Exploring the BIM adoption of public client organisations

A study of the German road infrastructure sector

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Summary

Building Information Modeling is transforming the architectural, engineering and construction industry worldwide. Although the potential value of BIM is becoming increasingly clear and the awareness and use of BIM is growing among actors, its widespread adoption is still hesitant. In order to increase the diffusion of BIM several countries, including Germany, have started to launch governmental initiatives that require public clients to demand BIM in public projects. Public clients are promoted as drivers for industrial change towards BIM, but yet little is known about BIM adoption of public clients on an organisation level. Hence, the aim of this study is to explore why and how public clients in the German road infrastructure sector adopt BIM and what driving forces and obstacles they face. In this way, the findings of this research contribute to gain a deeper understanding of BIM adoption of public clients and can help to develop measures to stimulate BIM adoption of public clients in the German road infrastructure sector, strengthening them in their potential role as drivers for industrial change towards BIM.

A cross-case study approach was applied, including 14 public client organisations of the German road infrastructure sector. Data was collected mainly through 15 interviews involving a total of 19 BIM representatives of the respective public client organisations. On the one hand, the current and expected future BIM adoption state of the public clients considered in relation to BIM experience, the frequency of BIM use and the extent of BIM use were investigated. On the other hand, the technology, organisation and environment framework with constructs from the diffusion of innovation theory and the unified BIM adoption taxonomy was used as theoretical lens for exploring the driving forces and obstacles of BIM adoption in the interviews.

First of all, this study revealed that all public clients considered have started to adopt BIM. However, a fragmentation could be identified. This fragmentation is characterised by a vast majority of public clients that show a reserved and late adoption behaviour and have only recently started to adopt BIM. Accordingly, most public clients have relatively little BIM experience and use BIM in a few projects. Only a few public clients could be identified that show a progressive and early adoption behaviour, and already have a certain degree of BIM experience, use BIM over a relatively long period of time and in several projects. The current share of BIM projects compared to traditionally executed projects among public clients is still low. Almost all public clients are in pilot use of BIM. In addition, the results indicated that BIM is used with a strong focus on civil structures and that the use of BIM for road structures is still low. The use of BIM is foremost limited to the inventory phase as well as the planning and design phase and the corresponding applications in the area of visualization possibilities, design coordination, clash-detection, quantity take-off and cost estimation as well as planning. The study showed that, despite an originally planned BIM mandate from the end of 2020 onwards, most public clients considered lack a clear and specific expectation of future BIM adoption and use for the next 1 to 2 years. However, the findings indicated that the frequency of BIM use of public clients is likely to increase in the next 1-2 years and that current main BIM use is expected to extend up to the construction phase, but use in the operation and maintenance phase will be the exception.

When considering driving forces and obstacles, this study identified the Federal Government's BIM initiative as the main reason and external impetus for BIM adoption among the public client organisations considered. Thereby, indicating that BIM adoption was not initiated solely on the basis of own initiative and was at least initially politically driven. The driving forces most frequently identified were (1) the Federal Government's BIM initiative, (1) testing BIM in pilot projects, (2) small

groups of highly committed employees, (3) the believe that BIM is more advantageous than traditional working methods and (4) a value-adding, supportive network. The obstacles most frequently identified were (1) the lack of BIM standards, (1) the high complexity of BIM, in particular in terms of the internal change process and the related additional expenditure of time required, (2) the lack of BIM expertise, (2) the lack of or inadequate personnel resources, (3) the lack of structural orientation of the organisation towards BIM and (4) the lack of major internal interest and demand. With regard to all identified driving forces and obstacles, the study revealed that the most frequently driving forces identified originate from the environment context and innovation and technology context. The most frequently obstacles originate from the organisation context. On the one hand, it becomes clear that external drivers are of great importance. On the other hand, it can be concluded that for most public clients the organisation context is the critical bottleneck for the adoption of BIM and the internal change process seems to be the major challenge. However, there are significant differences between the few progressive early adopters and the rest of the public clients considered, in terms of which driving forces are encountered and how many in total. This applies in particular to the organisation context.

Against this background, the study revealed that active support from state government may be one reason that explains the significant difference between the majority of public clients and the few progressive early adopters. Therefore, suggesting that active support from state government may be an important enabler for a higher BIM adoption state that positively influences the organisation context. In addition, this study found that the Federal Government's BIM initiative may not be as supportive and stimulating for public clients who lack driving forces and face many obstacles in the organisation context as it is for progressive early adopters. For many reserved public clients, the lack of detailed specifications by the Federal Government is perceived as an obstacle. Accordingly, in contrast to the progressive early adopters, who independently drive the adoption of BIM, a sluggish "actio reactio" adoption behaviour was observed among these clients, which tends to return the ball to the Federal Government and wait for detailed input and specifications before taking own next steps towards the adoption of BIM.

Based on the findings of this study three key recommendations can be made to promote and stimulate the adoption of BIM by public clients in the German road infrastructure sector. (1) Political bodies should overcome political fragmentation between federal and state level and accordingly extend the Federal Government's BIM initiative for federal projects to federal states and state projects. This would encourage state governments to play a more active role by showing that BIM has a certain priority on state level, by creating supportive environments for the BIM adoption of public client organisations, and by demanding BIM for state projects. (2) Policy makers should adapt the BIM initiative so that there is lower focus on exerting pressure and output-oriented targets in the sense of binding specifications and mandates, but rather a greater focus on showing the way to BIM adoption in order to enable public clients to drive BIM adoption themselves. This could be achieved by the development of measures in close collaboration with public clients which, on the one hand, activate the self-interest and motivation of public clients to adopt BIM and, on the other hand, actively support the adoption process enabling public clients to master the internal change process. (3) If practitioners in organisations of public clients or policy makers want to promote BIM adoption, an important focus should be on creating a supportive and enabling environment for dedicated employees within the organisations. Thereby, this study recommends to address the general shortage of personnel in order to give employees sufficient time to familiarise themselves with BIM, establishing or providing suitable BIM training programmes to generate BIM expertise and interest among the majority of employees, and aligning the organisational structure towards BIM by creating clear responsibilities for BIM adoption and capacities through specialised personnel with sufficient time and specialised departments.

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List of Abbreviations

AEC *Architecture, Engineering and Construction*

BEP *BIM Execution Plan*

BIM *Building Information Modeling*

BMVI *German Ministry of Transport and Digital Infrastructure*

EIR *Employer's Information Requirements*

HOAI *Honorarordnung für Architekten und Ingenieure*

ICT *Information Communication Technology*

DOI *Diffusion of Innovation*

IT *Institutional Theory*

NIBS *United States National Institute of Building Services*

TAM *Technology Acceptance Model*

TOE *Technology Organisation Environment*

TPB *Theory of Planned Behaviour*

TRA *Theory of Reasoned Action*

UBAT *Unified BIM Adoption Taxonomy*

UC *Use Case*

UK *United Kingdom*

UTAUT *Unified Theory of Acceptance and Use of Technology*

Chapter 1 Introduction

Building Information Modeling (BIM) is transforming the architectural, engineering and construction (AEC) industry worldwide (Azhar, 2011). As part of the desired digitalisation of the sector, BIM is presented as a way to address the perceived problems of internal fragmentation and slow productivity growth (Elmualim & Gilder, 2014). The efficient adoption and use of BIM can bring several benefits including faster and more efficient processes, better design and visualization, controlled life and environmental data, better production quality, automated assembly, better customer service, lifecycle data, integration of planning and implementation processes, an efficient and competitive industry, and much more (Chegu Badrinath & Hsieh, 2019). Building Information Modeling is seen as the opportunity to change the rigidity of the sector in its attitude to changes that have hindered the modernisation of the entire construction industry so far (Ahmed & Kassem, 2018). Within the sector, BIM is still perceived as the most widely discussed innovation and is now considered as a key factor in digital transformation, offering opportunities to introduce new paradigms in the built environment such as the Internet of Things, intelligent sensors, connectivity and large amounts of data to the construction sector (Ahmed & Kassem, 2018; Oesterreich & Teuteberg, 2016; Zhao, 2017).

However, while many studies have already indicated the potential value of BIM and the awareness as well as the use of BIM is increasing among actors in the construction industry, its widespread adoption is still hesitant (Lindblad & Guerrero, 2020; Smith, 2014). Against this background, the adoption of BIM in organisations is associated with a variety of challenges and difficulties, of which lack of client demand in the market is often perceived as one of the biggest barriers and obstacles from the perspective of companies (Borrmann, Lang, & Petzold, 2018; Bosch-Sijtsema, Isaksson, Lennartsson, & Linderoth, 2017; C. T. W. Chan, 2014; D. W. M. Chan, Olawumi, & Ho, 2019; Holzer, 2011). In order to increase the acceptance and adoption of BIM and to promote BIM diffusion in the respective markets, countries have started to launch governmental initiatives requiring public clients to demand BIM in public projects (Kassem & Succar, 2017).

Countries such as the United States, United Kingdom (UK), Singapore, Finland, Sweden and the Netherlands are pioneers in this field, where governments have already started early on to set up such BIM initiatives (Charef, Emmitt, Alaka, & Fouchal, 2019; Wong, Wong, & Nadeem, 2010). In the UK, for example, government authorities have defined that all public contracts from 2014 must require the use of BIM (CabinetOffice, 2011). According to international academic studies comparing the global BIM adoption levels, these early adopter countries have become the current leaders in BIM adoption and Germany is lagging behind (Borrmann et al., 2018; Charef et al., 2019; USPMarketingConsultancy, 2017). Most companies in the German AEC industry are still restrained to adopt BIM and struggle to implement BIM successfully in projects, especially in their German home market, and can therefore be classified as late or very late adopters (Borrmann et al., 2018; Galić et al., 2017; Packwitz, 2019; PwC, 2018).

With a delay compared to leading countries, the German Federal Government is now also actively promoting the transition to BIM-based workflows with the launch of a BIM initiative (Borrmann, Hochmuth, König, Liebich, & Singer, 2016; INFRABIM, 2018; PwC, 2018). This BIM initiative is based on a step-by-step plan published in 2015 by the German Federal Ministry of Transport and Digital Infrastructure (BMVI), which includes three successive phases and, from the end of 2020, prescribes

the mandatory use of BIM in all new public federal transport infrastructure projects in the area of responsibility of the BMVI (INFRABIM, 2018). Therefore, the German Federal Government hopes to bring about a cultural change and establish new standards beyond this sub-sector in the entire German construction industry (Borrmann et al., 2018; PwC, 2018).

Chapter 2 Research problem analysis

2.1 Problem statement

Previous research has identified the lack of client demand as a critical bottleneck for a widespread BIM adoption in the construction industry (Borrmann et al., 2018; Bosch-Sijtsema et al., 2017; C. T. W. Chan, 2014; D. W. M. Chan et al., 2019; Holzer, 2011). Against this background, client organisations are promoted as a necessary driver for the industry's shift towards an innovation like BIM (Porwal & Hewage, 2013; Tookey, Kulatunga, Kulatunga, Amaratunga, & Haigh, 2011). In this way, client organisations can exert particular influence on other actors involved in their construction projects by demanding changes in terms of new working practices or the implementation of the desired technology (Porwal & Hewage, 2013; Tookey et al., 2011).

This aspect is particularly emphasized in the context of the lagging German construction industry. The high fragmentation of the still traditionally shaped construction process in Germany into individual phases (conceptual design, detailed design, execution, operation), each of which is carried out by different companies, means that the industry's own drive to adopt and implement BIM is low, as the efficiency gains in the individual phases are not perceived as sufficient to justify the necessary investments. Consequently, the client should actually demand, control and support the use of BIM even more strongly in order to achieve the cross-phase quality improvement of construction projects in terms of schedule and cost certainty, from which he himself benefits most (Borrmann et al., 2018).

In this context, governments of countries, including Germany, are trying to activate public clients through initiatives by requiring BIM demand in public projects (Charef et al., 2019; Wong et al., 2010). However, recent research problematising this role revealed that for the successful promotion of BIM by public clients for an industry change, it is not sufficient to simply translate BIM directly to external actors by demanding BIM in public projects, but that public clients must also actively participate and support the implementation and use of BIM in projects. Consequently, the public clients first have to successfully adopt BIM internally within their organisations in order to take on this active role (Lindblad, 2016, 2019; Vass & Gustavsson, 2017).

In previous research there are a large number of existing studies examining the adoption of BIM on organisational level or assessing the implementation of BIM on project level. However, the focus so far has been almost exclusively on organisations such as contractors (Abubakar, Ibrahim, Kado, & Bala, 2014; Bosch-Sijtsema et al., 2017; T. Hartmann, Van Meerveld, Vossebeld, & Adriaanse, 2012), architects and designers (Ahuja, Jain, Sawhney, & Arif, 2016; C. T. W. Chan, 2014; Son, Lee, & Kim, 2015) or in industry and country context without focus on a specific addressed group (Ahuja, Sawhney, Jain, Arif, & Rakshit, 2020; Y. Cao, Zhang, McCabe, & Shahi, 2019; Gu & London, 2010; Kim, Park, & Chin, 2016; S. Liu, Xie, Tivendal, & Liu, 2015; Zakaria, Mohamed Ali, Haron, Ponting, & Abd. Hamid, 2014). In addition, recent literature shows an increased focus on small and medium-sized enterprises (Bosch-Sijtsema et al., 2017; Hong, Hammad, Sepasgozar, & Akbarnezhad, 2019; Hosseini et al., 2016; Saka, Chan, & Siu, 2020). There is still a lack of knowledge about BIM adoption of public client organisations. However, a deeper understanding of BIM adoption in public client organisations

can help to stimulate this adoption process and can contribute to strengthen the active role attributed to public clients in promoting BIM adoption for industrial change.

This problem particularly affects Germany, which is lagging behind internationally in terms of BIM adoption. In addition, the Federal Government's BIM initiative related to the upcoming BIM mandate for public clients prescribing BIM demand for infrastructure projects is still new in comparison to leading countries. Therefore, it can be observed that German public clients still struggle to adopt BIM and it seems questionable whether the defined goals of the Federal Government's BIM initiative can really be achieved and whether public clients can fulfil their role as drivers for change towards BIM in the German construction industry.

The investigation of these key issues therefore contributes firstly to closing the gap in scientific knowledge about BIM adoption of public client organisation in general and secondly contributes to promoting the currently struggling BIM adoption among public clients in the German infrastructure sector.

2.2 Research objective

As mentioned in the problem statement, recent research has shown that for the successful promotion of BIM by public clients in industry context, it is not enough to directly transfer BIM only to external actors by prescribing BIM in projects, but also the successful adoption of BIM in public client organisations, is necessary (Lindblad, 2016, 2019). Against this background, the problem motivating this study is the lack of knowledge about BIM adoption of public client organisations, with a special focus on struggling public clients in the German road infrastructure sector. Thus, this study aims to fill this gap by exploring the current state of BIM adoption, future expected state of BIM adoption and obstacles and driving forces for BIM adoption of public clients in the German road infrastructure sector. In this way, this research contributes to gain a deeper understanding of BIM adoption of public client organisations and can help to develop measures to stimulate BIM adoption of public clients, strengthening them in their potential role as drivers for industrial change towards BIM.

The research objective of this study is to understand why and how public clients in the German road infrastructure sector adopt BIM and what driving forces and obstacle they face.

2.3 Research domain and scope

The focus of this research is set to the BIM adoption of public client organisations in the German road infrastructure sector. For this purpose, this study links the domains of research related to the German construction industry in terms of public client organisations as the research context, building information modelling as the research item and innovation adoption and implementation theory as the theoretical perspective of the research (Figure 1).

