recommend further research in this field because of the impact that the characteristic fragmentation in construction project organizations appears to have. Compared to regular teams that have been investigated a lot in TMM research, the characteristic inter-organizational project teams in construction showed to be more challenging in terms of achieving shared understanding and are prone to various factors that influence project outcomes.

CHAPTER 6

CONCLUSIONS

This thesis set out to disentangle and explain variations in BIM maturity and their effects on the implementation and use of BIM on different levels of analysis in the construction industry. To that end, Chapter 2 focused on BIM maturity on the organization and subsector levels, Chapter 3 provided deeper insights into the organization level, while Chapters 4 and 5 addressed the inter-organizational level of projects. This chapter first provides answers to the associated research questions developed in the introduction. The contribution of this study to both theory and practice, as well as a reflection on the methodology are discussed in the subsequent section. The chapter concludes with suggestions for further research.

6.1 Major conclusions

In this section the main conclusions are drawn by answering the research questions addressed in the previous chapters of this thesis.

6.1.1 Maturity assessment and variations on organization and subsector levels

RQ1: What assessment model is appropriate to evaluate organizational BIM maturity in different types of organizations in the construction industry?

Previously developed BIM maturity models were usually designed to measure BIM maturity for specific disciplines or mainly addressed only the technological aspects of BIM. However, the multidisciplinary character of the construction industry asks for a more comprehensive maturity model that could be applied across different subsectors and be applicable for analysis on the levels of subsectors, organizations, and projects. In response to this need, the strengths of existing maturity models were evaluated and adapted in a newly developed BIM maturity model. Here, BIM was conceptualized as an information system that is part of an organization and its environment. This means that the functioning of the information system is dependent on an organization's strategy, procedures, people and culture as well as collaboration with supply chain partners. This conceptualization highlights the need to account for both technological and organizational aspects of BIM. The BIM maturity model consisted of 6 main criteria (covering the fields of strategy, organization structure, people and culture, processes, IT, and data) and 16 underlying sub-criteria. For all these criteria, maturity levels were defined on a scale from 0 to 5, where 0 represents a total absence of characteristic maturity-level conditions and 5 represents full maturity involving the continuous evaluation and optimization of processes.

The developed BIM maturity model was applied in a sectoral analysis of 53, mostly leading, firms in the Dutch construction industry. This validation provided valuable feedback on the appropriateness of the model's components and data collection procedures (i.e., the interview instrument). In general, respondents from all subsectors found that the interview instrument covered the relevant BIM-related aspects well. Based on the respondents' feedback and the research team's own evaluation, a few refinements to the maturity model were made. First, the model was seen as needing a stronger and more explicit anchoring of contractual aspects (i.e., the formalization of BIM-related processes between organizations) and so an additional criterion addressing this was added. Second, in response to feedback,

the openness and transparency between partners in respect of BIM was added to the criterion considering collaborative attitude. Third, in addition to process descriptions, the impact of BIM as a driver of process change was given additional emphasis.

Overall, the sectoral BIM maturity analysis showed that the BIM maturity model facilitated assessment of different types of organizations from different subsectors in the construction sector. Based on the BIM maturity insights, organizations were able to identify strengths and weaknesses in terms of BIM and derive conditions to improve maturity. By an aggregation on subsector level, the BIM maturity model provided valuable insights into variations between subsectors. These results could be utilized by sector associations to develop new policies to reduce BIM maturity gaps between disciplines and overcome challenges related to subsector-specific BIM perspectives.

6.1.2 Maturity variations in organizations related to implementation barriers

RQ2a: How can the barriers an organization encounters with respect to BIM implementation and use be mapped on to the particularly affected organizational levels?

In Chapter 3, the developed BIM maturity model was applied in an in-depth organization-level analysis of the relationship between implementation barriers and BIM maturity. Several barriers that hinder implementation and the further maturing of BIM have been extensively described in the literature. The case study on which this chapter is based covered nine units within a large contracting firm and added to the existing knowledge by revealing barriers that organizations encounter on different organizational levels, i.e., top management, middle management, supporting departments and project teams. In doing so, it provided deeper insights into the BIM implementation process and its obstacles, i.e., from strategic initiatives of top management down to operationalization at project level across these organizational levels. An inductive analysis revealed 13 main barriers that were mapped on to the organizational levels concerned. Primarily, the results showed the dominance, across all organizational levels, of barriers that relate to people's motivation and competences in using BIM. Further, the study showed that an organization's middle management level is key for successful BIM adoption in projects and for transferring BIM experience from one project to another.

RQ2b: To what extent are the barriers to BIM implementation and use that occur related to organizational BIM maturity?

Previous studies have failed to investigate whether the barriers that organizations encounter are linked to their BIM maturity. The hypothesis of this study is, however, that organizations that have progressed significantly with BIM will face different barriers to those faced by firms that have just taken the first steps in BIM. The findings indicate that it is only organizations with low BIM maturity levels that have to deal with a lack of BIM support from the level of top management. The interviews revealed that lacking such support, in terms of strategic initiatives and allocating resources, is detrimental to the implementation and maturing of BIM. On the other hand, organizations with high levels of BIM maturity tended to be confronted with barriers related to their external environment. It seemed that such organizations were often a leading party in a project and encountered barriers such as a lack of partner maturity or insufficiently defined sectoral standards. These barriers reflected the increased supply chain demands of relatively mature organizations in their efforts to satisfy ambitions in inter-organizational BIM use on the project level.

Overall, the insights from this study provided actionable knowledge on barriers that organizations need to overcome to foster the implementation of BIM and achieve higher levels of BIM maturity.

6.1.3 Project-level maturity variations and strategies for dealing with them

RQ3a: How is the BIM maturity of project partners related to the overall project maturity?

Most studies on BIM maturity have focused on providing insights into maturity on the level of individual organizations. Although a few studies have assessed maturity on the project level, none of these have clarified how variations in the maturity of individual partners relate to the maturity of the project as a whole. Chapter 4 therefore investigated the interactions between BIM maturity on these two levels of analysis: the organization level and the project level. Such insights are relevant to understanding the effects of, for example, partners with low maturities on the entire project. The research approach was a multiple-case study of four construction projects that were all making use of BIM in a multidisciplinary context.

The study found variations in the relationship between the maturity of the project and the maturity of the participating organizations. Two projects showed maturity levels that were similar to the average of partnering organizations. One project turned out to underperform in terms of maturity, with a maturity level well below that of partnering organizations. More surprisingly, one project had a project maturity that was much higher than the average of the partnering organizations, and higher than those of all the individual organizations involved. As the project maturity is hence not a simple equation of the average maturity of all partnering organizations, we looked at other forces that play a role when partners with different BIM-maturity levels engage in inter-organizational collaborations in projects.

RQ3b: What strategies do project managers use to deal with differences in organizational BIM maturity within a project organization?

Following on from the previous insights, the study aimed to explore strategies that project managers use to deal with variations in the maturity of project partners. The analysis of interview data revealed that these strategies influenced how the BIM maturity of the project was established in relation to the maturity of partnering organizations. First, the project management set BIM-related ambitions for the project that all partners would be able to meet. In this way, they aimed to avoid a potential negative impact from an immature partner: as such maturity variations among partners had little to no effect. A second strategy the study came across in two of the cases, was to minimize interactions with the least mature partners. By allocating only relatively simple BIM tasks to these partners, and by establishing tailor-made agreements on, for example, the delivery of BIM data, negative impacts of their low maturity levels were avoided. Third, the use of dedicated training programs and well-structured BIM support allowed one project to exceed the organizational maturities of all the involved parties. With this approach, the project could benefit from an increasing BIM capability of all the partners during its course.

To conclude, this study showed that project management, provided they are sufficiently aware of the BIM maturity of partners, could deploy strategies that prevent potential negative consequences from variations in the BIM maturity of project partners, or can have a crucial role in deliberately building collective maturity.