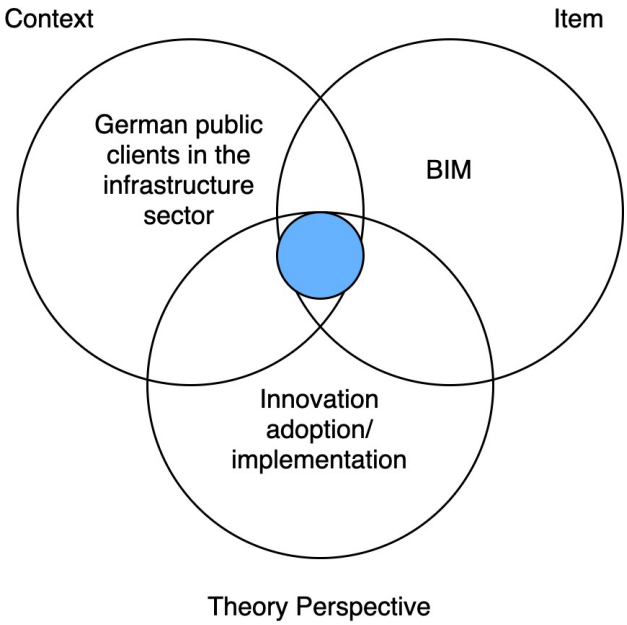

Figure 1 – Scope and research domain

The public client organisations considered in this study are to be understood as authorities and state enterprises which are responsible for the procurement, planning, construction, operation and maintenance of road infrastructure projects such as motorways, roads and the associated civil structures such as bridges and tunnels in Germany and which are affected by the Federal Government's BIM initiative due to their responsibility for federal projects. Public clients operating exclusively in transport infrastructure sectors such as air, water and rail are not considered in this study. In addition, small district authorities or municipalities responsible for district and municipal road infrastructure are also not included due to their small size and their lack of relevance in the context of BIM adoption as the upcoming governmental BIM mandate does not apply for them and nor role is attributed to this group as industry-wide BIM promoters or drivers.

In the literature, there are many different interpretations and uses for the term BIM adoption. There is no universal agreement on the definition of adoption and implementation and they are often used interchangeably (Ahmed & Kassem, 2018). To avoid misunderstandings, in this research, BIM adoption is, in contrast to what is often assumed, not to be regarded as the BIM adoption decision alone. In the context of this study, BIM adoption is to be understood much more as a holistic term, which in the broadest sense also includes the implementation and use of BIM.

2.4 Research questions

In order to achieve the research objective, the following main research question is defined:

Why and how do public clients in the German road infrastructure sector adopt BIM and what are the driving forces and obstacles they face?

To answer the main research question, four sub-questions are examined in this study:

1. What is the current state of BIM adoption among public clients in the German road infrastructure sector?

   The first research question aims to gain an overview of the current situation and practices by investigating whether, how and to what extent BIM is currently adopted by public client organisations. By answering this research question, a first insight into BIM adoption dynamics among the public clients is given. In this way a point of departure for answering the other research questions is created.

2. What is the future expected state of BIM adoption among public clients in the German road infrastructure sector?

   The second research question aims to gain an overview of the expected future situation by investigating whether, how and to what extent BIM is planned to be adopted by public client organisations in the future. By answering this research question, the first insight into the dynamics of BIM adoption among public clients gained through research question one is complemented. The findings of research questions one and two thus set the contextual frame for the subsequent investigation of the driving forces and obstacles in questions three and four.

3. What are the driving forces for the BIM adoption by public client organisations in the German road infrastructure sector?

   The third research question aims to explore why public clients adopt BIM, may adopt BIM in the future and what factors they experience as facilitators in the adoption of BIM. The answer to this question will therefore show which factors on the side of the public clients are perceived as beneficial and provides insights on aspects that are important for stimulating the BIM adoption and a further promotion.

4. What are the obstacles for the BIM adoption by public client organisations in the German road infrastructure sector?

   The fourth research question aims to explore why public clients do not adopt BIM, why they only adopt BIM to a certain extent or what barriers they face when adopting BIM. The answer to this question will therefore show which problematic factors on the side of the public clients will have to be addressed in the future in order to promote BIM adoption.

Chapter 3 Theoretical framework

This thesis deals with the topic of innovation adoption, with special emphasis on the adoption of Building Information Modeling with respect to public client organisations in the German road infrastructure sector. This chapter provides insight into the innovation to be adopted (BIM), the context of BIM and public clients, and an understanding of BIM innovation adoption and implementation in order to build the theoretical framework for this study.

3.1 Building Information Modeling (BIM)

Since BIM is the research item in the present study, it is fundamentally explained in this section in order to provide a sufficient understanding for exploring the BIM adoption of public client organisations. For this purpose, the aspects relevant to the scope of this research, such as the BIM concept, BIM benefits and BIM application areas and uses are presented.

3.1.1 BIM definition and concept

There is no uniform definition of BIM, it is rather a concept with a variety of meanings in different contexts, and depending on who you ask, you will get different descriptions. The term BIM has been tried to be defined by various scientists and organisations. Against this background, there seems to be a general agreement that BIM can be understood as a use of digital building information, but there are significant differences in the details (Lindblad, 2019). However, a commonly accepted definition of BIM is given by the United States National Institute of Building Services (NIBS) defining Building Information Modeling as "a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition" (Z. Liu, Lu, & Peh, 2019; NIMBS Committe, 2007, p. 149).

BIM, contrary to what is often assumed, can therefore be seen as not just a technology, digital software tool or 3D model. It can be rather assessed as a comprehensive new concept of working or even a new paradigm that encompasses instrumentation, information management and process re-engineering across the entire construction sector (Azhar, 2011; Succar, 2009). The BIM workflow can combine all information of various aspects, disciplines and systems of a facility within a 3D designed virtual model (see Figure 2) and enables more accurate and efficient collaboration of all project participants (i.e. between owners, architects, engineers, contractors, subcontractors and suppliers) over the entire life cycle and value chain compared to traditional processes (Azhar, Khalfan, & Maqsood, 2012; Zhao, 2017).

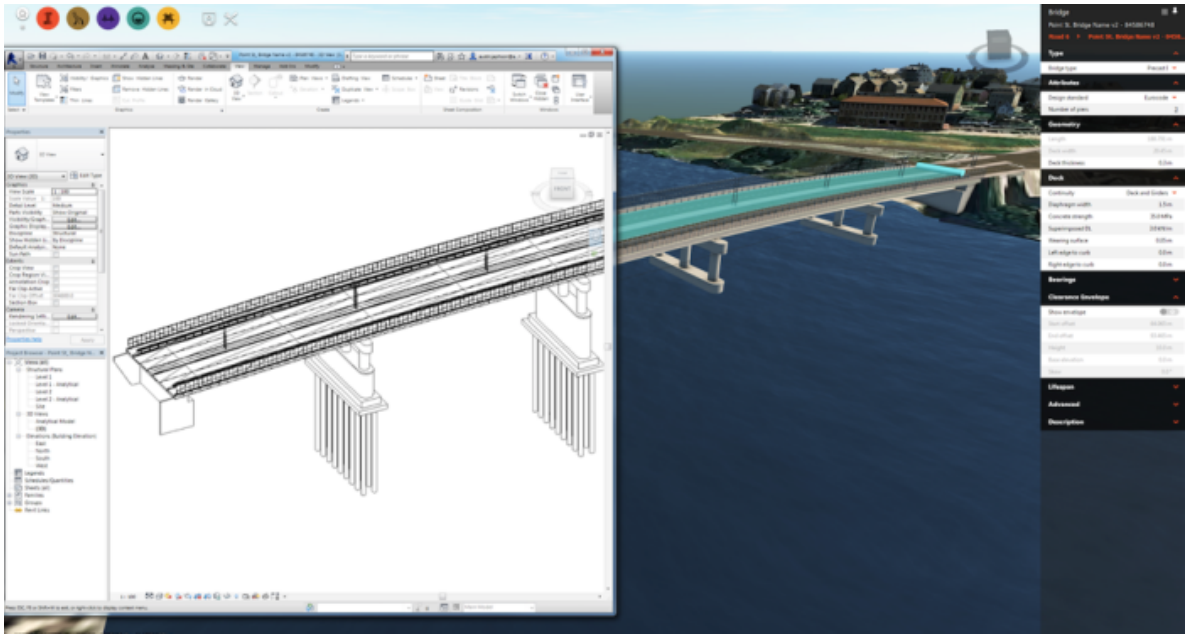

Figure 2 – Example of a 3D designed BIM model including several information

Source: (Ball, 2016)

3.1.2 BIM benefits

BIM offers a wide range of potential benefits due to its versatility across the entire value and supply chain of construction projects. These include i.e. technical-, knowledge management-, standardization-, integratison-, economic-, planning-/scheduling-, life-cycle- and decision support benefits. Potential improvements can be expected in aspects such as technical superiority, interoperability capabilities, early building information capture, use throughout the whole asset life cycle, integrated procurement, improved cost and time control, conflict reduction and collaboration benefits for project teams (Ghaffarianhoseini et al., 2017).

Based on a comprehensive literature study, D. W. M. Chan et al. (2019) has identified 12 common potential benefits of BIM (see Table 1).

Table 1 – Benefits of BIM implementation

Source: (D. W. M. Chan et al., 2019, p. 3)

Benefits of BIM implementation	Description
1) Improve project quality	BIM implementation improve project quality variables by facilitating the ease of assessment of construction materials and work process
2) Better understanding of design	The application of n-dimension (3D) could ease the ability of the project team to visualize and understand the design by using some essential functions like “rendering” and “walk-through”
3) Provide life cycle data	The information generated by the BIM system can be utilized in the whole life cycle of the project
4) Scope clarification	BIM is an appropriate tool to check clashes and reduce discrepancies among design drawings
5) Speed up the design process	BIM ease the process of the project design earlier to ensure all stakeholders understand and approve the design earlier
6) Reduce construction cost	BIM model can facilitate effective site planning to enhance efficiency as well as reduce the rework to save time and money
7) Better cost estimates and control	BIM can generate some data including the quantities of materials automatically which can increase the accuracy of the cost estimate and control compared to the manual measurement

8) Better construction planning and monitoring	BIM system can display a very clear full picture of the project and show the work sequences on a computer before the actual commencement of the project on-site
9) More efficient communications	The BIM system facilitates and eases the process of knowledge-sharing and coordination in the industry
10) Reduce project duration	BIM facilitates the delivery of a construction project on or before schedule
11) Improve safety performance	BIM system facilitates the integration of safety precaution and variables which can be simulated to improve safety on site
12) Enhance organisational image	An organisation policy or strategy toward integrating and implementing BIM in their work processes can improve their competitive advantage

3.1.3 BIM uses and application areas

As can be seen from the aforementioned definition and explanation of the BIM concept, Building Information Modeling can be used for a wide variety of applications. In addition to the ability to use BIM for individual purposes such as architectural 3D design (visualization aspects) or structural analysis, BIM supports the concept of integrated project delivery, a novel approach that integrates people, systems, and business structures and practices into a collaborative process to reduce waste and optimize efficiency at all stages of the project lifecycle (Azhar, 2011; Glick & Guggemos, 2009). Possible BIM applications thus cover the entire value chain and supply chain of the AEC industry illustrated in Figure 3.

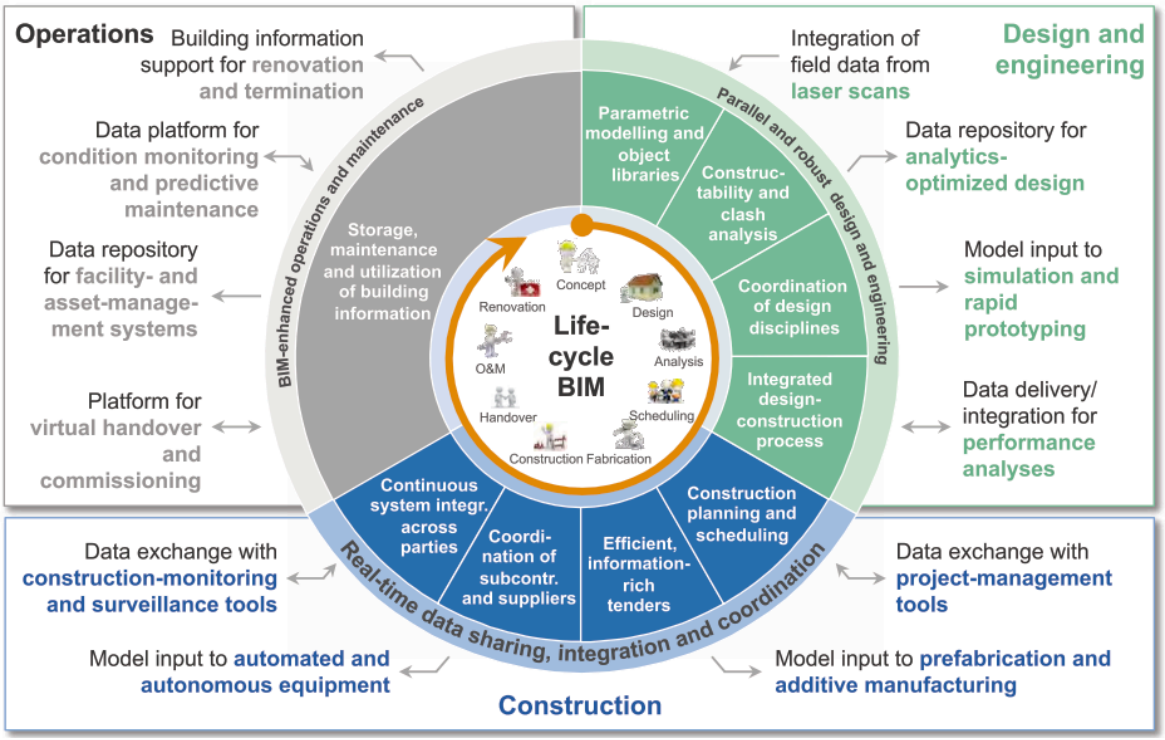

Figure 3 – Applications of BIM along the AEC value chain

Source: (WEF, 2016, p. 24)

To measure the extent of BIM usage, D. Cao, Li, & Wang (2014) identified 13 common cross-industry application areas for BIM in the design and construction phase of a project. With specific regard to transport infrastructure projects, Costin, Adibfar, Hu, & Chen (2018) have identified relevant applications and uses of BIM throughout the entire life cycle of an infrastructure asset. A summary of the possible application areas and uses can be found in Table 2.

Table 2 – Application areas and uses of BIM

Stage	Application
Design (D. Cao et al., 2014)	Site analysis Analysing scenarios and design options Three-dimensional presentation (visualisation) Design coordination Cost estimating Energy simulation Other performance simulations
Construction (D. Cao et al., 2014)	Clash detection Construction system design Schedule simulation Quantity take off Site resource management Offsite fabrication
Operations (Costin et al., 2018)	Maintenance Structural health monitoring Behaviour modeling and prediction

Against the specific German background, the "BIM 4 INFRA" initiative has defined 21 concrete potential use cases of BIM, which are already assigned to the standardized HOAI service delivery phases of a construction project typical for Germany (König & Feustel, 2018). This list of BIM applications is presented in Annex A.1.

3.2 BIM and public clients

Since this study focuses on the adoption of BIM in the specific context of public clients, further insight into the framing context of BIM and public clients is needed. For this purpose, this section provides an understanding of the role of public clients in BIM adoption.

3.2.1 Public client's role in BIM adoption

Previous research has shown that clients play a crucial role in the innovation processes of the construction industry (Blayse & Manley, 2004; A. Hartmann, Dewulf, & Reymen, 2006; Ivory, 2005; Ling, Hartmann, Kumaraswamy, & Dulaimi, 2007; Manley, 2006; Ozorhon & Oral, 2017). It is a widely accepted view in the AEC industry that innovative solutions are adopted or implemented to meet external needs, usually in response to new demands, mostly defined by clients (Harty, 2008). Clients are therefore argued to be in a key role to promote new innovations in the construction industry (Blayse & Manley, 2004; Loosemore, 2015). Due to their key role in a project, clients are on the one hand able to indirectly stimulate innovation by setting more demanding building specifications and demanding higher construction and process performance. On the other hand, they can directly demand and request certain innovations that are beneficial from their point of view, such as the establishment of specific mechanisms, working methods or desired technology (Blayse & Manley, 2004; Dewick & Miozzo, 2004; A. Hartmann et al., 2006; Tookey et al., 2011).

Against this background, it is also argued in relation to BIM, that client organisations are the actors that can best promote an innovation like BIM in the AEC industry (Olofsson, Lee, & Eastman, 2008). Porwal & Hewage (2013) even conclude that the degree of maturity and adoption of BIM in an industry depends mainly on the client. In addition, since BIM as an innovation is expected to have an impact not only on individual actors but also on the entire inter-organisational project network, it is also assumed

that the client can be considered as the biggest potential beneficiary of BIM adoption (Dehlin & Olofsson, 2008; Elmualim & Gilder, 2014). Even if the client does not actively demand BIM for his own perceived benefit or need, he may benefit from the BIM implementation because it satisfies the needs of the other project participants and thus can optimize the project as a whole (Singh & Holmstrom, 2015). In this context, in particular, governments of countries are trying to activate public clients through initiatives by requiring BIM demand in public construction projects in order to promote BIM adoption and diffusion in the industry (Charef et al., 2019; Wong et al., 2010).

However, previous research has also shown that technical competence of clients is an important factor with regard to the active role attributed to clients in promoting an innovation like BIM for industrial change (Nam & Tatum, 1997). Thus, client organisations with a higher level of technical competence tend to become more involved in projects, exert influence on other project participants and as consequence actively promote the implementation of innovations (Lindblad, 2019; Nam & Tatum, 1997). In addition, more demanding and experienced client organisations would be more likely to encourage innovation (Barlow, 2000) and the internal structure of the client organisations would be crucial for its innovation capability, especially with regard to specialized units and people who drive innovation across multiple projects (Bygballe & Ingemansson, 2011). Furthermore, the particularly pronounced intention of risk avoidance related to new innovations on the part of clients has so far been identified as the main reason for restraint in actively promoting innovation adoption (A. Hartmann, Reymen, & Van Oosterom, 2008; Ivory, 2005).

With regard to the role of public clients in promoting BIM, recent research has shown that for successful promotion of BIM by public clients in an industrial context, it is not sufficient to simply translate BIM directly to external actors by demanding BIM in public projects, but that public clients must also actively participate and support the implementation and use of BIM in projects. Consequently, the successful adoption of BIM is also necessary internally, in public client organisations (Lindblad, 2016, 2019; Vass & Gustavsson, 2017).

It therefore becomes clear that the assumed influence of clients in general and public client organisations on BIM adoption in the construction industry is linked to certain conditions, cannot be generalised as a matter of course and strongly depends on BIM innovation adoption in client organisations themselves. Thus, some client organisations may not have the necessary prerequisites or may not be in a position to demand changes according to their theoretically attributed role as drivers for industry change towards BIM (Lindblad, 2019).

3.3 Understanding BIM adoption and implementation

After having addressed the innovation to be adopted and the contextual framing of BIM and public clients, it is needed to provide insight into theoretical concepts of BIM innovation adoption and implementation. This builds the foundation for exploring the adoption of BIM by public clients in the German road infrastructure sector and to identify driving forces and obstacles. For this purpose, this chapter presents innovation adoption and implementation models as well as drivers and barriers for BIM adoption.

To frame BIM in the context of innovation adoption, Ahmed & Kassem (2018, p. 112) understand BIM as an multitype innovation characterized by three attributes:

1) "BIM unlike other finite innovations is a multifaceted innovation (i.e. a product, process, technology and policy innovation) involving multiple stages of implementation targeting different capability stages (i.e. modelling, collaboration, and integration)."

2) "BIM implementation is also a project network topic affected by interdependences of supply chains."

3) "BIM is one of the fewest innovations within the construction sector that attracted the interest of stakeholders longitudinally across construction sectors (i.e. industry associations, academia and communities of interest) and vertically across countries (i.e. at city, region and nation level)."

3.3.1 BIM Innovation adoption and implementation models

In the literature, the adoption of BIM is considered closely related to the topic of innovation adoption or more specifically to the field of technology adoption. Against this background, Ahmed & Kassem (2018) have conducted a comprehensive literature review across 34 existing studies to identify the theories, frameworks and models used by various scholars in order to investigate the adoption and diffusion of BIM as an innovation in construction. The main innovation theories adopted in the examined literature include: diffusion of innovation theory (DOI) (53%), institutional theory (IT) (26%), technology acceptance model (TAM) (21%), mixed theories (21%) and theory of reasoned action (TRA) (6%) (Ahmed & Kassem, 2018). In addition to the models considered by Ahmed & Kassem (2018), the technology, organisation and environment framework (TOE) (Oliveira & Martins, 2010; Tornatzky, Fleischer, & Chakrabarti, 1990) and the "theory on actor's use of interorganisational ICT in construction projects" (Adriaanse, Voordijk, & Dewulf, 2007, 2010b, 2010a) are commonly used frameworks addressing innovation and technology adoption like BIM.

The diffusion of innovation theory of Rogers (1982) is probably the most influential theory for gaining an understanding of how, why and at what speed an innovation spreads across cultures operating at the level of individuals and the organisations. It is a broad theory that provides a comprehensive structure for understanding adoption and collective diffusion. This theory is the fundamental basis for the synthesis of adoption and diffusion literature across various disciplines (Straub, 2009). According to the DOI of Rogers (1982), the innovation adoption process is defined as a five-step model consisting of awareness, persuasion, decision, implementation and validation. In this context, there are two groups

of factors influencing the mentioned steps of innovation adoption. The first group of factors are the perceived characteristics of an innovation: relative advantage, compatibility, complexity, trialability and observability (Figure 4). The second group are the characteristics of an adopter (i.e. characteristics of an individual, organisation or decision unit) with regard to socio-economic characteristics, personality variables and communication behaviour (Rogers, 1982; van Oorschot, Hofman, & Halman, 2018). In summary, the DOI theory is more of a descriptive theory that describes why and how fast innovations are adopted. It does not address prescriptive aspects such as how to facilitate the adoption of innovations. It offers a flexible and broad framework without addressing a specific application domain or level.

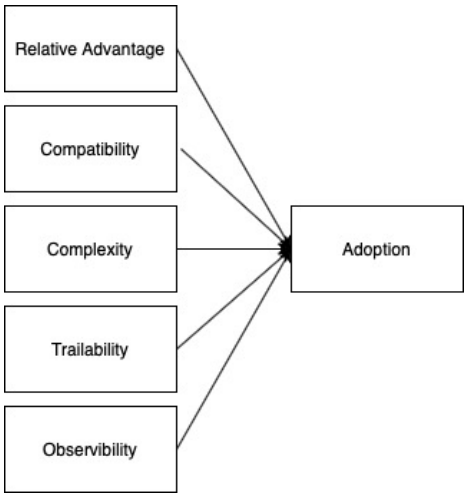

Figure 4 – Innovation diffusion theory
Source: (Rogers, 1982)

The core idea of the institutional theory is that organisations accept and eventually adopt innovations that have been legitimized either by their use by a large number of organisations, by reputable organisations, or by government regulations (Haunschild & Miner, 1997; van Oorschot et al., 2018). According to DiMaggio & Powell (1983), the institutional theory is characterized by a diffusion dynamic in which external isomorphic pressures motivate organisations to change behaviour and structure and at the same time try to achieve social legitimacy. The institutional pressures include: coercive, mimetic and normative pressures (see Figure 5). In this context, organisations comply with formal pressures (e.g. mandates and regulations) and emulate successful practices or adapt to informal obstacles (i.e. beliefs, norms and conventions). Institutional legitimacy is determined by how organisations respond to these pressures (Ahmed & Kassem, 2018; Heugens & Lander, 2009). Among scholars of institutional theory, there is an ongoing debate between the camps of “conformity” and “performance” scholars (Heugens & Lander, 2009). Conformance scholars argue that the adoption of innovations arises from the pressure to be accepted and appear legitimate, while performance scholars argue that the main reason for adopting innovations is the perceived expected benefits (Heugens & Lander, 2009).

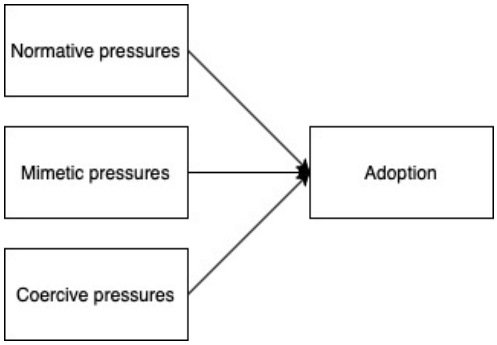

Figure 5 – Institutional theory

Central aspects of the theory of reasoned action and the technology acceptance model are individual behaviour, intentions and the acceptance of innovations, especially of technology innovations. The most widely used model of this set of theories is the TAM (see Figure 6), grounded in the TRA, developed and constantly refined (Davis, 1985, 1989; van Oorschot et al., 2018). Over time, further development of the model has led to new versions such as TAM2, TAM3 or the unified theory of acceptance and use of technology (UTAUT) (Venkatesh & Bala, 2008; Venkatesh & Davis, 2000; Venkatesh, Morris, Davis, & Davis, 2003). The UTAUT merges the theory of reasoned action (TRA), the technology acceptance model (TAM), the motivational model, the theory of planned behaviour (TPB), the model of PC utilization, the diffusion of innovation theory (DOI) and social cognitive theory. The basic assumptions of TAM essentially comprise that the actual use of innovations can be explained by the behavioural intention of use, which is influenced by the perceived ease of use and the perceived usefulness (Davis, 1989; van Oorschot et al., 2018). According to Ahmed & Kassem (2018, p. 161) "it establishes theoretical links between belief, intention and action to explain the use of a system: The user's belief (i.e. perceived ease of use and perceived usefulness) within a given system influences the user's behaviour and intention to use the system, which in turn determines its actual use".

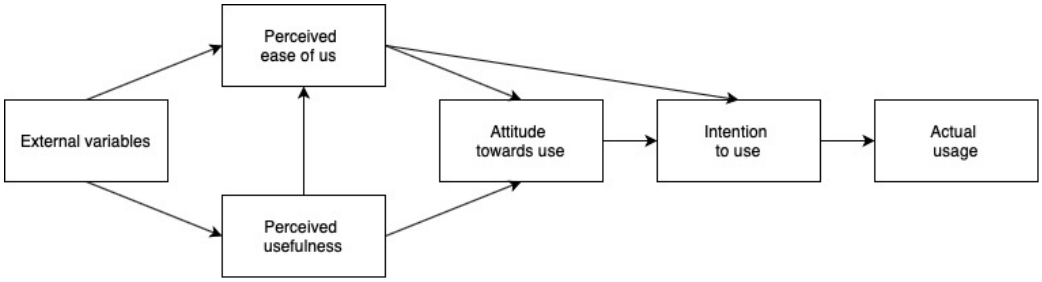

Figure 6 – Technology acceptance model

Source: (Davis, Bagozzi, & Warshaw, 1989)

The technology, organisation and environment framework of (Tornatzky et al., 1990) is suitable for investigating the adoption of IT innovations at internal organisational and inter-organisational level. The underlying assumption of the framework is that technological, organisational and environmental factors influence the adoption of an innovation (see Figure 7). Against this background, technology factors focus on how the perceived characteristics of a technology influence its adoption. Organisational factors describe those attributes of an organisation that can influence adoption decisions. Environmental factors capture aspects of the environment in which an organisation operates that can influence adoption decisions (Henderson, Sheetz, & Trinkle, 2012). Against this background the TOE framework provides a high-level theoretical foundation that enables the study of technology adoption in different application areas. The specific factors identified in the three contexts may be different for the respective applications and intentions of different studies. For the specific application of the TOE framework in a

certain area, it should therefore be combined with other theories to identify specific technological, organisational and environmental factors and to establish the causal relationships necessary for hypothesis development (Henderson et al., 2012).

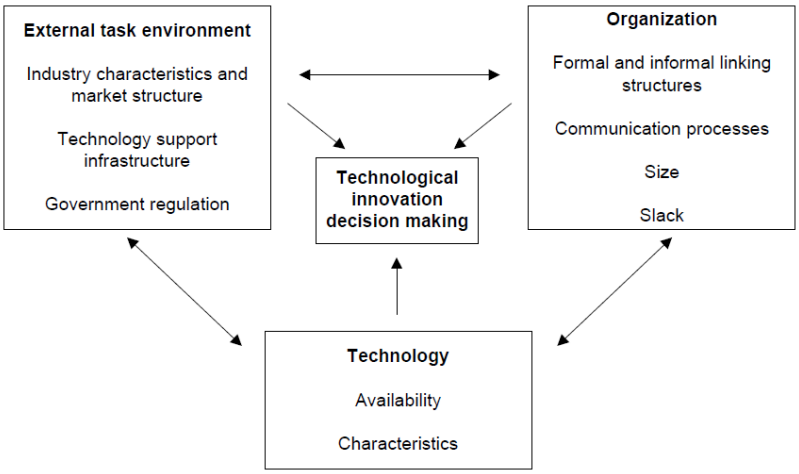

Figure 7 – An example of a TOE framework

Source: (Oliveira & Martins, 2010, p. 112)

Adriaanse et al. (2007, 2010a) has created a theoretical model specific to the implementation and use of information and communication technology (ICT) in construction projects, building on more general innovation adoption and implementation models already existing, with a focus on the individual, such as the UTAUT, TPB and TAM. The model was created to identify the key mechanisms that influence the way actors use inter-organisational ICT in order to provide insights into the intention of using ICT and to find solutions to the barriers to successful use of ICT in construction projects. Depending on the issue at hand, an actor in this case could be persons (or roles of persons), groups of persons, departments or entire companies. In this context, Adriaanse et al. (2010a, p. 1003) defines interorganisational ICT as "a digital coordination and collaboration tool used for communicating and sharing project information between participating organisations in a construction project." BIM can therefore be considered as a type of information and communication technology.

The theoretical model developed by Adriaanse et al. (2007, 2010a) lists four main mechanisms that determine the way actors use ICT in construction projects and various sub mechanisms that influence the way ICT is used: (1) personal motivation: perceived benefits and disadvantages of ICT use, perceived time pressure; (2) external motivation: availability of contractual arrangements about ICT use, presence of a requesting actor; (3) knowledge and skills: clarity of procedural agreements, clarity about operating ICT and (4) acting opportunity: alignment between ICT and working practices, availability of technical means. The model is presented in Figure 8.