6.1.4 Variations in Team Mental Models of BIM use in projects

RQ4a: What variations in project participants' mental models of BIM use are present within the cases studied?

Many construction projects suffer from the industry's fragmentation in terms of working in silos, unclear task division, or missing information. To perform well, projects need well-coordinated tasks and a shared understanding of the team's work, also referred to as a Team Mental Model. The body of knowledge on Team Mental Models in construction contexts is very limited, particularly in relation to inter-organizational BIM use. Chapter 5 therefore set out to explore variations in Team Mental Models in terms of BIM use in four construction projects through a multiple-case study. First, the study discerned four Team Mental Model variables that are relevant to build a shared understanding of the team's work and task concerning the use of BIM in a construction project: shared understandings of BIM project maturity, of BIM-related goals, of BIM-related conditions for success, and consensus on BIM use. The findings showed that, in general, most project partners had similar mental models of BIM use within a project, albeit the exception of one or two parties. These parties, mostly supplying firms in the cases studied, appeared to operate at a distance from the core of the project team. They had a limited and demarcated scope in their involvement in BIM tasks and were less aware of inter-organizational agreements. Moreover, the benefits from and uses of BIM differed in these more distant parties. Proximity theory provided explanations for these findings: Team Mental Model perception scores were lower for parties that were at greater geographical, operational, or technological distances. Further, the study showed that parties at the center of the project organization, i.e., those responsible for setting the BIM approach and accompanying plans, had more positive perceptions of the collaboration and use of BIM. However, these coordinating parties tended to rate the project in line with the plans for BIM on paper, rather than the situation in reality.

RQ4b: How do Team Mental Models of BIM use in the cases relate to the project outcomes?

The literature has linked effective collaboration and a high team performance to the extent to which team members have a shared understanding of the task at hand. Therefore, following on from the exploration of variations within the cases, the identified sharedness in mental models were related to project outcomes. To that end, four project outcome variables were defined: project BIM maturity, absence of BIM-related barriers, team performance, and team satisfaction. In terms of the relation between Team Mental Models and project outcomes, a positive

relationship was found between the variables consensus on BIM use (TMM) and a project's BIM maturity (project outcome). However, no significant relationships were found between the sharedness of mental models and other project outcome measures. The study was able to identify a few factors that influenced the relationships between Team Mental Models and project outcomes that could explain the absence of these expected relationships. First, a project that places only low demands on BIM use could enable a project team's partners to perceive good team performance and team satisfaction despite a lack of a shared mental model. Second, the collaborative approach adopted, either integrated or segregated, seemed to play an important role in the interaction and communication between parties, and this influenced project outcomes. Third, in one project, external factors caused delays and ongoing debates in the project team and diminishing belief in BIM as a value-adding approach. Fourth, a lack of BIM knowledge and competence in one partner could require additional efforts by other parties, introduce barriers to inter-organizational collaboration and, as such, affect project outcomes negatively.

6.2 Theoretical contributions

6

This section describes the main theoretical contributions of this thesis to the body of knowledge on BIM and BIM-maturity-related research.

6.2.1 Improved measurement of BIM maturity

Drawing on the strengths of existing BIM maturity models, this thesis provides an improved model to measure BIM maturity that can be applied in different subsectors of the construction industry, can be used on different levels of analysis (i.e. subsector, organization, project), and can account for both technological (Bew et al., 2008; National Institute of Building Sciences, 2012) and organizational aspects (Computer Integrated Construction Research Program, 2013) of BIM. This BIM maturity model has been well-grounded in the general literature on capability maturity (Software Engineering Institute, 2010) and supply chain management process maturity (Lockamy & McCormack, 2004), and was validated across various contexts and disciplines. As such, the new BIM maturity model built on previous literature that illustrated the key importance of managing people, in terms of organizational structure, culture, and roles, to get people to use technology (Liao & Ai Lin Teo, 2018). The organizational change processes required for BIM implementation generally depend as much on softer, people-related and

organizational aspects as they do on technical skills (Lines & Reddy Vardireddy, 2017). By assessing both the organizational and technological aspects of BIM, the new BIM maturity model is suitable for analyzing the extent to which organizations are able to leverage the potential of BIM. This importance of analyzing both organizational and technological aspects has also been addressed in Information Systems research (Alshaw, 2007). Further, the analysis of barriers to BIM implementation and use (Chapter 3) highlighted the need to incorporate softer BIM aspects related to people and culture as an essential part of the model. Finally, clearly defining maturity levels in the BIM maturity model allows one to distinguish conditions with which to rank organizations, an aspect emphasized by Liang et al. (2016). Producing consistent results in this way is essential for future research on BIM maturity, its influencing factors, and implications, and the developed instrument is able to produce comparative analyses of subsectors (as seen in Chapter 2), between organizations (as seen in Chapter 3), and between partners collaborating on projects (as seen in Chapters 4 and 5).

6.2.2 Understanding BIM maturity variations and their implications on different levels of analysis

The case studies in this thesis made use of the developed BIM maturity model to reveal variations in BIM maturity on different levels of analysis (i.e., subsector, organization, project). Variations in BIM maturity on the *organization level* are relevant to all chapters in the thesis but are specifically addressed in Chapter 3 illustrating variations across nine organizational units of an internationally operating construction firm. Here, it appeared that the level of BIM maturity is related to barriers encountered in BIM implementation and use. The presented framework, by mapping the barriers encountered, provided insight into the obstacles to BIM implementation met from the level of top management down to the operational project level. The broader literature on IT innovations in organizations argues that such a multi-level perspective is key to understanding the main stages of adoption (i.e., initiation, adoption decision, and implementation) (Pichlak, 2016). A further added value of the multi-level perspective is in its representation of the implementation process from the organization level down to the level of individual users (Hameed, Counsell, & Swift, 2012). Here, different actor activities can be distinguished from top management creating awareness and making decisions, to realizing real users' acceptance in projects (Pichlak, 2016). In particular, top management support is identified in the literature as one of the best predictors of IT adoption (Jeyaraj, Rottman, & Lacity, 2006). This thesis extends these insights to the context of organizational maturity and implementation of BIM, and we saw that only organizations with lower maturity levels appear to have

issues related to the extent of top management support. Elsewhere, organizations with higher levels of BIM maturity faced more barriers that relate to the external environment, i.e., immature partners or a lack of standards. These findings add to research in the field of supply chain management in indicating a shift from an internal process focus to an inter-company orientation with joint goals and benefits as the level of organizational maturity increases (Cohen & Roussel, 2013; Estampe, Lamouri, Paris, & Brahim-Djelloul, 2013; Lockamy & McCormack, 2004). In a BIM-related context, the effectiveness of information management and exchange improves as the maturity of a firm increases (van Lith, Voordijk, Castano, & Vos, 2015). Hence, a partner with a low BIM maturity on these aspects limits firms' ability to satisfactorily exchange information in inter-organizational BIM use.

Furthermore, the multi-level perspective of our case study shed light on the central role of middle management in BIM implementation, either facilitating, delaying, or redirecting strategic BIM initiatives (Tarakci et al., 2018; Wooldridge et al., 2008). Indeed, we saw that barriers to BIM implementation and use predominantly occurred on the middle-management level. The study also revealed that the level of BIM maturity had no effect on their predominance.

On the *subsector* level, this thesis reveals discipline-specific trends in BIM maturity and perspectives. Some subsectors, especially engineering firms and general contractors, put more effort into boosting BIM maturity because of their general belief in BIM as a value-adding approach for their work (Dainty et al., 2017). Conversely, many suppliers were lagging in terms of BIM maturity, and often expressed their concerns regarding the disproportionate efforts required for little benefit. In a broader perspective, the sectoral analysis in Chapter 2 underlines the importance of firms allocating sufficient resources to the adoption of BIM, where we saw that it was mostly larger general contractors or engineering firms that were in a position to do so (Benjaoran, 2009; Lönngren et al., 2010).