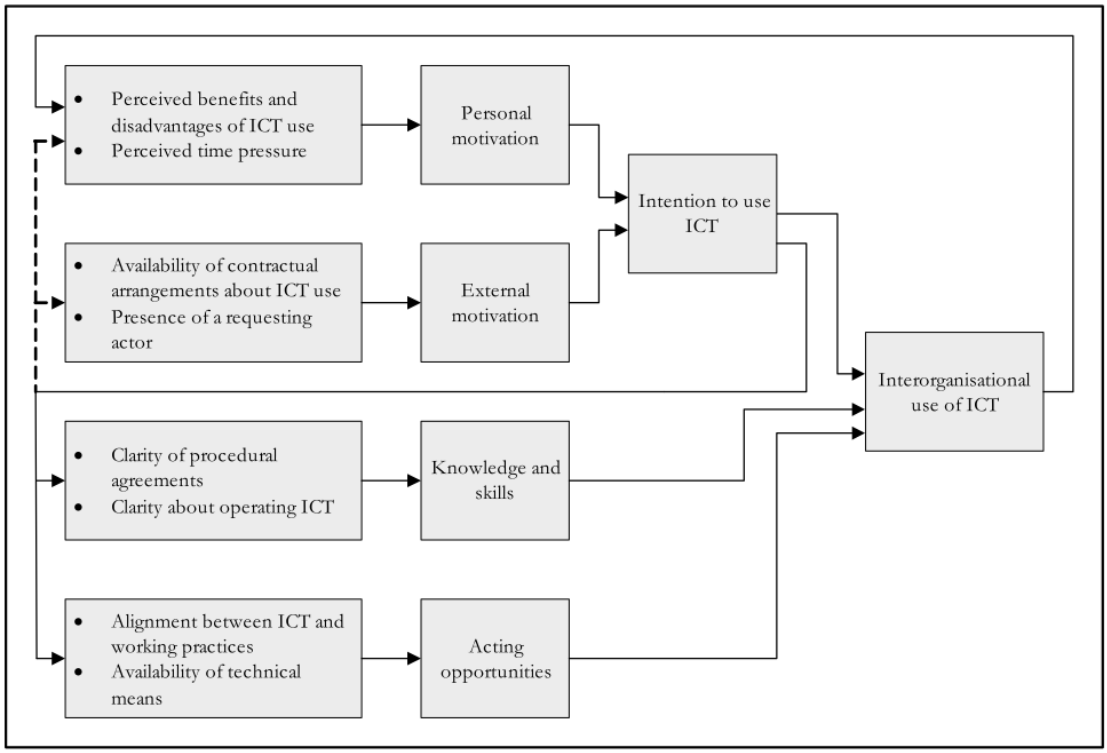

Figure 8 – Adriaanse's theory on actor's use of interorganisational ICT in construction projects

Source: (Adriaanse et al., 2007, p. 158)

3.3.2 Drivers and barriers for BIM adoption

There are numerous studies on drivers and barriers of BIM adoption and implementation. As already implied by the identified research gap underlying this study, the existing scientific literature lacks driving forces and barriers for BIM adoption studied in the specific context of public clients. Only Vass & Gustavsson (2017) took a closer look at the public client perspective and identified nine challenges in implementing BIM for industrial change. However, the main focus of the research was on challenges of driving the shift towards BIM in the AEC industry, rather than focussing more in-depth on BIM adoption on organisational level. Drivers and barriers of BIM adoption have mostly been investigated from the perspective of e.g. contractors (Abubakar et al., 2014; Bosch-Sijtsema et al., 2017; T. Hartmann et al., 2012), architects and designers (Ahuja et al., 2016; C. T. W. Chan, 2014; Son et al., 2015) or in industrial and country context without focus on a specific addressed group (Ahuja et al., 2020; Y. Cao et al., 2019; Gu & London, 2010; Kim et al., 2016; S. Liu et al., 2015; Zakaria et al., 2014). In addition, recent literature shows an increased focus on small and medium-sized enterprises (Bosch-Sijtsema et al., 2017; Hong et al., 2019; Hosseini et al., 2016; Saka et al., 2020). The literature review revealed that probably the most comprehensive list of potential factors affecting BIM adoption on organisational level as driving force or barrier is the unified BIM adoption taxonomy (UBAT) developed by Ahmed & Kassem (2018).

Table 3 shows potential driving forces and barriers of some of the reviewed key literature.

Table 3 – Potential drivers and barriers for BIM adoption

Authors	Potential drivers and barriers for BIM adoption
(Saka et al., 2020, p. 15)	*Key drivers:* Organisational readiness, Top management support, Adequate financial resources, Organisational structure, Organisational culture
(D. W. M. Chan et al., 2019, p. 5)	*Key barriers:* Cultural barrier (resistance to change), Organisational structure that does not support BIM, Insufficient interoperability of computer software, Lack of industry standards, Difficulties in measuring impacts of BIM, Shortage of BIM implementation data in construction phase
(Ahmed & Kassem, 2018, pp. 107, 120–122)	*Drivers/Factors:* Perceived usefulness, Perceived ease of use, Relative advantage, Compatibility, Complexity, Trialability, Observability, Technological factors, Coercive pressures, Mimetic pressures, Normative pressures, Top management support, Communication behaviour, Financial resources, Organisational readiness, Social motivations, Organisational culture, Willingness/Intention, Organisation structure
(Bosch-Sijtsema et al., 2017, p. 9,10)	*Key drivers:* Follow technical development, BIM should give competitive advantages, Enough internal competence to use BIM, BIM would be of strategic importance for the company, A good network of external actors who support the use of BIM *Key barriers:* No demands from the clients, Partners do not use BIM, high investments in hard- and software, No internal demand in the company, Problem with the user-friendliness, High demands for technical competence
(Abubakar et al., 2014, pp. 174, 175)	*Key drivers:* Availability of trained professionals to handle the tools, BIM Software availability and affordability, Enabling environment, Clients' interest in the use of BIM in their projects, Awareness of the technology among industry stakeholders *Key barriers:* Social and habitual resistance to change, Legal and contractual constraints, High cost of training, Lack of enabling environment (government policies and legislations), Lack of trained professionals to handle the tools, Clients not requesting the use of BIM on projects
(Vass & Gustavsson, 2017, p. 604)	*Barriers/Challenges:* Changing work practices, Providing education and learning, Developing a mutual BIM definition, Evaluating the business value of BIM, Demanding BIM in procurement, Creating incentives, Including maintenance department, Creating new roles, Managing interoperability

3.4 Theoretical model

In this study the technology, organisation and environment framework (Tornatzky et al., 1990), integrating some constructs of the diffusion of innovation theory of Rogers (1982) and the unified BIM adoption taxonomy of Ahmed & Kassem (2018), is chosen as the theoretical lens. In this way, the theoretical model enables the exploration and investigation of factors affecting BIM adoption of public client organisations in the German road infrastructure sector in order to identify driving forces and obstacles for BIM adoption from the perspective of a technology innovation context, an organisation context und an environment context.

The reasons for choosing this theoretical perspective are manifold. First, the TOE framework and the DOI theory have a solid theoretical basis, strong empirical support and have been applied to study the adoption of technological innovations (Oliveira & Martins, 2010) and BIM adoption (Ahuja et al., 2016, 2020; Saka et al., 2020). Second, the TOE framework considers adoption at the organisational level (including adoption at the inter-organisational project environment) and since this research focuses on

the study of BIM adoption of public client organisations and not by individuals, an adoption theory at organisational level is considered appropriate for the present research. Other widely used theoretical perspectives, such as TAM, TPB, UTAUT are also partly applied at the organisational level, but a few researchers point out that the core constructs of these theories are better suited to study the adoption on individual level, focusing on adoption acceptance or the behaviour of individuals (Ahuja et al., 2016; Oliveira & Martins, 2010). Third, since in this study BIM adoption is understood as a "summarizing" term, which in its entirety also includes BIM implementation and use and does not explicitly distinguish between these and other phases, the TOE framework offers a compact and suitable perspective for the basis of the theoretical model compared to other adoption theories at the organisational level. Other theories often focus on different stages of adoption and the adoption process at different levels in an organisation and are therefore too broad for the scope of this research. In addition, since adoption of BIM in an organisation also involves aspects of BIM implementation in projects and collaboration with external actors, the TOE framework, through the component of the environmental context, offers the possibility to include these inter-organisational BIM adoption influences, despite the main focus on the organisational level. Furthermore, a few scholars show that the TOE framework is consistent and compatible with the DOI theory and is suitable to extend the DOI theory by important aspects such as the environmental context (Oliveira & Martins, 2010).

As the literature review revealed that there is not yet much knowledge about specific driving forces and obstacles for BIM adoption in the context of public client organisations, especially not in the German infrastructure sector, the theoretical model of this study consists rather of more abstract constructs that indicate relatively wide and open phenomena (Verschuren & Doorewaard, 2010). Against this background, common factors identified in the literature that influence BIM adoption at the organisational level from other contexts such as architectural firms or contractors have been chosen as constructs for this model to identify driving forces and obstacles that are relevant for public clients. In this context, the selected constructs are mainly based on the unified BIM adoption taxonomy (UBAT) of Ahmed & Kassem (2018). The selection of the UBAT as the main source for the constructs of the proposed theoretical model was based on three facts. First, the selection process of the factors for the development of the UBAT was based on an extensive literature review, which shows that the UBAT has strong theoretical foundations. Secondly, the classification of the factors into three clusters, namely the BIM innovation characteristics, the external environment characteristics, and the internal environment characteristics, is consistent with the fundamentals of the TOE framework. Thirdly, most of the driving forces and barriers identified in the literature review are reflected in the themes covered by the UBAT. However, the scope of factors and determinants of the UBAT has been greatly consolidated and simplified for the purposes of this study.

In summary, the aim of the selected constructs within the proposed TOE framework was to provide themes and topics for interviews to facilitate discussion and guide the interviewer to valid data, rather than to test or validate detailed constructs of the model. Accordingly, the model was used in an exploratory and qualitative way and not in a testing approach (Verschuren & Doorewaard, 2010).

The proposed theoretical model for this study is shown in Figure 9 and the chosen constructs are briefly described in the following.

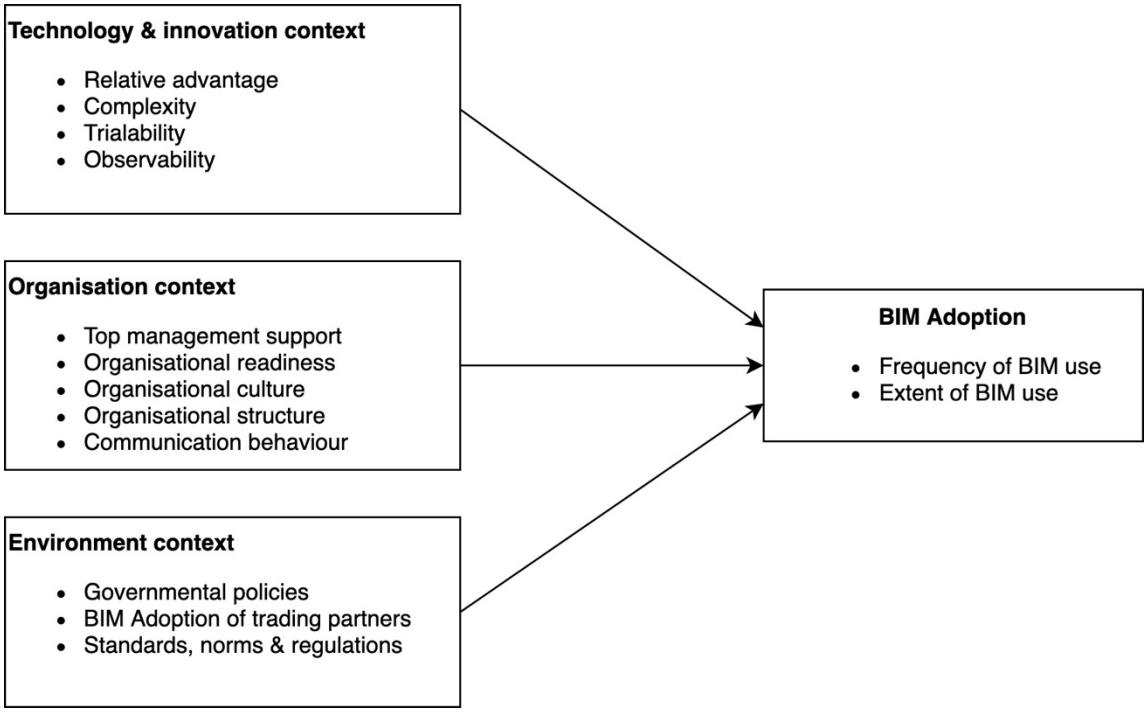

Figure 9 – Theoretical model

3.4.1 Technology and innovation context

The technology and innovation context of the proposed theoretical model based on the TOE framework consists of constructs from the DOI theory of Rogers (1982). According to Rogers (1982), the perception of innovation attributes influences the evaluation of a new idea and the adoption behaviour of an innovation. These innovation attributes are commonly used factors in investigating BIM adoption in different contexts and have a strong theoretical basis (Ahmed & Kassem, 2018; Ahuja et al., 2016, 2020; Gledson & Greenwood, 2017; Kim et al., 2016; Saka et al., 2020; Son et al., 2015). The proposed model involves four of the innovation attributes defined by Rogers (1982), namely relative advantage, complexity, testability and observability.

Relative advantage is defined as "the degree to which an innovation is perceived as being better than the idea it supersedes" (Rogers, 1982, p. 15). It can therefore be understood as the degree to which BIM is perceived by organisations as better than traditional working methods and how potential benefits of using BIM are assessed. In this context, the diffusion theory holds that the adoption rate of an innovation like BIM increases the more favourable the perception of its advantage is (Gledson & Greenwood, 2017).

Complexity is defined as "the degree to which an innovation is perceived as difficult to understand and use" (Rogers, 1982, p. 15). On the one hand, this may involve how organisations assess the learnability of BIM for employees, the familiarization of internal processes with BIM and the collaborative use of BIM in projects. On the other hand, it also refers to technological aspects, such as technical implementation and interoperability between software applications and data (Ahmed & Kassem, 2018; Ahuja et al., 2016). Against this background, previous research on innovation diffusion has shown that the adoption rate decreases as the complexity of adopting an innovation increases (Ahuja et al., 2016).

Trialability is defined as "the degree to which an innovation may be experimented with on a limited basis" (Rogers, 1982, p. 15). Thus, this factor refers to the opportunity, necessity and ease to test BIM tools and workflows as well as to verify BIM features and effects by organisations before adoption and implementation in regular operation, i.e. through pilot projects (Ahmed & Kassem, 2018). A high degree of testability tends to have a positive influence on BIM adoption due to the possibility to examine different benefits of BIM in a lower-risk environment and reduce existing uncertainties (Ahuja et al., 2016).

Observability is "the degree to which the results of an innovation are visible to others" (Rogers, 1982, p. 16). This factor is concerned whether the benefits of BIM are already visible and proven in practice to organisations. From the diffusion theory it can be deduced that the visibility of positive outcomes of an innovation positively influences BIM adoption (Gledson & Greenwood, 2017).

3.4.2 Organisation context

The organisation context of the proposed theoretical model consists of constructs that describe those attributes of an organisation that can influence BIM adoption (Henderson et al., 2012). Against this background, the proposed model involves top management support, organisational readiness, organisational culture, organisational structure and communication behaviour as constructs that may influence the adoption of BIM by public clients in the infrastructure sector.

Top management support is understood as the attitude to encourage and support internal motivations to actively use and promote innovative technologies such as BIM (Ahmed & Kassem, 2018). Through increased encouragement, resource allocation, and supportive climate, top management can have a positive influence on BIM adoption and also ensure that appropriate changes are made to internal business processes for successful implementation (Ahuja et al., 2016, 2020; Linderoth, 2010; Xu, Feng, & Li, 2014).

Organisation readiness is the current status of an organisation representing their ability to adopt and implement BIM. This factor summarizes aspects such as the existence or lack of BIM experience, know-how, competencies, a guiding BIM strategy or training programs, and the availability of resources which can be of technological, financial or human nature (Ahmed & Kassem, 2018).

Organisational culture can be understood as the cultural environment for BIM adoption and implementation within the organisation. On the one hand, this environment can be characterised by aspects such as internal acceptance, motivation and internal pressure from individuals or groups for BIM adoption, but on the other hand also by people's resistance to BIM adoption (Ahmed & Kassem, 2018).

Organisational structure includes aspects such as the organisational complexity, flexibility and hierarchy influencing the BIM adoption capabilities of an organisation, but also the structural orientation towards BIM such as the existence or lack of specialized units and people who drive the adoption of BIM (Ahmed & Kassem, 2018; Bygballe & Ingemansson, 2011).

Communication behaviour represents the effectiveness of information and communication flows regarding BIM, the strength of relationships and the existence or lack of networks with other external parties (Ahmed & Kassem, 2018; A. Hartmann et al., 2006).

3.4.3 Environment context

Environmental factors capture aspects of the environment in which an organisation operates that can influence the BIM adoption (Henderson et al., 2012). Against this background, the proposed model involves governmental policies, BIM adoption of trading partners and existing norms, regulations and standards as constructs that may influence the BIM adoption of public client organisation.