Next, this thesis brought the insights on organizational and sectoral variations in BIM maturity to the inter-organizational *project level*. Here, variations in maturity are to be expected as collaborating organizations have distinct interests, cultures, and strategic intentions (Ireland & Webb, 2007). In general, this reflects the complex and fragmented nature of the construction industry, the temporary character of project organizations, and the discipline-specific knowledge of parties involved (Edmondson & Nembhard, 2009; Van Der Vegt & Bunderson, 2005). Given the challenging project context, the typical BIM maturity levels of subsectors and the resulting variations in organizational maturity (Chapters 2 and 3), this

thesis further investigated the causes and effects of project-level variations in BIM maturity. In particular, the thesis contributes to unravelling how, in projects, the individual organizations' BIM maturities are transformed into a project-level BIM maturity. This extends the existing body of knowledge that has mainly examined the BIM maturity of individual organizations (e.g. Bew et al., 2008; Computer Integrated Construction Research Program, 2013) and the limited project-level studies (e.g. Chen et al., 2014; Kam et al., 2014). This thesis highlighted that simply averaging the various BIM maturity levels of project partners does not provide a reliable estimate of a project's overall BIM maturity. That is, a decoupling is present between the maturity levels of the project and of the individual organizations involved (Dubois & Gadde, 2002).

In an attempt to explain these variations, the presented multiple case study builds theory on how project managers can deal with maturity variations in project teams by illustrating strategies that managers used in the four cases. The outcomes drew on research on the influence that leaders in project teams have on how innovations are adopted, and how the project identity can be shaped to achieve objectives (Ozorhon, Abbott, & Aouad, 2014). One of the project management approaches identified is to set low BIM maturity ambitions that match the minimum project requirements and the capabilities of the least mature partners. This "minimal effort" approach has some resemblance to lean principles (Koskela, Howell, Ballard, & Tommelein, 2002). Indeed, according to some of our interviewees, working towards a higher level of BIM maturity was considered a waste of project team resources. Another of the cases, with a more ambitious approach, showed that project-level BIM maturity could exceed the maturity of all the individual organizations through structured BIM support and education programs. This project was also characterized by a strong cohesive attitude and awareness of the importance of developing skills together and sharing a mutual long-term orientation (Larsson et al., 1998). Here, project management had created a team spirit that enhanced the success of the project (Aronson, Shenhar, & Patanakul, 2013). In line with Bresnen, Goussevskaia, and Swan (2004), we saw that a strong project team identity is not only able to embed organizational knowledge and intentions at the project level, but that it can also be the foundation for new and more mature practices. As such, the study showed that explorative learning can lead to building project capability (Bartsch, Ebers, & Maurer, 2013; Brady & Davies, 2004), and added specific insights into the effects of individual project partners' BIM capabilities. As a final note, we saw that, in inter-organizational BIM use and knowledge creation, the absence of common data platforms proved to be a frequently occurring barrier to learning in terms of team knowledge creation and

sharing (Berente, Baxter, & Lyytinen, 2010). Rather, in the BIM practices studied, the shared data platforms seemed to function more as an enabler and driver of project-based learning, reflecting the digitalization progress being made in the industry.

Overall, the research reported in this thesis contributes to the wider body of knowledge by providing a multi-level perspective on digitalization developments in the construction industry through BIM implementation. BIM maturity has not been only considered in individual organizations, but with respect to the stages of implementation, influencing factors and project-level supply chain interdependencies.

6.2.3 Placing inter-organizational BIM use in a Team Mental Model perspective

This thesis has further addressed inter-organizational BIM use by adopting a team concept from the social sciences. In particular, we have drawn on the literature linked to Team Mental Models, viewed as a shared and organized understanding of the task in hand (Converse et al., 1993; Klimoski & Mohammed, 1994) that can lead to effective collaboration and high team performance (Cooke et al., 2003; DeChurch & Mesmer-Magnus, 2010; Druskat & Pescosolido, 2002; Fisher et al., 2012; Van den Bossche et al., 2011). Applying the Team Mental Model lens to BIM use is highly relevant because of the challenges in the construction industry stemming from the diversity and interdependence of the disciplines involved in inter-organizational projects (Bankvall et al., 2010; Oraee et al., 2019; Sydow & Braun, 2018). In addition, applying the TMM perspective to BIM use in Chapter 5 provides a novel context, responding to the call by Mohammed et al. (2010) to increase empirical evidence on the role of TMMs in various contexts.

Insights from the multiple case study showed that variations in the mental models of project partners could be explained through proximity theory (Knoben & Oerlemans, 2006). The rating scores by parties operating further from the center of a project team were lower for the Team Mental Model variables and project outcome variables. The fact that these parties did not engage in integrated collaboration at the project office, or in frequent team meetings, hindered interaction and the exchange of tacit knowledge between project members (Shaw & Gilly, 2000). In terms of Crossan, Lane, and White (1999), it was not possible for effective integration of knowledge through shared understanding and mutual adjustment at the group level of project members to take place. As a consequence, these more distant parties lacked insights into the agreements made for

collaborative BIM use, such as over allocated responsibilities, agreed procedures for data management, or available training options. In our study, the most distant parties tended to be supplying firms whose perspective on BIM use in the project was different to the other project participants (Dainty et al., 2017). This also corresponds to the insights from Chapter 2 on variations in subsector perspectives on BIM use.

Furthermore, the thesis contributes to the literature by highlighting factors that influenced the relationship between TMM and project team performance in the investigated cases. Although not addressed in the analysis, the literature suggests that some of the encountered factors that influence performance could be linked to team composition, e.g. heterogeneity and the demographic attributes of team members (Bell, Villado, Lukasik, Belau, & Briggs, 2011; Higgs, Plewnia, & Ploch, 2005; Mach & Baruch, 2015). Overall, the TMM-related insights gained within a BIM context begin to unravel how inter-organizational projects could invest in developing their Team Mental Model of BIM to promote satisfactory project outcomes.

6.3 Managerial contributions

The methods adopted and insights from this thesis have already proven useful in various real-world applications. Managerial contributions can be highlighted for different actors and on different levels of analysis. This section provides an overview of these practical contributions.

6.3.1 Actionable knowledge of the current BIM status of an organization

In essence, the developed BIM maturity model has provided a method that organizations can use to measure their current BIM status. The method covers a wide range of BIM aspects in the areas of strategy, organization and project structure, people and culture, IT, and data. As such, the maturity scores on these criteria provided by the model give hands-on information on the characteristics that are satisfied and those that are holding back the achievement of higher levels of maturity. Further, the explicit conditions for a given maturity level also show what conditions need to be met to increase BIM maturity. In this way, organizations, and in particular their experts, BIM managers, middle managers, or top managers, can use the BIM maturity model to set their ambition level for various aspects, prepare a roadmap for BIM, and deliberately work on improvements. As illustrated in Chapter 3, the in-depth analysis of a large

construction firm and its nine organizational units provided them with insights into the current BIM status of individual units as well as mutually comparable outcomes that guided them in setting new BIM goals and plans. Over a longer timescale, conducting BIM maturity assessments every year or so could reveal the growth in BIM maturity that an organization has achieved.

6.3.2 Supporting sectoral policies and measures

Alongside the value of the BIM maturity model for providing insights into a single organization, the scores can be used to compare one's own company with other organizations or to establish a benchmark for a given sector. The sectoral analysis in Chapter 2 provided insights into BIM maturity for both individual organizations and subsectors in the construction industry. The BIM maturity results for organizations in a particular subsector can help to identify general strengths and weaknesses in that subsector. From the sectoral analysis undertaken, it emerged that subsectors have different perspectives on BIM and different interests in using BIM. As such, with respect to multidisciplinary project-level collaboration, the outcomes showed that the disparities between subsectors in their BIM perspectives need to be reduced. At the very minimum, partners need to understand the perspectives of different subsectors. Sectoral associations could benefit from these insights by, for example, focusing on sector-wide standards or raising awareness of the value-adding features of BIM for their area of work.

6.3.3 Evaluating BIM maturity (alignment) in projects

Inter-organizational project organizations can benefit from BIM maturity analyses on the project level and for each of the individual partners collaborating in BIM. Chapter 4 showed the practical value of evaluating whether a partner is able to meet the desired BIM maturity level in a project. This was illustrated by the project manager in one of the investigated cases who said that, in the future, he would put more effort into evaluating the BIM readiness of consortium partners in order to avoid issues he had experienced with a project partner with limited maturity. Moreover, an assessment of project-level BIM maturity helped BIM managers and experts identify whether the ambitions for different aspects of BIM use were realistic. In addition, in one of the projects, the project team used the analysis of project BIM maturity as a basis for a discussion among partners about the BIM approach to adopt and mutual expectations. Here, as a follow-up action, education and training specifically purposed for the project team was put in place to overcome competence deficits. Alignment between the BIM capabilities of project partners and the BIM maturity of the project can also be realized by tuning the

BIM-related ambitions of the project or by steering project partners' involvement, as illustrated in strategies identified in this thesis.

6.3.4 Guiding strategic organizational initiatives

Most organizations in the studied cases considered BIM to be a radical shift in their way of working, rather than just a tool to be used by a few BIM experts. This shift included new function profiles and process descriptions. Thus, managements have started to realize that their entire organizations need to go through a process of change, leading to gradual adoption of more digitized working methods including BIM. Indeed, as shown in Chapter 3, barriers to BIM implementation can be found on all organizational levels, from top management down to the operational project level. Given this awareness, top managements were very much interested in the level of BIM maturity in their organization. In the large contractor firm studied, this information was not only used to compare the maturities of their organizational units, but also to make yearly strategic and operational plans. To support these plans, the outcomes of the BIM maturity model have been visualized in a radar chart, as shown in Figure 29. The radar chart shows at a glance the areas where BIM is already sufficiently mature and where it needs to be enhanced. It provides an immediate impression of the overall level of BIM maturity and can be used to plot both actual and targeted levels of maturity. As such, the radar charts have shown themselves to be a very effective means of communication between top management and middle management. These visualizations also helped to raise awareness of BIM and present current maturity assessment outcomes in an understandable way to a broader audience within the organization. That is, it made it easier for non-experts to grasp the essence of BIM and its implications for working practices.

Figure 29. BIM maturity radar chart showing both actual and targeted levels for each of the model's 18 criteria.

6.3.5 Unravelling shared understandings on project-level BIM use

Complementary to the conducted BIM maturity analyses at the project level and of the individual partnering organizations, the case study in Chapter 5 provided project teams with insights into the sharedness of their understandings of BIM use. Insights first involved assessing the degree of alignment in BIM perspectives for the project. In other words, what are the basic intentions in using BIM in the project? Moreover, the analysis showed the extent of a shared understanding of

BIM goals, conditions for success, and consensus on BIM use. The discussions with project management providing feedback on the study findings gave them information on whether parties had different views in terms of BIM goals etc. Often these variations could be traced back to the position of one of the partners or to a failure to communicate BIM goals in the project plans. The project managers, being responsible for drafting the BIM plans, appeared to be very interested in finding out about the dissemination of their plans across the whole project organization. In particular, they wanted to know whether the detailed information was absorbed by the subcontractors and suppliers, and whether they were all on the same page regarding the project's BIM use. Further, insights on project outcomes such as experienced barriers enabled the project team to recognize ongoing issues from the perspectives of all the parties. In everyday working, with constant time pressures, these differing perceptions of projects partners often remain implicit and therefore cannot be acted upon. Here, the presented results guided the teams in better engaging in BIM as a collective.

Although managers often deliberately choose to place some subcontractors and suppliers outside the main project organization (Chapter 4), a more cohesive approach is considered beneficial. Reducing the distance of these more remote partners to the core of the project team is expected to stimulate the consensus on BIM use and, as such, is likely to contribute, as shown in Chapter 5, to increased project maturity. Moreover, with the better integration of all relevant project partners, supply chain parties might feel more involved and more motivated to engage in efforts to improve knowledge and competences in BIM. As a consequence, the apparent gaps in BIM maturity between subsectors, as illustrated in Chapter 2, and variations in BIM maturity on the project level, as seen in Chapter 4, are likely to reduce.

6.4 Reflections on the methodology

The general methodology, visible in all aspects of this research, is a case study approach. Nevertheless, distinctions can be made on the specific applications of the case study approach in the various chapters. This section therefore reflects on the approaches and methods applied in each of the chapters.

Chapter 2 adopted an explorative case study approach to investigate the BIM maturity of various subsectors of the Dutch construction industry. This case study was a key component of the validation, implementation, and evaluation of the

developed BIM maturity model, designed following the cycle stages proposed by Wieringa (2014). The strength of this design methodology is in its iterative character, meaning that the stages of problem analysis, design, validation, implementation, and evaluation will be repeated based on new insights from the evaluation of the implementation. To satisfy the intended purposes of the design cycle stages, respondents from mostly leading firms in terms of BIM use were selected for the case study. Choosing such respondents, rather than a more representative sample of the industry, was justified for two main reasons. First, given that their own BIM usage would generally reflect higher levels of maturity, the contents and the procedures of the BIM maturity model could be tested more extensively than in organizations with only low levels of maturity. Second, these more knowledgeable respondents from leading firms would be better placed to reflect on the completeness of the BIM maturity model and could, in general, provide more information about obstacles they had come across during the implementation process. As such, in the choice of this sample, the richness of the data collected and the quality of the validation of the BIM maturity model prevailed. However, the drawback of studying only leading firms is the inability to gather a sound sector-wide image of the progress with BIM, including the many firms that make limited use of BIM or no use of BIM at all. As such, the case selection limits the generalizability of findings from the particular context of “relatively mature” firms to the construction industry as a whole. A step towards a more representative picture of the BIM maturity in the Dutch construction sector has been made by means of a second sectoral analysis, two years after the first study, in the Dutch construction industry. Based on the evaluation and subsequent refinements of the BIM maturity model, 105 organizations participated in an online survey on organizational BIM maturity. The results of this second sector analysis were published in a report for sectoral associations but have not been reworked into a scientific contribution for this thesis.

Next, in Chapter 3, an inductive approach was adopted to gain an in-depth understanding of barriers to BIM implementation and use on different organizational levels. The case study followed the methods proposed by Gioia et al. (2013) to achieve “qualitative rigor” in inductive research. To that end, the study involved in-depth interviews to gain insights into the types of barriers, their causes, and their consequences experienced by respondents working at different levels within the organization. The grounded nature of the approach, starting from respondent quotations, very much contributed to building theory that accounts for the complexity of BIM implementation from real actors’ perspectives. Indeed, the respondents argued that the adopted interview format gave them the opportunity

for an open discussion and in-depth reflection on all BIM-related matters. Looking back on the complete dataset of interviews, archival data, and observations of steering group meetings, we feel confident that saturation was achieved since at some point during the analysis no new barriers emerged.

Despite theoretical generalization, the case study approach in Chapter 3 fails to provide statistical evidence. The generalization is first limited by the choice to study nine organizational units from one large construction firm. The selection of the general contractor was justified by its central position in projects, providing insights into barriers that cross project phases and disciplines. However, although operating in diverse contexts of the construction industry, these nine cases could not be considered as mutually independent due to overarching corporate strategies and organizational structures. Further, all the investigated firms operated in the general contracting subsector, which limited the view on particular organizational barriers that other disciplines in the industry could face. Additional explorative research including different subsectors as well as quantitative research approaches will enable the identification of barriers to BIM implementation and use by a more representative sample. Moreover, the conducted analysis amounts to a snapshot of the current observed practice and therefore no definitive statements on causal relations can be drawn. Longitudinal research is needed to better understand how barriers affect the evolution of BIM maturity in organizations over time. For such a dynamic view, methods that account for the temporal order and sequence of steps in the implementation process are encouraged, such as the innovation process analysis by Van de Ven and Poole (1990) and qualitative process research by Berends and Deken (2021).