Governmental policies refer, on the one hand, to existing or lacking governmental BIM initiatives, mandates and obvious pressure from governments to adopt BIM and, on the other hand, to existing or lacking support through adoption directives and guidelines or financial support which influences BIM adoption (Ahmed & Kassem, 2018).

BIM adoption of trading partners refers to the inter-organisational BIM use in projects related to the BIM adoption level and readiness of trading partners as well as the perception of BIM collaboration, i.e. with regard to a common BIM understanding about processes, payment, mutual learning and the respective influence on organisational BIM adoption (Ahmed & Kassem, 2018; Ahuja et al., 2016, 2020).

Standards, norms and regulations refer to existing or lacking BIM standards and the compatibility of current norms and regulations influencing BIM adoption (Ahmed & Kassem, 2018; Ahuja et al., 2016, 2020).

Chapter 4 Research methodology

This chapter explains the research strategy as well as the data collection and data analysis methods that have been applied for conducting the present research. An outline of the research design showing the key phases and elements of this study is presented in Figure 10. Furthermore, this chapter briefly presents the research context of BIM and public clients in the German road infrastructure sector, thereby providing important background information for understanding the empirical case study.

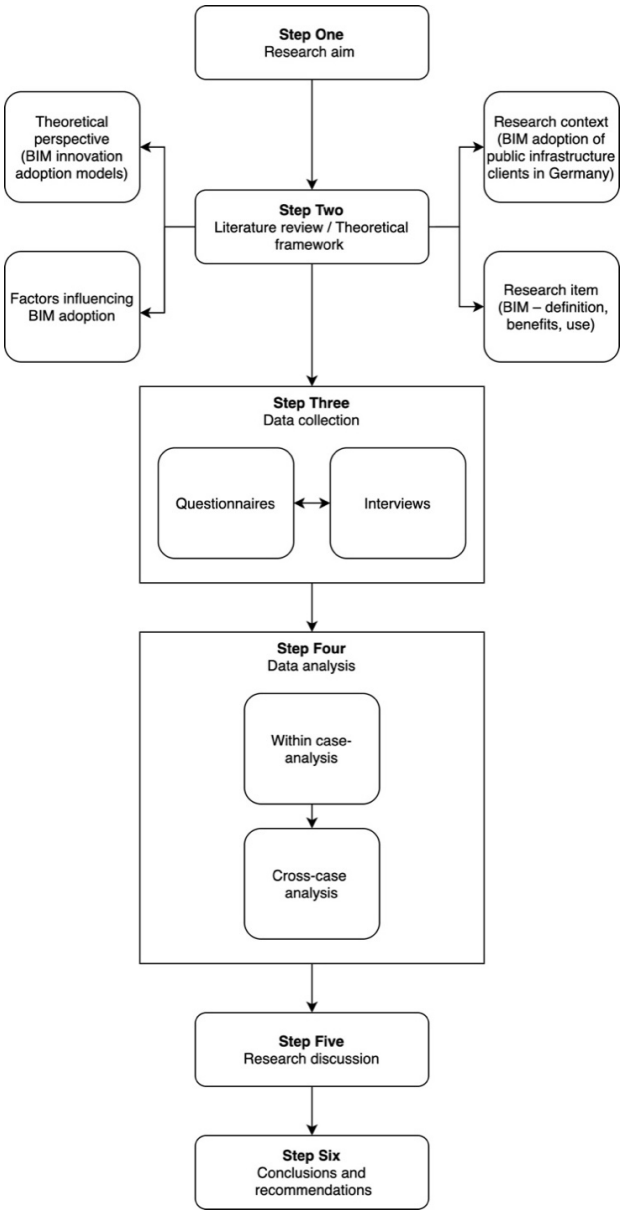

Figure 10 – Research design

4.1 Research strategy

In order to explore the BIM adoption of public client organisations in the German road infrastructure sector and to identify the driving forces and obstacles of BIM adoption, a qualitative multiple exploratory case-study research approach was chosen. The reasons for this choice were manifold. Qualitative case research is an established method for conducting explorative and theory building research (Saunders, Lewis, & Thornhill, 2009). Caste study research is a commonly preferred approach in order to find answers on 'how' and 'why' questions (Eisenhardt, 1989; Yin, 2009). Case studies seemed to be particularly appropriate to this research since they address the holistic nature of real-world contexts in which phenomena occur and shed light on largely unexplored phenomena (Eisenhardt & Graebner, 2007). Moreover, a multiple rather than a single case study approach was chosen in order to analyse pattern-matching properties between the cases analysed by conducting a cross-case analysis (Rialp, Rialp, & Knight, 2005). This multiple case design enabled the authors to clarify whether findings in one case can be replicated in another case. Replication logic was also the reason for focusing on a particular type of public client (Yin, 2009). Furthermore, selecting a multiple-case design over a single-case design was preferable in the present research, because it reduces vulnerability to unexpected circumstances in the chosen cases and increases analytical benefits (Yin, 2009). Finally, another reason for this choice was the interest in investigating and comparing different public clients with different BIM adoption levels throughout Germany and gain a nationwide overview of BIM adoption among German public clients. This enabled to compare the effects of influencing factors in terms of obstacles and driving forces of public clients with a higher BIM adoption state with those of public clients with a lower BIM adoption state and to derive recommendations.

4.2 Data collection

To ensure construct validity, multiple sources of evidence were used (Verschuren & Doorewaard, 2010). Besides the literature review conducted in the course of the development of the theoretical framework, the data collection involved two sources. The main source were semi-structured interviews. In addition, multiple sources of secondary information were used, e.g. websites, press releases and published articles. Relying on different sources of information allowed data triangulation to ensure the validity of the study and to obtain a more comprehensive and accurate view of the topic analysed. Interviews have been selected as the main source of data collection as interviews provide the researcher with in-depth knowledge and detailed information in which various processes take place and were therefore considered a suitable method to identify obstacles and driving forces (Verschuren & Doorewaard, 2010).

Cases selection

A qualitative analysis was applied in this study. Against this background, the purpose of case selection was not to obtain a sample from which statistically meaningful results can be drawn, but a purposive sampling so that the cases provide as much information as possible about BIM adoption among public clients in the German infrastructure in order to identify perceived drivers and obstacles of BIM adoption (Saunders et al., 2009). Against this background, three criteria were used in order to select public client organisations for the series of case studies. All of these criteria relate to the type of organisation and should ultimately ensure that the same type of public client organisation was selected to achieve a high degree of comparability. First, the public client needed to operate in the infrastructure sector in the sense

of road transport infrastructure (motorways, roads and related civil structures like bridges and tunnels). Transport infrastructure in the sense of water, rail and air were excluded. Second, the public client organisation should, if possible, be at the same level in the organisational hierarchy of public clients and road administration in the German road infrastructure sector. This means preferably the level which is responsible for the operative road infrastructure business, which appears and acts on the market as a public client to trading partners (i.e. contractors and engineering offices) and which is ultimately responsible for the operative organisational BIM adoption and implementation of BIM in road infrastructure projects. Finally, the public client had to be affected by the upcoming Governmental BIM mandate due to its area of responsibility and its hierarchy level in the German road transport infrastructure sector.

Interviews and interviewees selection

In order to assure the validity and reliability of the research, design and analytical requirements were followed in conducting the open ended and semi-structured interviews (Yin, 2009). Against this background, a questionnaire with predefined themes according to the theoretical framework was defined, which had to be filled out and returned by the interviewees before the interview. The filled-out questionnaire then served as a basis for the interviews and was used to facilitate the discussion. Accordingly, each public client organisation was interviewed following the same defined structure based on the questionnaire specifically built for the research. Furthermore, despite the given structure, the respondents had the possibility to set their own priorities beyond the questionnaire and add their own topics and aspects.

The questionnaire sensitized the interviewees to the topic before the interview and enabled a productive and prepared discussion. Furthermore, the questionnaire prevented miscommunication, misinterpretation and false mutual understanding. Due to the structured but free methodology a high degree of comparability was guaranteed which nevertheless made it possible to take up new aspects from the interviewees. The filled-out questionnaires supported the subsequent analysis process of the transcribed interviews. The questionnaire can be found in Appendix B.

The participants for the interviews were selected based on their position, responsibility and function in the respective public client organisation. More precisely, the interviewee had to be the person who is either primarily responsible for the BIM adoption of the respective public client organisation or a person who, due to his position, function and tasks, is at least significantly involved in the BIM adoption at organisational level.

Summary of selected cases, interviews and interviewees

A total of 14 public client organisations in the German road infrastructure were considered in this study. 13 public clients were state enterprises or state authorities, which means that 13 different federal states were represented, and one public client organisation was a national authority operating across different states (Case1). Therefore, the present study provides a good overview of the road infrastructure sector in Germany. As part of the data collection, 15 interviews were carried out with 19 participating respondents, each of which lasted between 30 and 90 minutes, resulting in a total duration of 790 minutes. In addition to the previously defined requirement criteria for selecting interview partners, almost all of the interviewees who took part in the interviews were BIM representatives of their organisation for their federal state at the highest German BIM adoption committee, the "Bund-Länder-Dienstbesprechung". This proves that the interviewees had extensive knowledge of the BIM adoption process in their organisation, in their federal state and throughout Germany. The interviews were conducted in a period from March 2020 to June 2020.

4.3 Data analysis

The collected data were analysed using an inductive approach. First, the interviews were transcribed and a within-case study was conducted. In the course of the within-case study the current and expected future state of BIM adoption, as well as the driving forces and obstacles affecting the BIM adoption of each public client organisation were revealed by coding and categorising the data from the interview transcripts according to the theoretical model. The examination of the current adoption states based on existing experience, frequency of BIM use and the extent of BIM use allowed to categorise the public clients. Second, a cross-case analysis was carried out to find similarities and differences between the cases. This approach made it possible to identify general driving forces and obstacles, as well as to gain insights into driving forces and obstacles in relation to different adoption states and adoption behaviour of the public clients and to derive recommendations.

4.4 Research context

As this research focuses on BIM adoption of public clients in the specific context of the German road infrastructure sector, further background information is needed to understand the empirical case study. For this purpose, the BIM initiative of the German Federal Government is presented, which frames BIM and public clients in Germany, and a contextual overview of the structure and hierarchy of public clients in the German road infrastructure sector is given.

4.4.1 Germany's governmental BIM initiative

The Federal Government's initiative to promote BIM in the German construction industry started in 2015 with the publication of a step-by-step plan for the adoption of BIM and the set goal of a BIM mandate from the end of 2020 for all public infrastructure projects in the area of responsibility of the Federal Ministry of Transport and Digital Infrastructure (BMVI, 2015; Borrmann et al., 2016).

Starting point for the governmental BIM initiative was the large number of failed major projects in Germany such as the globally known disaster projects "BER" airport in Berlin, the "Elbphilharmonie" in Hamburg und the new central station "Stuttgart 21". During the years from 2013 to 2015 the failure of projects of this kind was examined by a national commission and as a result the use of IT-based methods, especially the use of BIM, in future projects was recommended in order to avoid such negative project completions (INFRABIM, 2018; PwC, 2018). Consequently, the BIM step-by-step was developed by the BMVI.

In summary, the step-by-step plan addressed to public client organisations in the infrastructure sector defines three stages:

2015 – 2017, Preparation phase:

Within this phase, first early-bird pilot projects should be carried out in order to enable the adaptation of standards, codes, clarification of legal issues and the development of guidelines for the implementation of BIM. In other words, the aim of this phase was to gain practical experience and identify development gaps and the need for action (Borrmann et al., 2016; INFRABIM, 2018; PwC, 2018).

2017 – 2020, Extended pilot phase:

A systematically increased number of projects should be implemented according to the target BIM Niveau 1. The main aim was to evaluate the feasibility of the measures from the preparatory phase and to adapt standards (BMVI, 2015; Borrmann et al., 2016; INFRABIM, 2018; PwC, 2018).

From 2020, Implementation phase:

From 2020, all new projects to be planned should meet the minimum requirements of BIM Niveau 1 (Borrmann et al., 2016; INFRABIM, 2018; PwC, 2018).

The minimum requirements for BIM Niveau 1, which will be mandatory for BIM based project delivery in public infrastructure projects from the end of 2020, are defined as follows (Borrmann et al., 2016, p. 872):

- Project delivery based on ISO 19600 (the upcoming international version of PAS 1192-2:2013)
- Employer's information requirements (EIR) for defining which data is required by the employer, when and in which detail
- Principle of federated domain-specific BIM models merged into a coordination model
- Development of a BIM Execution Plan (BEP) by all stakeholders defining: frequency of model coordination, level of detail delivered in which phase, usage of the model for visualization, quantity take-off, simulations and life-cycle assessment
- Usage of a common data environment according to ISO 19600
- Derivation of 2D plans from 3D BIM models
- Use of open data exchange standards (mainly IFC, but also OKSTRA and GAEB)
- Checking of data/models for fulfilment of the EIRs

The step-by-step plan described above initially envisages to keep the general execution of construction projects as stable as possible with regard to the legal framework conditions as well as the current fee structure for architects and engineers (HOAI). Through these decisions, the responsible parties hope for a simple and hurdle-free transition to BIM-based project delivery. Changes in laws and remuneration regulations may be considered in the future for a potential higher mandatory BIM Niveau (Borrmann et al., 2016).

Through the adoption of BIM in infrastructure projects, the German government hopes to see a cultural change and the establishment of new standards beyond this sub-sector in the entire German construction industry (Borrmann et al., 2018; PwC, 2018).

4.4.2 Public clients in the German road infrastructure sector

The type of public client organisations considered in this study are public authorities responsible for the procurement, planning, construction, maintenance and operation of road transport infrastructure in Germany and affected by the Federal Government's BIM initiative. In this context, the basic hierarchy in the German road administration is shown in Figure 11. The hierarchical structure is subdivided into the supreme authority of the federation and the supreme authority, the upper or middle authority and lower authorities of each of the 16 federal states in Germany.

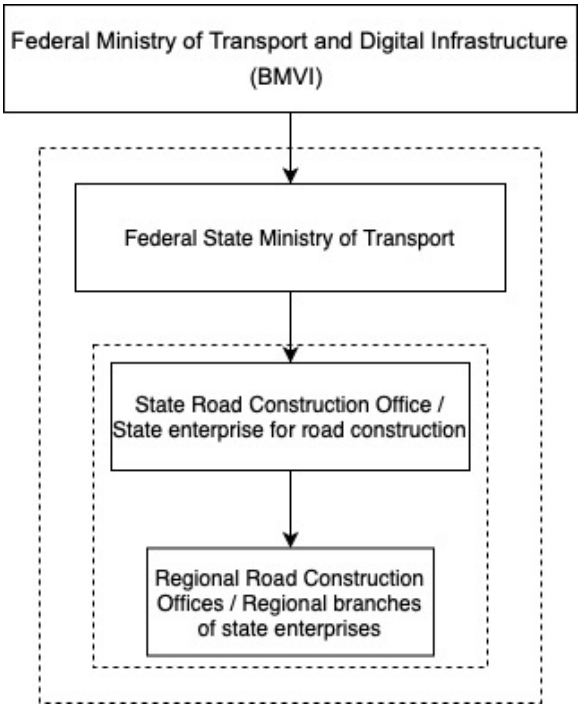

Figure 11 – Hierarchy of road administration in Germany

Source: (Durth & Hanke, 2004)

The supreme federal authority is the Federal Ministry of Transport and Digital Infrastructure (BMVI). The supreme authority of a federal state is the responsible Ministry of Transport. A state office forms the upper or middle authority and the lower authorities are regional road offices. These executive authorities are accordingly assigned to the federal state ministries. However, the hierarchies and structures within the federal states are not uniform and in some cases vary greatly, but are roughly oriented to the hierarchy described. In addition, the upper or middle-level road construction authorities of many federal states have already been transferred to state enterprises.