Subsequently, Chapter 4 adopted a multiple case study approach involving four construction projects that were using BIM in an inter-organizational setting. The study gained insights into the relation between the maturity of participating organizations and the maturity of the project as a whole by making use of the methodological steps proposed by Eisenhardt (Eisenhardt, 1989). A combination of both within-case and cross-case analyses supported in-depth understanding of the individual cases and the identification of cross-case differences and similarities. This approach proved very useful in illustrating the various strategies that project managers used to deal with maturity variations among a project's partners. In order to improve the reliability of the evidence gained from the multiple-case study, triangulation was used in various ways (Scandura & Williams, 2000). First, by means of data triangulation, multiple sources of evidence (interviews and project documentation) were used to determine the maturity of a project. Second, the use of both qualitative interviews and questionnaires, i.e.,

method triangulation, supported the strength of the evidence from the cases. Furthermore, the selection of project partners to be considered in the study deserves reflection. A limitation of the study is that only core project partners have been involved. Hence, this scope neglected the influence from other supply chain partners on inter-organizational use of BIM. As a consequence, the conducted multiple-case study could not grasp a complete image of BIM collaboration. Nevertheless, based on a kickoff meeting with the project manager, all project partners that actively exchanged BIM-related data and were most dependent on each other's work were selected. In doing so, the study attempted to cover the most influential maturity variations within the project organization. Additional evidence from future research is needed to determine whether the assumptions of limited third-party influence on the maturity of inter-organizational BIM use were justified.

For the final study in this thesis, a deliberate choice was made to adopt a perspective used in social science to widen the overall perspective on BIM use (Chapter 5). The chosen approach not only allowed a thorough understanding of the similarities and differences in the perspectives of project partners, but also improved explanations of the results found for project outcome variables. In the analysis process, the research team could make use of their different scientific backgrounds, rooted in both construction and social science. Discussing the results from different fields of expertise opened up avenues for additional analyses and provided a more varied interpretation of study outcomes. This gives confidence that the results of this and the other case studies in this thesis reflect an agreed interpretation across the research team, rather than a biased interpretation based on the personal characteristics of a single researcher. The exploration of TMMs in a BIM context also had some limitations. First, the literature did not provide a detailed conceptualization of a TMM for BIM use. Therefore, assumptions had to be made regarding aspects that are most relevant within the inter-organizational context in construction projects. Hence, the resulting research model might omit items relevant to include in a TMM for BIM use, for which more explorative research is recommended. Second, the assessment of project outcome variables introduced limitations as some of the variables are based on team member perceptions, i.e., team performance and team satisfaction. In particular, the assessment of team performance could benefit from a more objective assessment with quantitative measures for costs, time, and quality. This could reduce the apparent dependency of perceived project performance on project ambition. However, it should be noted that the complexity of the suggested approach will

require cases (projects) that are able and willing to share detailed data on such precise performance measures.

To summarize, case studies formed the general approach adopted in this thesis, but their application made use of different data collection and analysis techniques. The qualitative data collection methods used in the cases enhanced the richness of the data through gathering in-depth insights from real users and actors steering BIM use (Eisenhardt, 1989). This real-life context provided a deep understanding of the investigated variables, giving the ability to explore relationships between variables, including analysis of causes and effects (Yin, 2003). Moreover, understanding the contexts of the case studies enabled a comprehensive view of the use of BIM, i.e., the subsector characteristics in Chapter 2, the organizational context in Chapter 3, and inter-organizational project settings in Chapters 4 and 5. In this way, the case study approach supported theory building across these different levels of analysis. The following section will suggest future research directions that follow on from both the limitations of the case study method, such as the limited generalizability of the findings, and serve as a means to test and extend the insights presented in this thesis.

6.5 Future research directions

In general, the case studies in this thesis encourage future research to extend the empirical evidence for the propositions made in each of the chapters and, in a broader sense, to elaborate further on the adopted multi-level perspective. Below, some specific suggestions for future research are offered.

First, this thesis presented the development and testing of a BIM maturity model in a sectoral analysis of the Dutch construction industry (Chapter 2). Following this sector-wide application, a recommendation is made for longitudinal studies that address the progress made in the industry over time. This would add to existing longitudinal studies in specific countries or for specific disciplines (Gurevich & Sacks, 2020; Samuelson & Björk, 2014). In addition to providing longitudinal insights, a continuation of the BIM maturity assessment would stimulate efforts to ensure the appropriateness of the model in the future through new iterations of the design cycle.

Second, the case study on barriers to BIM implementation and use in Chapter 3 pointed towards the key role of middle management in overcoming barriers between different organizational levels. Previous studies have already highlighted

the central position of middle management in various organizational processes (Wooldridge et al., 2008), and also addressed the need to investigate the middle-management level in the specific context of construction (Tarakci et al., 2018). In line with this, the outcomes from Chapter 3 suggest addressing middle management in more detail in future research within the context of BIM implementation. It would be particularly interesting to extend the body of knowledge on the role these middle managers play in transferring BIM-related knowledge and experiences from one project to another.

Third, the multiple case study reported in Chapter 4 identified some strategies that project management could adopt to cope with variations in the BIM maturities of project partners. Given the novelty of considering BIM maturity variations on the project level, a major recommendation is to apply a similar research approach to different construction contexts in order to further reveal strategies employed. More evidence could support or extend the observations made in this study, such as those concerning dealing with a lack of maturity of some project partners, or enhancing learning as a project team to improve BIM maturity. The latter particularly suggests linking BIM use in construction projects to concepts found in workplace learning and continuous learning (Malloch, Cairns, Evans, & O'Connor, 2011; Sessa & London, 2006).

Furthermore, future research could usefully investigate how BIM maturity growth in projects is transferred back to the organization level, a subject studied in the literature on project-based versus organizational learning (Bartsch et al., 2013). Indeed, this institutionalization, from group learning to organizational learning (Crossan et al., 1999), is an important mechanism for increasing the maturity of an organization. However, previous research has also shown that organizational learning is only occasionally successful (Swan, Scarbrough, & Newell, 2010). A suggestion for future research is therefore to investigate how project-based learning and maturity growth can effectively be institutionalized in higher organizational maturity.

In the TMM study in Chapter 5, we saw that the body of knowledge on TMMs in inter-organizational contexts is limited. The exploration of TMMs in the context of BIM use in construction projects should be regarded as a first step to developing theory in this particular field. Results from our study suggest that the specific characteristics of the construction industry (Dubois & Gadde, 2002; Sydow & Braun, 2018) may introduce factors that change the relationship between TMMs and team performance. Consequently, a recommendation for future research is to increase the evidence for factors that influence the relation between TMMs and

project performance. In particular, it would be valuable to know whether either the sharedness of mental models or the performance of projects is disproportionately affected by influencing factors.

The study in Chapter 5 showed a positive correlation between consensus on BIM use and project-level BIM maturity, which resonates with the theory on the relation between TMMs and team performance (e.g. DeChurch & Mesmer-Magnus, 2010; Van den Bossche et al., 2011). An interesting follow-up study would be to see whether project maturity can be increased by actively steering the consensus on BIM use among project partners. This could for example be studied in an experimental setting in which interventions are carried out to influence consensus on BIM use.