On the one hand, the road construction authorities and state enterprises of the federal states are responsible for the planning, construction and operation of federal state roads and, on behalf of the Federal Government and against reimbursement of costs, also take responsibility for all federal roads located in in the federal state, from planning to construction and operation (order administration for the Federal Government). For district roads, on the other hand, the district administrations are responsible, for municipal roads the cities and municipalities. In some cases, the districts also delegate certain tasks to the state road construction authorities.

In addition to this existing hierarchy, there are two public client organisation that operate across individual federal states. The organisations are to merge into a single organisation of the federation at the beginning of 2021 and will take over the responsibility for the planning, construction and operation of motorways throughout Germany, which is now still in the hands of the individual federal states. However, the responsibility for all other federal roads remains with the individual road construction authorities or state enterprises of the federal states in the course of order administration for the Federal Government (BMVI, 2019).

In summary, it is clear that the road administration within Germany is characterized by a complex and fragmented structure with a large number of independent state road construction authorities and state enterprises of the individual federal states, which also differ in their hierarchy and structure within the

individual states. In addition, in the course of the order administration of federal roads for the Federal Government by the individual federal states, there is a great need for coordination between these levels with regard to the division and overlapping of responsibilities, tasks and financing. In this context, it also becomes clear that the aforementioned BIM initiative and the planned BIM mandate of the Federal Government, which relate to federal projects, only apply to partial tasks and partial responsibilities of the vast majority of public client organisations, as there are no planned BIM mandates for state projects on the part of state governments to date.

Chapter 5 Results

This chapter presents the results of this research. The findings of the qualitative multiple exploratory case-study are structured and described according to the defined research questions. The current state of BIM adoption, future expected state of BIM adoption as well as driving forces and obstacles among public clients in the German infrastructure sector are presented on the basis of the conducted cross-case analysis. The preliminary investigation of the current state and future expected state of BIM adoption gives an insight into the current adoption dynamics and provides an overview of BIM use among the considered public client organisations. Among other things, this enables to classify different states of BIM adoption among the public clients. Consequently, this first step represents the point of departure and sets the contextual frame for the subsequent examination of the driving forces and obstacles. The findings in terms of driving forces and obstacles among the public clients are presented according to the theoretical model underlying this study, based on the TOE framework.

5.1 Current state of BIM adoption

This section presents the results with regard to the current state of BIM adoption among the considered public client organisations in the German road infrastructure sector and takes into account the *existing experience with BIM use*, the *frequency of BIM use* to date and the *current extent of BIM use*. In this way, a first insight into BIM adoption dynamics among the public clients is given and a point of departure for the subsequent analysis is created.

5.1.1 Existing BIM experience and current frequency of BIM use

Figure 12 shows the existing BIM experience among the organisations considered in this study. The current experience is illustrated by the number of years since BIM has been used by public clients.

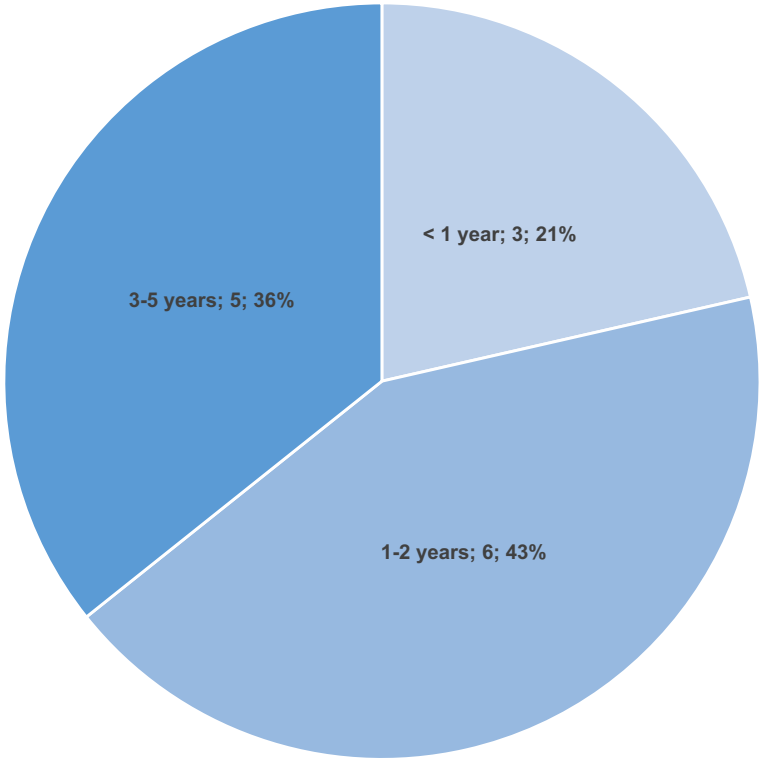

Figure 12 – Existing BIM experience among public client organisations

Six organisations have been using BIM for one to two years, which makes up the majority of the considered public clients. Five organisations have been using BIM for three to five years and three organisations have been using BIM for less than a year. It becomes clear that the vast majority of the public client organisations considered have only recently started to adopt BIM considering the start of the Federal Government's BIM initiative in 2015 (9 organisations with less than 2 years of BIM experience).

Figure 13 illustrates the frequency of BIM use to date in terms of the number of BIM projects among the public clients that have participated in this study. Four public clients already use BIM in one project, four other public clients in two projects, two in five or more projects and four organisations in ten or more projects. It can be observed that the vast majority of the public clients considered have so far used BIM in a relatively small number of projects (8 organisations with 2 or less BIM projects).

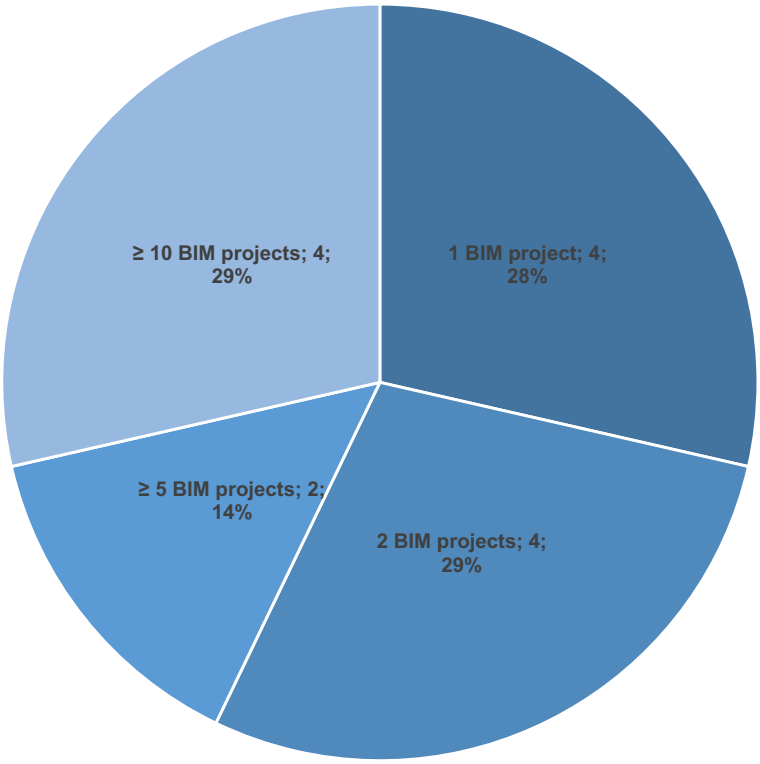

Figure 13 – Current frequency of BIM use among public client organisations

Putting the existing BIM experience in relation to the frequency of BIM usage to date provides a basic qualitative overview of the current BIM adoption dynamics among the public clients considered in this research. This overview is shown in Figure 14.

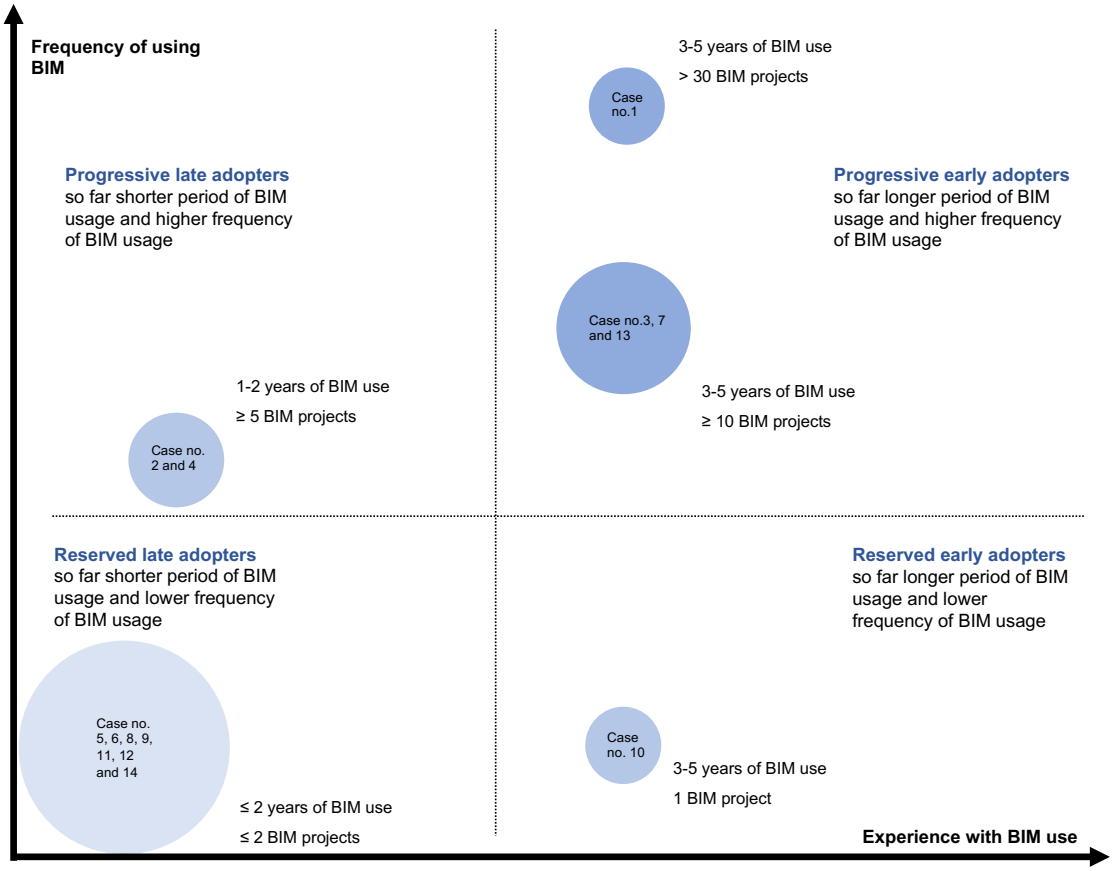

Figure 14 – Current BIM adoption dynamics among public client organisations

Against this background, the public client organisations can be classified into four groups shown in Figure 14. The group that makes up the majority of the cases considered are public clients that have only recently started using BIM (≤ 2 years) and use BIM only in a small number of projects (≤ 2 BIM projects). This group of seven organisations is referred to by the author in this study as *"reserved late adopters"*. The second largest group are those public clients that have been using BIM for a relatively long time (3-5 years) and have used or use BIM in a relatively large number of projects (≥ 10 BIM projects). This group of four public clients is referred to as *"progressive early adopters"* in this study. Between these adoption states, two much smaller groups can also be categorized. First, the *"progressive late adopters"*, which have also been using BIM for only a short time (1-2 years), but use BIM in a slightly higher number of projects (≥ 5 BIM projects). The last category consists of only one public client that has been using BIM for a relatively long time (3-5 years), but so far only in one project. Therefore, this public client organisation is called a *"reserved early adopter"*.

Based on the estimates of the representatives of the surveyed organisations, the share of BIM projects in all ongoing projects among all public clients can be estimated at less than 1% to 10%. Among the progressive early adopters, the share of BIM projects is estimated at around 5% to 10% and among all other groups at less than 1% to less than 5%. This indicates that the frequency of current BIM use in projects among all the public client organisations considered is still rather low compared to projects based on traditional working methods.

All in all, Figure 14 shows a fragmentation and reveals different BIM developments. This may indicate that there are different driving forces or obstacles for BIM adoption in the respective organisations.

Furthermore, these could be of different nature, have different degrees of impact or have a different relevance in the specific organisational contexts.

5.1.2 Current extent of BIM use

On a more general level, it can be noted that BIM is currently used by the public clients considered in this case study with a strong focus on civil structures such as bridges and tunnels. Road construction in the sense of line structures still account for a rather small proportion of current BIM use. The main reasons mentioned by respondents for the increased focus on civil engineering structures compared to traditional road construction are: more existing BIM experience in the market and among public clients; a more mature BIM technology in terms of more advanced software and data exchange formats; and the higher tangibility of BIM application in general as it is more similar to the traditional and already more advanced building construction sector. Accordingly, it was added that the BIM software available on the market for the route planning of roads is not yet fully developed and in road construction there are other specific requirements that have not yet been 100% transferred to the BIM methodology.

The current BIM usage among public clients in terms of project and life cycle phases is shown in Figure 15. It can be observed that almost all public client organisations considered in this study use BIM in the inventory phase and that all public clients use BIM in the planning and design phase. In all other phases, such as the approval phase, the tendering phase, the construction phase and the operation and maintenance phase, BIM has so far been used by very few to no public clients. In terms of the approval phase, BIM is currently only used for the extraction of 2D plans which is not in accordance with the actual BIM methodology, or is used for internal pre-approval purposes. The mentioned reason for this limited BIM usage is the lack of BIM adoption by the approval authorities. In the construction phase, BIM has so far been used by only three organisations, all of which can be classified as progressive early adopters. One public client of the progressive early adopters is currently in transition to the operation and maintenance phase. However, it was mentioned that the use of BIM for operation and maintenance is still rather in the preparatory phase.

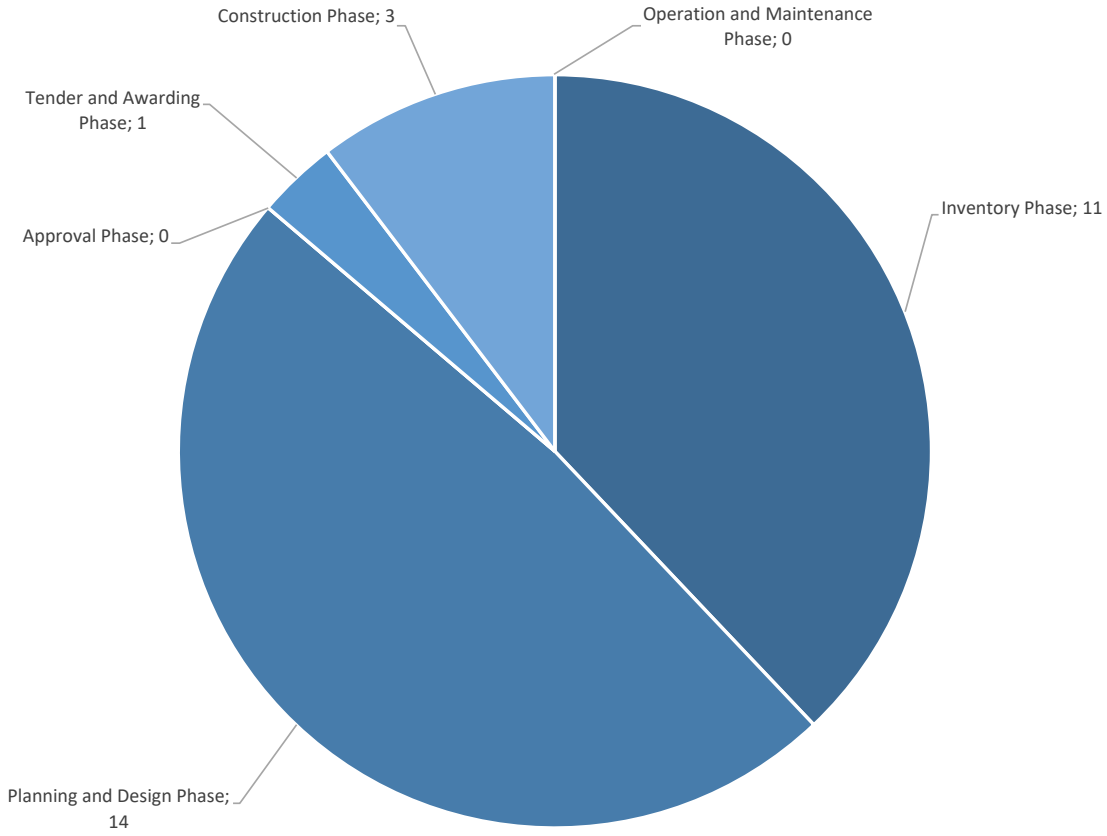

Figure 15 – Current BIM use in terms of life-cycle phases among public client organisations

It becomes clear that BIM so far has a strong design and planning focus among the public clients, and that there is a lack of BIM use in the construction and operation and maintenance phases. The very few organisations that use BIM in the subsequent phases can be assigned to the progressive early adopters. This means that those public clients that have been using BIM for a longer and more frequent period of time also use BIM to a greater extent.