I would like to conclude this thesis with a personal note on future developments in the field of BIM use. The industry has already shown a transformation from a limited BIM scope that focused on the advantages of designing in 3D, to a multidisciplinary approach with diverse uses in all the lifecycle stages of a project. The future is expected to see the introduction of wider technological developments with the large-scale implementation of, for example, cloud and mobile technology, robotization, augmented reality and the Internet of Things. These technological advancements will further intensify data exchange between disciplines, but may also ease or automate data exchange processes between disciplines. For that reason, one may question whether current obstacles to successful digitalized collaboration will become more severe or will diminish. Moreover, technological advancements and accompanying changes of data usage and exchange are also expected to lead to different maturity demands in an inter-organizational context. Given this dynamic context, studying variations in maturity in a multi-level perspective will surely remain a research topic of interest.

SUMMARY

SAMENVATTING

Summary

For a decade or so, digitalization in the construction industry has been driven through the adoption of Building Information Modelling (BIM). BIM can be considered as an object-based, multidisciplinary approach that aims to facilitate collaboration between parties and to integrate object-related information over the entire life cycle of an asset in a digital model. Generally considered as an essential part of BIM is that it captures building objects as 3D representations. The use of BIM in the construction industry is seen as an approach that can enhance productivity and significantly reduce costs. To date, however, the expected benefits of BIM have not always been realized, mainly because of challenges related to inter-organizational collaboration. Some partners make use of BIM in a professional manner, while others do not or have only just taken their first steps towards its implementation. That is, organizations in the construction industry show variations in their levels of BIM maturity.

This PhD thesis shows the relevance of insights into BIM maturity variations on different levels of analysis: subsector, organization, and project. Inter-organization collaboration involves organizations from different subsectors, with specific scopes and interests in BIM use, working together on the project level. It is therefore argued that the subsector, organization, and project levels of analysis should be seen as interdependent. Following from this, the objective of the thesis is to disentangle and explain variations in BIM maturity and their effects on the implementation and use of BIM on different levels of analysis in the construction industry. Given the explorative nature of the research, the context-specific complexities of the construction industry, and BIM maturity variations in particular, case studies form the core research approach of this study. Various data collection and data analysis techniques are applied for the different topics in this thesis. First, Chapter 2 presents an explorative case study that aims to implement and test a newly developed BIM maturity model in a large number of firms representing different subsectors of the construction industry. This model is then applied in Chapter 3 in an in-depth organization-level analysis linking BIM maturity levels to barriers to BIM implementation and use. Following this, Chapters 4 and 5 focus on inter-organizational BIM use on the project level. Chapter 4 explores how the maturities of individual project partners relate to the maturity of the project as a whole. Finally, Chapter 5 adopts the broader perspective of Team Mental Models to consider BIM use in projects, aiming to reveal how BIM-related project outcomes relate to shared understandings of a

team's aims and tasks in using BIM. The main findings from each of the chapters are summarized below.

Chapter 2 develops a method to evaluate the BIM maturity of organizations that is applicable to different subsectors and incorporates both organizational and technological aspects of BIM. In doing so, it builds on the strengths of existing BIM maturity models, maturity models related to capability maturity and to supply chain maturity. The developed BIM maturity model is then validated through a sectoral analysis of leading firms in terms of BIM use within the Dutch construction industry. This explorative case study first provides an understanding of maturity differences between subsectors: general contractors and engineering firms scored relatively highly on BIM maturity, whereas supplying firms could often be characterized by lagging maturity levels. Interviews with respondents from different subsectors revealed subsector-specific perspectives on BIM use and the many barriers that organizations encounter in adopting BIM. The latter gave rise to an in-depth analysis of barriers to BIM implementation and use in Chapter 3. Moreover, experiences from the implementation of the model and feedback from respondents are used to evaluate the appropriateness of the developed BIM maturity model and its accompanying data collection methods. Based on this, the chapter identified aspects where the BIM maturity model needed to be improved prior to its further application.

Chapter 3 adopts an organizational perspective to gain a deeper understanding of barriers to BIM implementation and use. The multiple case study of nine organizational units within a large construction firm uses the Gioia methodology to develop a grounded framework for barriers mapped on to various organizational levels: from top management, through middle management, down to the operational project level. In this way, the study set out to provide actionable knowledge that organizations could use to grow their BIM maturity by better understanding barriers that hinder the implementation of BIM on various organizational levels. The findings reveal that organizations with relatively low BIM maturity tend to have internally oriented barriers and were the only organizations in the case study where BIM appeared to lack top management support. The organizations with higher BIM maturity levels tended to face externally oriented barriers. They generally raised concerns about the limited BIM level of partners and inadequate sectoral standards. In all organizations, barriers on the middle-management level seemed to be crucial in terms of disseminating BIM both within and across projects.

Given the inter-organizational collaboration of parties representing different subsectors, it is on the level of projects that variations in BIM maturity on different levels of analysis come together. In addressing this project level of analysis, Chapter 4 provides insights into variations in organizational BIM maturity in relation to project-level maturity. Here, previous research had focused on methods to assess BIM maturity on the organization level or on the project level but failed to address how these two levels relate. To address this, this chapter presents a multiple case study of four projects from the Dutch and Belgian construction industry. The findings reveal that the BIM maturity level of a project could not be simply determined by averaging the maturities of individual organizations: the study encountered cases where the project maturity level was either below or above the average of partnering organizations. In seeking to explain these variations, the study also found that project management employs various strategies to deal with partners' BIM maturity variations. In one case, they set low ambitions for BIM, such that all partners could match that level and satisfy the minimal project requirements. In two other cases, the project managements limited interaction with the least mature partners to minimize negative effects of their lack of BIM maturity. Finally, in one project, the project management aimed for, and achieved, a maturity level that exceeded that of the individual organizations through offering structured BIM support and a dedicated training program.

In addition to analyzing variations in BIM maturity in subsectors, organizations, and projects, Chapter 5 adopted a novel perspective to inter-organizational BIM use. As in the previous chapter, the study focuses on the level of projects, but here adopts the lens of Team Mental Models in the particular context of a project's BIM use. The literature relates a team's mental model, its shared and organized understanding of a task, to its effective collaboration and performance. The challenges stemming from the typical fragmentation seen in the construction industry emphasize the relevance of exploring whether the degree of sharedness in team members' mental models of BIM contribute to project outcomes. To that end, the multiple-case study discerns different Team Mental Model variables (X, Y, Z) and links these to different project outcome variables (A, B, C). The study shows that variations in the mental models of project team members can generally be attributed to parties operating at a greater distance from the core of the project team. This is in line with proximity theory: the distantly operating parties lack physical interaction at a project office and their knowledge related to BIM can diverge. Consequently, these parties often lack understanding of intentions or agreements related to the project's BIM use. Furthermore, the case study supports

studies in other fields regarding a significant positive relationship between consensus on BIM use and the BIM maturity of the project. For other investigated relations, the study points towards factors that might explain the lack of a positive relationship between the sharedness in the team's mental models and project outcomes. These factors were characterized as the low project demands for BIM, the absence of a collaborative approach, disturbing external factors such as building permits, and a partner's lack of knowledge or competence.

The final chapter of the thesis concludes the research by answering the research questions, discussing the scientific and practical contributions, and by reflecting on the methodology. Furthermore, Chapter 6 proposes directions for future research that address some of the main limitations of the adopted case study approach and would extend testing of the generated research output. In brief, this PhD thesis reveals the interactions of variations in BIM maturity on different levels of analysis. First, it provides an improved method for evaluating BIM maturity variations and generating consistent and mutually comparable outcomes on the levels of subsectors, organizations, and projects. Here, the BIM maturity of an organization is not analyzed in isolation but within a multi-level perspective. The gathered insights into variations in BIM maturity levels shed light on the various stages of implementation and the associated barriers, and impacts of variations in inter-organizational projects. These insights contribute to the literature on BIM, but also elaborate on the more general theory related to the construction industry's fragmentation, its consequences, and ways of overcoming related obstacles. In concluding the research, the application of the Team Mental Model approach begun to explore how building a shared understanding of BIM use in projects could contribute to a team's performance. As such, the insights can serve as a guide for promoting the further professionalization of inter-organizational BIM use and can be extended regarding future BIM uses and other upcoming digitization developments in the industry.

Samenvatting

Sinds ruim een decennium is de adoptie van BIM (Building Information Modelling of in het Nederlands vertaald naar Bouwwerk Informatie Modellerings) de belangrijkste aanjager van de digitalisering in de bouwsector. BIM kan worden gekarakteriseerd als een objectgerichte, multidisciplinaire aanpak om de samenwerking tussen partijen te faciliteren door middel van de integratie van object-gerelateerde data over de gehele levenscyclus van een bouwproject in één digitaal model. Een belangrijk onderdeel van BIM is dat bouwobjecten doorgaans worden weergegeven via een 3D-representatie. Het gebruik van BIM wordt in het algemeen gezien als een aanpak die de productiviteit kan verhogen en tot een aanzienlijke kostenreductie leidt. Echter, tot op heden worden de verwachte voordelen van BIM in de praktijk niet altijd gerealiseerd. De uitdagingen die behoren bij de samenwerking tussen diverse organisaties vormen hiervoor een belangrijke oorzaak. Het blijkt dat sommige organisaties BIM op een professionele wijze toepassen, terwijl anderen daarin tekortschieten aangezien zij slechts de eerste stappen hebben gezet in BIM-gebruik. Met andere woorden, organisaties in de bouwsector worden gekenmerkt door variaties in hun BIM-volwassenheid (BIM maturity).

Dit proefschrift laat de relevantie zien van het verkrijgen van inzicht in variaties van BIM maturity op verschillende analyseniveaus: deelsectoren, organisaties en projecten. Samenwerking tussen partijen op projectniveau vindt namelijk plaats tussen medewerkers van individuele organisaties vanuit diverse deelsectoren van de bouw, ieder met een specifieke scope en een eigen motivatie voor het gebruik van BIM. Het is daarom van belang om deze analyseniveaus (deelsector, organisatie en project) in hun onderlinge afhankelijkheid te beschouwen. De hieruit afgeleide doelstelling van dit proefschrift is het ontrafelen en verklaren van variaties in BIM maturity en de daaruit volgende effecten op de implementatie en het gebruik van BIM op verschillende analyseniveaus. Hierbij vormen casestudies de centrale onderzoeks aanpak, ingegeven door de exploratieve aard van het onderzoek, de context-specifieke complexiteit van de bouwsector en van BIM maturity variaties in het bijzonder. Binnen deze casestudie-aanpak zijn diverse technieken voor dataverzameling en -analyse toegepast. Op basis van een exploratieve casestudie gaat hoofdstuk 2 in op het implementeren en testen van een nieuw ontwikkeld BIM maturity model binnen een groot aantal bedrijven vanuit diverse deelsectoren van de bouw. Dit BIM maturity model wordt vervolgens binnen hoofdstuk 3 toegepast op organisatieniveau om diepgaande

inzichten te vergaren over de relatie tussen BIM maturity niveaus enerzijds en barrières bij de invoering en het gebruik van BIM anderzijds. In hoofdstuk 4 en 5 staat de samenwerking tussen partijen op projectniveau centraal. Hoofdstuk 4 stelt ten doel te verkennen hoe de BIM maturity van een project zich verhoudt tot de BIM maturity van partijen binnen de projectorganisatie. In hoofdstuk 5 wordt BIM beschouwd vanuit het perspectief van een gezamenlijk gedeeld beeld onder projectleden en partijen over BIM-gebruik in het project. Deze verkenning van zogenaamde Team Mental Models (mentale modellen) binnen de BIM-context heeft als doel inzicht te verschaffen in de relatie van de gedeeldheid van deze Team Mental Models met de uitkomsten van het project. Hieronder worden de belangrijkste bevindingen uit ieder hoofdstuk nader toegelicht.

In hoofdstuk 2 is een BIM maturity model ontwikkeld waarmee analyses van BIM maturity op organisatieniveau kunnen worden uitgevoerd, en dat tevens toepasbaar is binnen de diverse deelsectoren van de bouwsector. Bovendien zijn binnen het BIM maturity model zowel organisatorische als technologische aspecten van BIM opgenomen. De ontwikkeling van het model bouwt voort op de sterke punten van een breed scala aan bestaande modellen: van maturity modellen die specifiek focussen op (aspecten van) BIM maturity tot modellen die gericht zijn op de maturity van competenties of maturity van processen binnen de bouwketen. Het ontwikkelde BIM maturity model is vervolgens gevalideerd middels een sectoranalyse van partijen die relatief gezien vooroplopen ten aanzien van het BIM-gebruik. Deze exploratieve casestudie in de Nederlandse bouwsector geeft inzicht in de verschillen tussen deelsectoren. Zo zijn het in deze analyse doorgaans de bouwbedrijven en ingenieursbureaus die relatief hoge BIM maturity niveaus laten zien, terwijl toeleverende partijen daarbij achterblijven. Naast inzicht in verschillende maturity niveaus, heeft de sectoranalyse inzichten verschaft in de specifieke perspectieven van deelsectoren op BIM-gebruik en het grote aantal barrières dat wordt ervaren bij de invoering en het gebruik van BIM. Dit laatste gaf aanleiding om diepgaander onderzoek te doen naar barrières in hoofdstuk 3. Al met al heeft de sectorbrede toepassing van het BIM maturity model bijgedragen aan de doorontwikkeling van het BIM maturity model. Hiertoe zijn de ervaringen met het gebruik en de feedback van respondenten tijdens de interviews grondig geëvalueerd. Het aangescherpte BIM maturity model is daarmee geschikt bevonden voor verdere toepassing.

In hoofdstuk 3 wordt een organisatieperspectief gehanteerd om diepgaand inzicht te verkrijgen in barrières ten aanzien van de implementatie en het gebruik van BIM. Om deze reden is een meervoudige casestudie uitgevoerd binnen negen bedrijfsonderdelen die behoren tot een grote, internationaal opererende

aannemer. Hierbij is de Gioia-methode toegepast om een inductief schema te ontwikkelen waarin de barrières worden weergegeven op de organisatorische niveaus waarop barrières spelen, dan wel invloed hebben (van topmanagement, tot middenmanagement en het niveau van projecten). De bevindingen laten zien dat organisaties met een relatief lage BIM maturity voornamelijk te kampen hebben met intern-georiënteerde barrières: van de onderzochte bedrijven zijn zij de enigen met een gebrek aan ervaren ondersteuning vanuit topmanagement. Daarnaast laat de studie zien dat de bedrijven met een relatief hoge BIM maturity grotere problemen ondervinden ten aanzien van de externe omgeving. Dat wil zeggen dat zij vaker een gebrekkige BIM maturity van andere partijen en een gebrek aan sectorbrede standaarden voor BIM-gebruik als barrières benoemen. Voor alle onderzochte cases geldt echter de cruciale rol van barrières die spelen op het niveau van het middenmanagement. Dit niveau blijkt een bepalende positie in te nemen bij de mate van invoering van BIM binnen projecten en de verdere uitrol richting andere projecten. Middels deze studie is toepasbare kennis ontwikkeld die bedrijven met een bepaalde BIM maturity handvatten biedt om barrières op verschillende niveaus in de organisatie te herkennen, weg te nemen of te voorkomen.