The BIM applications used so far among the public clients considered correspond to the BIM usage identified in the different phases already described above and are presented in Figure 16. Accordingly, BIM applications that can be assigned to the planning and design phase like 3D visualisation and design coordination are used by almost all public clients. BIM applications that can be assigned to the subsequent phases, i.e. the construction logistics and construction progress monitoring assigned to the construction phase, have been used less so far, and if only by a small part of the progressive early adopters.

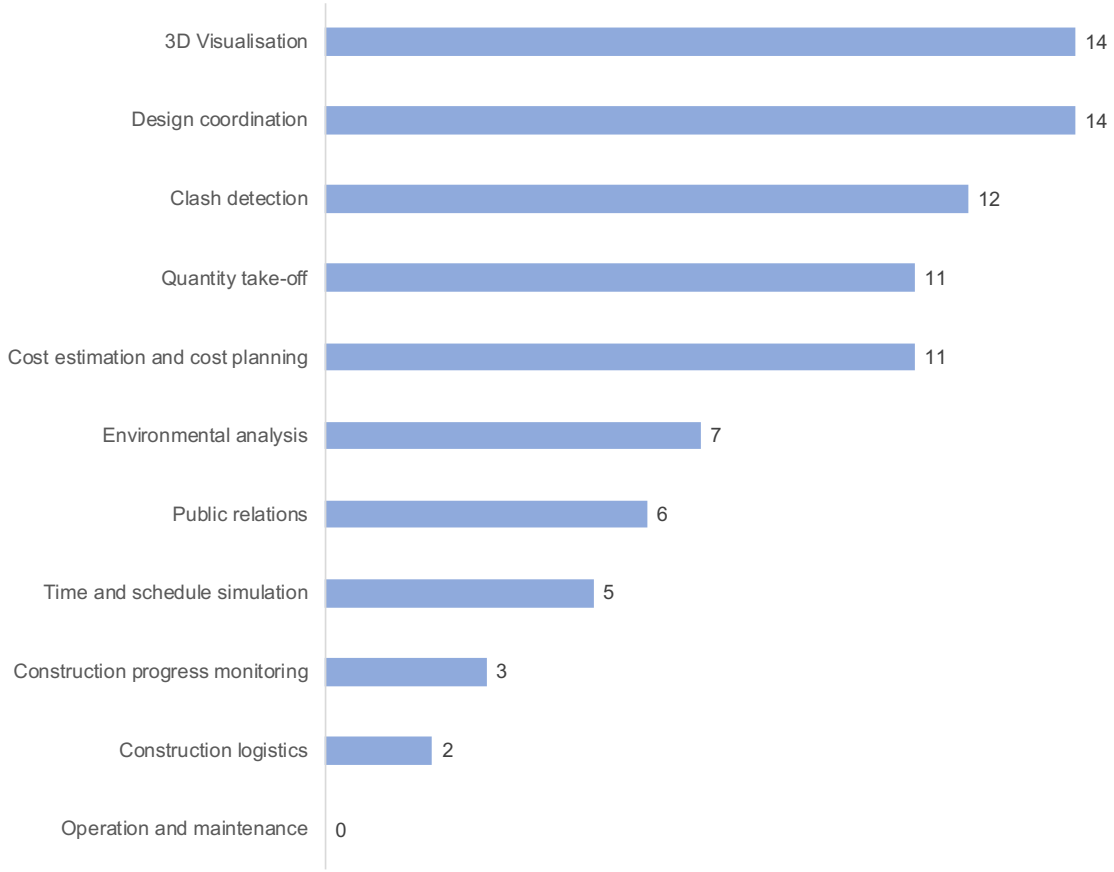

Figure 16 – BIM applications currently used among public client organisations

Current BIM usage with pilot character

When considering the current extent of BIM use, it should be noted that according to the respondents, all public clients considered are currently using BIM in the pilot phase. This means that all used BIM applications and carried out or ongoing BIM projects have pilot character. Only in organisations of two progressive early adopters BIM is slowly moving into standardised regular operation in initial projects, such as less complex bridges. According to the respondents, the main objectives of the BIM pilot projects are to test BIM as a technology and working methodology, to gain experience, to understand and learn BIM, and to identify where BIM has potential and advantages and what consequences BIM has for the organisation. Of particular interest in the pilot projects is the exploration of the interplay of the different trades and, accordingly, the merging and linking of the different BIM models of all project participants.

Selecting a project for BIM use

In the selection process for the use of BIM in a project, similar selection criteria in terms of project characteristics were identified among all public client organisations. These are: not in political focus or politically critical which is related to not time critical and lower time pressure; lower complexity which is related to a manageable project size in terms of building size (rather small) as well as number of project participants (rather less) and technical complexity (technical solution of the project should be clear); reflection of main areas of responsibility in the project; and types of BIM projects selected by other public clients. On the latter point, some respondents stated that the same project types as other

public clients were selected to ensure an exchange of experience. Other respondents indicated that other project types were selected to gain completely new experience in the field of road infrastructure.

5.2 Future expected state of BIM adoption

This section presents result with regard to the expected future state of BIM adoption among the considered public organisations in the German road infrastructure sector and refers to the period of the next one to two years. Thereby, it takes into account the same aspects as the examination of the current BIM adoption state except experience of BIM use. Accordingly, *future expected frequency of BIM usage* and *future expected extent of BIM usage* are considered. In this way, the potential development of BIM adoption is examined, which complements the understanding of adoption dynamics among the public sector organisations that participated in this study and, together with the insight into the current state of adoption, provides the contextual frame for the subsequent investigation of the driving forces and obstacles.

5.2.1 Expected future frequency of BIM use

The interviews conducted with the representatives of the public clients under consideration made it clear that the future frequency of BIM use in the next one to two years is rather unclear, as the vast majority of those questioned had problems making clear statements or statements at all. More specifically, the future frequency of BIM use mentioned were rough indications and were estimated differently by the respondents of all organisations. Therefore, no clear picture could be drawn about the expected future frequency of BIM use among the public clients. In general, however, all respondents agreed that BIM use will increase in the future, but more accurate estimates were not possible. Based on the insights from the interviews, it can be noted that the group of public clients assigned to the progressive early adopters expects to use BIM most frequently in the future among all organisations. The majority of the reserved adopters, on the other hand, do not firmly expect to use BIM in a significantly higher number of projects in the next one to two years and remain reluctant.

All in all, a dynamic can be identified which, on the one hand, is characterised by advanced public clients who want to continue to promote the adoption of BIM in the future but without precise expectations. On the other hand, there are less advanced public clients who are still hesitant to adopt BIM in the future. In addition, there is a small group of public clients, which are in an intermediate stage of BIM Adoption in this ratio. This indicates that the currently prevailing BIM fragmentation among the organisations of public clients could also be expected in the future.

5.2.2 Expected future extent of BIM use

With regard to the future extent of BIM use, the surveyed representatives of the public client organisations were able to make more concrete statements, as they were able to refer to future BIM use in the further course of their current BIM projects independently of potential future BIM projects.

Figure 17 shows the future expected BIM usage among public clients in terms of project and life cycle phases. It can be observed that the expected future use of BIM extends beyond the previous focus on the inventory phase and the planning and design phase into subsequent phases. Accordingly, the vast majority of public clients considered expect to use BIM in the next one to two years beyond its current

use, in the approval phase, tendering phase and construction phase. In addition, however, less than half of the organisations surveyed expect BIM to be used in the operation and maintenance phase. All respondents also mentioned that a deepening of previous BIM usage will be a strong focus in the future.

The extension of BIM use beyond the first two phases generally applies to all groups of public clients. However, two public clients of reserved late adopters expect to continue to use BIM for the next one to two years solely in the inventory as well as in the planning and design phase.

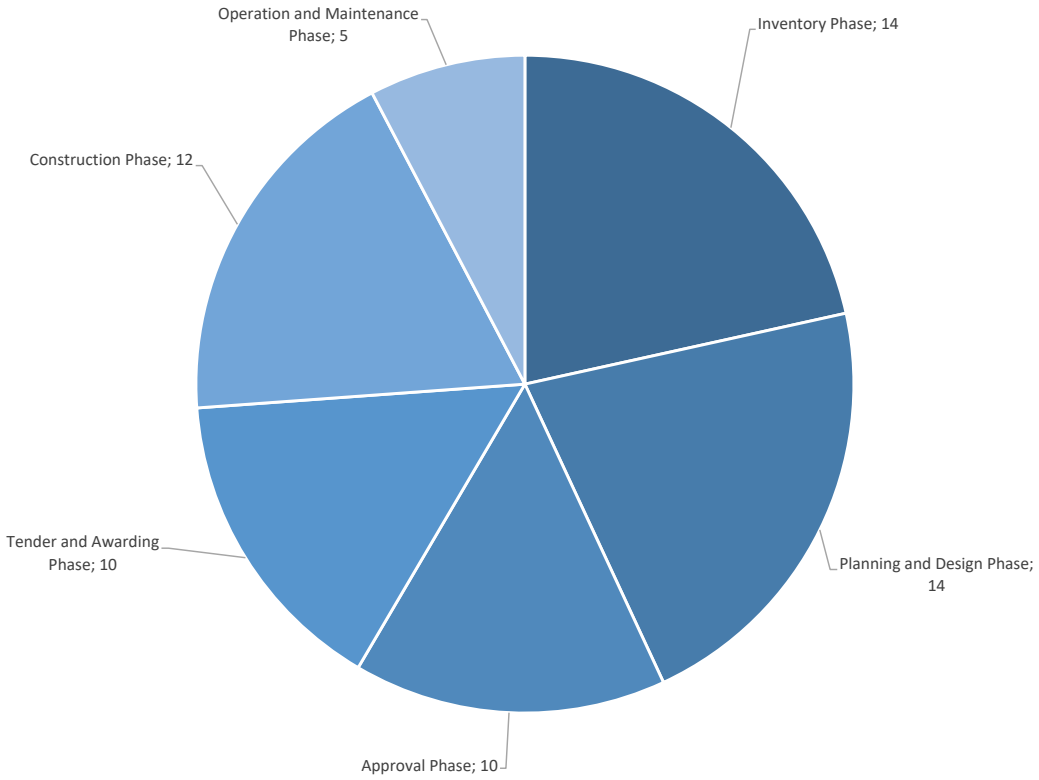

Figure 17 – Future expected BIM use in terms life-cycle phases among public client organisations

Similar to the consideration of the current BIM usage, the future expected BIM applications correspond to the expected BIM usage identified in the different phases already described above and is shown in Figure 18. Accordingly, with regard to the more advanced BIM applications that can be assigned to the planning and design phase, such as clash detection, quantity take off, and cost planning, it can be seen that more public clients expect to use these applications than today. This confirms the statements made by the respondents that the current BIM usage will be deepened in the future. BIM applications that can be assigned to subsequent phases are expected to be used by more public clients in the future, which is consistent with the aforementioned expansion of BIM use to other phases.

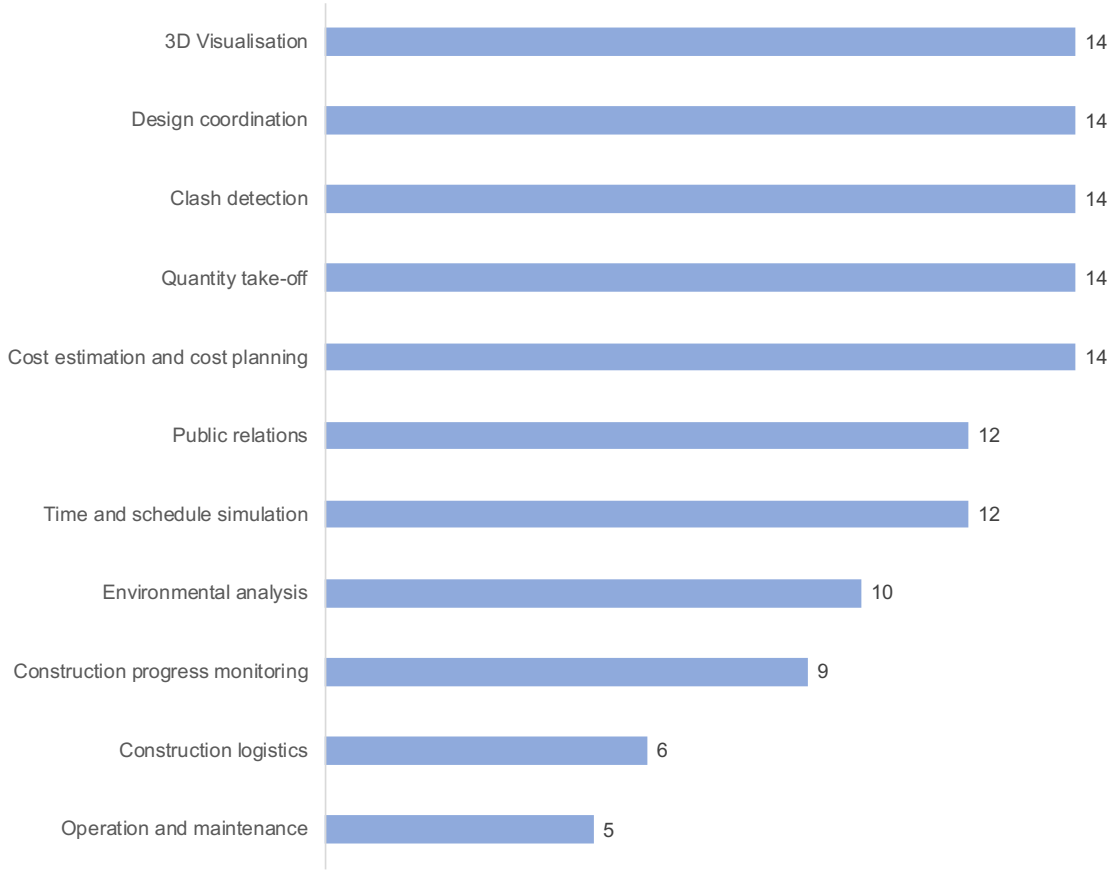

Figure 18 – Future expected BIM applications among public client organisations

5.3 Driving forces and obstacles

This section provides the results of the driving forces and barriers identified among the public client organisations in the German road infrastructure sector considered in this study. The findings are presented according to the theoretical model underlying this research, based on the TOE framework.