Variaties in BIM maturity tussen deelsectoren en organisaties komen samen op het niveau van projecten. Hoofdstuk 4 beschouwt daarom de multidisciplinaire samenwerking tussen partijen binnen projecten, waarbij nieuwe inzichten zijn verkregen over de variaties in organisatorische maturity ten opzichte van de maturity van een project. In voorgaand onderzoek is deze relatie onderbelicht gebleven, omdat maturity modellen zich tot op heden richtten op ofwel de meting van organisatorische BIM maturity, ofwel de meting van BIM-maturity op projectniveau. De meervoudige casestudie in hoofdstuk 4 onderzocht daartoe de aanwezige variaties in organisatorische BIM maturity binnen vier projecten uit de Nederlandse en Belgische bouwsector en relateert deze variaties aan de BIM maturity van het project. De uitkomsten tonen dat de BIM maturity van het project niet eenvoudig kan worden voorgesteld als een gemiddelde van de BIM maturity van deelnemende partijen in het project. De casestudie stuitte namelijk op maturity niveaus van projecten die lager, gelijkwaardig of aanmerkelijk hoger zijn dan het gemiddelde van de betrokken organisaties. In een poging om deze verschillende relaties te verklaren, geeft de studie inzicht in strategieën die het management van een project hanteert om in te spelen op variaties in maturity tussen partijen. Eén van de strategieën is om de BIM maturity waarop het project functioneert zodanig te verlagen dat alle organisaties voldoende volwassenheid hebben om hierin mee te gaan en gelijktijdig ook aan de minimale eisen van het

project wordt voldaan. Een tweede strategie is om partijen met een relatief lage BIM maturity bewust buiten intensieve BIM-samenwerking te plaatsen, waardoor hun mogelijk negatieve invloed op de BIM maturity van het project wordt voorkomen. De studie liet daarnaast een derde strategie zien waarbij de inzet van zowel een trainingsprogramma voor BIM als een gestructureerde ondersteuning bij BIM-gebruik de projectorganisatie in staat stelt om een maturity op projectniveau te behalen die het niveau van alle individuele organisaties overstijgt.

Naast de analyses van BIM maturity variaties binnen deelsectoren, organisaties en projecten, wordt in hoofdstuk 5 met een vernieuwend perspectief naar multidisciplinaire BIM-samenwerking tussen partijen gekeken. Evenals voorgaand hoofdstuk gaat het daarbij om een studie op projectniveau, maar wordt ditmaal de Team Mental Model benadering toegepast binnen de context van BIM-gebruik in projecten. Een Team Mental Model, voorgesteld als een onderling gedeeld begrip van de taken en doelen in een team, wordt in de bestaande literatuur veelvuldig gerelateerd aan de effectiviteit van samenwerking en prestaties van een team. Het belang van het Team Mental Model perspectief binnen de bouwcontext wordt benadrukt door een aantal karakteristieke uitdagingen in de bouw, waaronder de sterke fragmentatie tussen disciplines en fasen in een project. Daarbij is het de vraag of een sterkere mate van een gedeeld begrip van het BIM-gebruik onder teamleden en partijen bijdraagt aan de prestaties van het project. Daartoe zijn in een meervoudige casestudie verschillende Team Mental Model variabelen gemeten (X, Y, Z) en die zijn gekoppeld aan verschillende uitkomstmaten (A, B, C). De resultaten laten zien dat de relatief sterke afwijkingen in mentale modellen van teamleden voornamelijk konden worden toegeschreven aan de partijen die een grotere afstand hebben tot de kern van het projectteam. Deze partijen hadden minder directe en fysieke interactie met andere partijen in het project en hadden bovendien een meer afwijkende kennisbasis ten aanzien van BIM. In de duiding van deze bevindingen worden verklaringen gezocht vanuit de proximity theorie. Verder tonen de uitkomsten, in lijn met literatuur uit andere contexten, een significante positieve relatie tussen de consensus over BIM-samenwerking in het team en de BIM maturity van het project. De casestudie heeft daarnaast factoren geïdentificeerd die mogelijk het gebrek aan positief effect van gedeelde mentale modellen op de andere onderzochte projectuitkomst-variabelen verklaren. Deze factoren zijn getypeerd als: de lage eisen ten aanzien van BIM in het project, de afwezigheid van een integrale samenwerking, versturende externe factoren, en een gebrekkige kennis en ervaring van één van de partijen.

In het afsluitende hoofdstuk van dit proefschrift worden de bevindingen uit voorgaande hoofdstukken samengebracht via de beantwoording van de

onderzoeksvragen, de discussie van wetenschappelijke en praktische bijdragen, alsmede een reflectie op de gehanteerde methodologie. Hoofdstuk 6 sluit af met aanbevelingen voor toekomstig onderzoek, waarin tekortkomingen van de casestudie benadering worden geadresseerd en waarmee de ontwikkelde theorie kan worden getoetst en uitgebreid. Samengevat heeft dit proefschrift nieuwe inzichten vergaard over verklaringen en effecten van BIM maturity variaties op verschillende analyseniveaus (deelsector, organisatie, project). In de eerste plaats is hiertoe een BIM maturity model ontwikkeld waarmee consistente en onderling vergelijkbare resultaten kunnen worden gegenereerd om dergelijke variaties in BIM maturity in kaart te brengen. De BIM maturity van organisaties is dus niet afzonderlijk beschouwd, maar in relatie tot meerdere analyseniveaus die van toepassing zijn op de bouwsector. De daarbij verkregen inzichten in verschillende BIM maturity niveaus hebben verduidelijking gegeven ten aanzien van voorkomende barrières in verschillende volwassenheidsstadia van de implementatie van BIM, en op de impact van verschillende BIM maturity niveaus binnen multidisciplinaire samenwerking tussen partijen in projecten. De inzichten uit het proefschrift leveren daarmee een bijdrage aan specifieke literatuur op BIM-gebied, maar bouwen tevens voort op meer generieke literatuur die ingaat op de fragmentatie in de bouw, de bijkomende gevolgen en de wijze waarop hiermee kan worden omgegaan. Tot slot heeft de Team Mental Model benadering voor BIM-gebruik in projecten een startschot gegeven voor verdere exploratie over de rol van een gezamenlijk gedeeld beeld over BIM-gebruik in het project in relatie tot de prestaties van het project. Daarmee dienen de inzichten als een handvat om verdere professionalisering van multidisciplinaire BIM-samenwerking tussen partijen te bevorderen. In de toekomst kunnen de verkregen inzichten worden uitgebreid in relatie tot nieuwe toepassingen van BIM of andere baanbrekende technologieën die tot verdere digitalisering in de bouw leiden.

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About the author

Sander Siebelink, born 1987 in Warnsveld, the Netherlands, has a master's degree in Civil Engineering and Management from the University of Twente. A specialization in Water Engineering and Management led to starting his career working on a large infrastructure project in which hydraulic structures were built to protect the surrounding area against flooding. With this practical experience in project and information management under his belt, Sander subsequently returned to academia in 2014, where he started researching BIM maturity. From that moment on, he was captivated by the digital transformation in the construction industry involving both technological and organizational perspectives. His pursuit of this comprehensive view stems from a particular interest in the interface and interdependence of technological potential and the complexity of real-world applications. The development of a BIM maturity model for the Dutch construction industry initially provided insights into progress and mutual variations for sectoral associations. Based on this design-oriented research, Sander graduated with a Professional Doctorate in Engineering at the University of Twente in 2017. Building on this foundation, a PhD project extended the research perspective towards the organizational and project levels through case studies at Royal BAM Group, a large construction company. BIM developments in their Dutch and western European business units have been investigated in close collaboration with their digital construction team. The resultant maturity assessments contributed to hands-on recommendations for project teams, and also aided middle and senior management in analyzing the actual status, setting tangible goals, and guiding strategic planning. In addition to the aforementioned research activities, Sander is very much interested in management and governance within the university. Parallel to the research role, he has worked as a program coordinator for the bachelor's and master's programs in civil engineering and has been a member of the Faculty of Engineering Technology's council.

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Although the adoption of Building Information Modelling (BIM) has driven digitalization in the construction industry for more than a decade, not all organizations are equally mature in its use. This dissertation disentangles and explains variations in BIM maturity and their effects on the implementation and use of BIM on the sector, organization, and project levels of analysis. The gathered insights shine a light on the various stages of implementation, and the associated barriers, and highlights the impacts of variations on inter-organizational projects. As such, this study can serve as a guide in promoting the further professionalization of inter-organizational BIM use.