5.3.1 Technology and innovation context

5.3.1.1 Relative advantage

The representatives of 11 public client organisations interviewed who are responsible for BIM adoption stated that they generally consider BIM to be more advantageous for the work of their organisation than traditional working methods. In two organisations that can be assigned to the reserved late adopters the respondents (C9, C12) were not entirely convinced, questioned the sense of BIM and were critical whether BIM has clear advantages for them. The expected top BIM benefits given by the respondents are: improvement of project quality; more efficient communication; better life-cycle assessment; better understanding of planning and design; and improved public relations. Potential benefits such as reduction of project duration or reduction of costs were viewed rather critically by the respondents and are accordingly not expected to be achieved by using BIM. At best, one could imagine that BIM would

lead to less claims due to the increased project quality and enables more stable costs in the course of a project. According to the respondents, aspects such as health and safety and improving the organisational image are also seen as potential benefits, but are given low priority.

The representatives (C9, C12) of the two reserved late adopters, who questioned the possible benefits of BIM rather critically, justified this perspective with a lack of detailed knowledge about BIM and a lack of experience. Against this background, they made clear that they have to rely almost exclusively on input from other parties, i.e. specifications from the Federal Government or insights from other public clients. This has so far made it difficult for them to accurately assess the relative advantages of BIM. In addition, they indicated that they are not yet able to see clear benefits in projects of other organisations either. Furthermore, they stated that BIM in road construction, with the exception of civil structures, is not yet mature enough to be able to assess whether BIM makes sense and is advantageous. These two critical respondents indicated that they are still reluctant to adopt BIM because of the uncertainty about the potential benefits of BIM on the one hand and the enormous resources required for BIM adoption on the other. One added (C12) that he does not yet believe that BIM solves the problems that are really responsible for failed project.

The representatives of the other public clients who believe BIM to be more beneficial explained that relative advantage of BIM is their fundamental personal motivation to promote BIM adoption in their organisation. Furthermore, the relative advantage of BIM is the "selling point" for employees to engage in and use BIM.

Table 4 provides an overview of the driving forces and obstacles identified among the public clients considered in terms of relative advantage.

Table 4 – Overview of relative advantage

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Driving forces															
Believe that BIM is advantageous	x	x			x		x	x	x	x	x	x	x	x	11
Obstacles															
Believe that BIM does not give clear advantages				x		x									2

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

5.3.1.2 Complexity

The respondents from all 14 public client organisations involved in this study consider BIM to be complex and BIM adoption as accordingly challenging. The respondents, made clear that the complexity of BIM adoption can be seen as an interplay of the internal change process, the technological use of BIM in terms of software and data handling as well as the inter-organisational implementation of BIM in projects. In this context, the respondents explained that BIM adoption is enormously time-consuming in relation to all three of these aspects. This extra time is said to have to be managed by the employees in addition to their normal daily work, which slows down and hinders the adoption process accordingly.

Most representatives of the organisations considered stated that the internal change process is the most complex and time-consuming in terms of familiarising with BIM, developing a strategy and training program, learning BIM as an organisation and by employees, and promoting BIM among employees

during BIM adoption. Technological challenges, such as data exchange that is not yet functioning properly or immature software capabilities, take up a lot of time and sometimes lead to frustration among employees. This can reduce employee interest and commitment, but can mostly be solved, albeit through initially unsatisfactory interim solutions. In addition, respondents indicated that BIM as a technology is constantly evolving and that solutions would be developed in the future for problems encountered today. The situation is similar for the inter-organisational BIM use in projects. Using BIM in projects is currently still challenging and characterized by a learning process of all participants, which also takes up a lot of additional time, but is rather secondary in the context of the overall BIM adoption.

Table 5 provides an overview of the driving forces and obstacles identified among the public clients considered in terms of complexity.

Table 5 – Overview of complexity

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Obstacles															
BIM adoption is complex	x	x	x	x	x	x	x	x	x	x	x	x	x	x	14

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

5.3.1.3 Trialability

Respondents from all public client organisations, regardless of the number of pilot projects they have carried out, indicated that they are currently testing BIM successfully in pilot projects. According to the respondents, BIM pilot projects are essential to test BIM as a technology and working methodology, to gain experience, to understand and learn BIM in order to build up own know-how, and to identify where BIM has potential and advantages in practice and what consequences BIM has for the organisation. In addition, BIM pilot projects act as a multiplier to create interest and awareness among employees. In this context, the respondents explained that the knowledge gained from pilot projects often forms the basis for subsequent organisational developments such as the development of an own strategy and training program. Accordingly, the internal BIM experts of public client organisations usually develop in the course of pilot projects.

Against this background, respondents stated that the official pilot character of these projects outside the regular standard operation plays a key role for successfully testing BIM, as they are characterized by freer framework conditions under which public clients can operate. This has a positive effect on the adoption of BIM. For example, public procurement processes, which are otherwise highly regulated, are more flexible, allowing, for example, a freer choice of different software or tools, which results in faster, easier and more efficient learning. Moreover, pilot projects tend to be characterised by an environment where it is clear that the project represents a collaborative learning process among all participants, which could be characterised by trial and error processes. In contrast to regular operational projects, this project understanding ensures that the focus is less on money and that there is a greater mutual understanding of financial issues and possible disturbances in the BIM process, which creates a positive environment for learning and thus for the adoption of BIM.

Table 6 provides an overview of the driving forces and obstacles identified among the public clients under consideration in terms of trialability.

Table 6 – Overview of trialability

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Driving forces															
Testing BIM in pilot projects	x	x	x	x	x	x	x	x	x	x	x	x	x	x	14

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

5.3.1.4 Observability

The respondents (C1, C3, C4, C13) from four organisations that can be assigned to the progressive adopters indicated that they already see first clear benefits of BIM in practice, but not to the full extent and not in terms of all potential benefits. They explained that these first tangible BIM benefits are important to keep employees motivated who invest a lot of time in BIM adoption and that these are also important for promoting BIM and creating acceptance among employees in their organisations. Moreover, the tangible benefits show that they are generally on the right track. The representatives (C2, C5, C10, C11, C14) of six organisations, which make up the majority of the clients considered and can be assigned to all identified categories of adopters, stated that benefits become visible in practice and that some potentials can already be increasingly observed. However, they were unable to provide more precise details. In contrast, according to the respondents (C6, C8, C9, C12) from organisations that can be assigned to the reserved late adopters have not yet observed any clear advantages of BIM in practice. As mentioned earlier in considering relative advantage, these respondents indicated that they are still hesitant to adopt BIM because of the uncertainty about BIM benefits and the lack of visibility of BIM benefits in practice on the one hand, and the enormous resources required to adopt BIM on the other.

According to the rather vague statements of the respondents, the advantages or potentials of BIM, which have so far been most evident are: better understanding of planning and design; more efficient communication; and improved public relations. These match three of the top five expected potential benefits of BIM already identified in terms of relative advantage. A clear improvement in project quality or improvement in the life cycle assessment, which are also considered as top expected benefits, cannot yet be observed.

The reasons given by the respondents for not yet seeing clear BIM benefits in practice, or so far only in to limited extend, are: lack of practical experience in the sense of projects that are not yet progressed enough and insufficient number of projects, since every project is unique and benefits must be evaluated across projects; it is generally difficult to measure the benefits of BIM, as the results so far have tended to be of a more qualitative nature, and the evaluation is therefore based rather on experience and feeling; and the current use of BIM is still too pilot-like due to obstacles caused by immature technology or lack of know-how and the additional effort due to massive learning, which dilutes the potential BIM benefits.

Especially with regard to the lack of experience, it was explained that the exploration of potential BIM advantages from the client's point of view takes a very long time and therefore has an inhibiting effect on the adoption of BIM. Unlike engineering firms or contractors, the greatest benefits of BIM for the client are expected over the entire life cycle and not only in relation to individual phases such as the design phase relevant for an engineering firm or the construction phase relevant for a contractor. Accordingly, for several projects, clients must first go through all phases up to the end of life, including the late phase of operation and maintenance, which is considered most relevant for the client's use of BIM, in order to gain a full and clear understanding of the potential benefits of BIM. In addition, there are be special circumstances in the infrastructure sector, which are characterised by long planning

approval procedures that are very time-consuming in which public clients cannot gain practical experience.

Against this background, many of the respondents, also from the progressive early adopters, made it clear that currently the vision of beneficial BIM use in the future is still driving BIM adoption more than current concrete observable practical references.

Table 7 provides an overview of the driving forces and obstacles identified among the public clients considered in terms of observability.

Table 7 – Overview of observability

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Driving forces															
Tangible BIM benefits										x	x	x		x	4
Obstacles															
Lack of clarity and evidence of BIM benefits		x	x	x		x									4

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

5.3.1.5 Summary innovation and technology context

Table 8 shows a summary of driving forces and obstacles for BIM adoption in the innovation and technology context identified among the public clients considered.

Table 8 – Summary of innovation and technology context

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Driving forces															
Testing BIM in pilot projects	x	x	x	x	x	x	x	x	x	x	x	x	x	x	14
Believe that BIM is advantageous	x	x			x		x	x	x	x	x	x	x	x	11
Tangible BIM benefits										x	x	x		x	4
Obstacles															
BIM adoption is complex	x	x	x	x	x	x	x	x	x	x	x	x	x	x	14
Lack of clarity and evidence of BIM benefits		x	x	x		x									4
Believe that BIM does not give clear advantages				x		x									2

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

5.3.2 Organisation context

5.3.2.1 Top management support

The respondents (C1, C3, C7, C13) of the four progressive early adopters mentioned that their top management is interested in BIM and has officially communicated support for BIM. They explained that top management committed to BIM is important to show that BIM has a certain priority within the organisation and to create a supportive environment for motivated employees to effectively promote BIM adoption. According to the respondents, the support of top management is particularly important in public authorities due to bureaucratic and hierarchical structures.

Three of the respondents (C5, C9, C11) from organisations that can be assigned to the reserved late adopters explained that the lack of priority of BIM within the organisation and the lack of support from top management and across all levels of hierarchy inhibits BIM adoption. One respondent (C5) stated that due to the lack of priority, the necessary resources and capacities are not being made available to adequately promote the adoption of BIM. Another interviewee (C9) pointed out that top management is aware about the fact that BIM needs to be addressed, but is clearly not willing to do so. In addition, one respondent (C11) indicated that BIM is currently treated as a marginal phenomenon in his organisation. The top management believes that enough is being done with initiating one pilot project for the time being and that real progress will only be seen through more official pressure from the Federal Government on state ministries and public clients.

Table 9 provides an overview of the identified driving forces and obstacles among the public clients considered in terms of top management support.

Table 9 – Overview top management support

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Driving forces															
Top management support											x	x	x	x	4
Obstacles															
Lack of top management support	x			x	x										3

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

5.3.2.2 Organisational readiness

The organisational BIM readiness of the public involves five factors, namely *BIM expertise, IT infrastructure, financial resources, personnel resources* and *BIM strategy*.

BIM expertise

The vast majority of respondents from eleven public client organisations indicated that there is a lack of internal BIM expertise in their organisations. Only representatives (C1, C3, C13) of three organisations, all of which can be classified as progressive early adopters, stated that they have adequate internal BIM expertise to strongly promote the adoption of BIM and to use BIM frequently.

The majority of respondents, regardless of the level of internal BIM expertise, consider a certain level of BIM expertise in the organisation and thus among the employees generally to be important for the adoption of BIM. They explained that developing BIM expertise is not only essential for the professional implementation of the BIM method itself, but also for the internal change process. Against this background, BIM expertise builds the basis for creating interest, acceptance and enthusiasm for BIM among employees, communicating the added value of BIM and reducing reservations. Employees with BIM expertise serve as multipliers for developing BIM acceptance among employees.

As already noted in section 5.3.1.3, all respondents mentioned BIM pilot projects as a key source for developing their own internal BIM expertise. Accordingly, the interviewees who perceive a lack of BIM expertise reported that they still lack practical experience and a sufficient number of BIM projects to build up strong internal BIM competence. Furthermore, regardless of the level of internal BIM expertise, respondents agreed that the transfer of BIM know-how from the individual pilot projects to the organisational level is a major challenge. Against this background, most of the respondents

identified a BIM knowledge gap between the few project staff involved in BIM pilot projects and the majority of employees who have not yet carried out any BIM projects. In particular, the representatives of public clients with a lack of BIM expertise stated that the BIM know-how built up so far is almost exclusively located in the environment of the few pilot projects. Although some organisations have first cross-project BIM working groups, the number of employees actively involved is rather small compared to the size of the entire organisation. Only the respondents of the four progressive early adopters stated they have already implemented organisation-wide BIM training programs for employees. Whereas the respondents from other organisations indicated that individual employees in the course of their pilot projects still have to develop their BIM knowledge autodidactically in practical project work or have to look for external training courses.

Against this background, respondents (C2, C4, C5, C6) from four organisations stated that they intend to implement BIM training programs in the near future. One representative (C5) made it clear that the implementation of a training program has so far failed due to a lack of time and personnel capacities and that they therefore have to see whether BIM training can be purchased externally. The respondents (C6, C10) of two organisations, on the other hand, stated that there are no suitable BIM training programs on the market specifically tailored to the role of public clients in the road infrastructure sector that can be easily purchased or adopted. According to respondents from these organisations that intend to implement organisation-wide training programs, a lack of time and personnel resources and the lack of suitable training programs on the market complicate the adoption of BIM.

In five other public client organisations, however, the respondents (C8, C9, C10, C11, C12) indicated that their organisations do not intend to implement an organisation-wide BIM training program in the near future at all. The majority of representatives (C8, C9, C11, C12) from these organisations explained that due to a lack of resources (time, personnel and finances), a lack of expertise and since the adoption of BIM is primarily initiated by the Federal Government, they are waiting for further political specifications and guidelines in the course of the Federal Government's planned BIM mandate or are waiting to see whether training courses are developed at federal level which can then be used or adopted. One of these respondents (C10) particularly pointed out that due to the lack of priority for BIM in his organisations, no BIM training program is intended to be implemented and the Federal Government has to exert more pressure to make something happen in this respect.

In addition, the respondents that have already or intend to implement BIM training programs stated that BIM training for managers and leadership in public client organisations plays a key role in BIM adoption. These interviewees reported that especially in hierarchically structured authorities, a certain amount of BIM know-how among management personnel is decisive in ensuring that employees receive permission from their superiors to deal with BIM and to promote the adoption of BIM. Accordingly, the representatives surveyed observe that superiors with a lack of BIM competence and a lack of knowledge about the added value of BIM do not give employees sufficient freedom to deal with BIM and this inhibits BIM adoption.

Furthermore, the respondents indicated that the expansion of BIM expertise by new employees in the sense of hiring BIM specialists has not been of great importance for the public clients considered so far. On the one hand, many respondents stated that there are no internally approved vacancies that can be filled. On the other hand, those who have vacancies indicated that it is difficult for public clients to recruit BIM specialists on the open market due to the limited salary possibilities at public authorities. Finally, most agreed that, similar to the BIM training programs, there are almost no suitable BIM specialists for the specific role of public clients in the road infrastructure sector.

Table 10 provides an overview of the driving forces and obstacles identified among the public clients considered in terms of BIM expertise.

Table 10 – Overview BIM expertise

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Driving forces															
Adequate BIM expertise											x	x		x	3
Obstacles															
Lack of BIM expertise	x	x	x	x	x	x	x	x	x	x			x		11

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

IT infrastructure

Many respondents of the public client organisations considered indicated that their IT infrastructure is indeed not always up to date and that new purchases in hardware and software will have to be made in future, but that IT infrastructure generally plays a minor role in their current BIM adoption. Since they put the actual BIM services like design services out to tender and award contracts to engineering firms and contractors, they explained that they initially only need a common data environment and a BIM viewer or BIM model checker. According to these respondents, this does not entail any major technical problems.

Two respondents (C6, C9) of the public clients that can be assigned to the reserved late adopters stated that the use of a common data environment in terms of responsibilities and procurement in their organisation is still unresolved and inhibits BIM adoption. One respondent (C9) even stated that they currently have to check the BIM models of their trading partners using 2D plans, which of course means that the advantages of BIM in this regard could not be achieved. Moreover, he also added that there is a general lack of sufficient IT infrastructure in his organisation. The representatives of three organisations that can be assigned to the progressive adopters (C1, C2, C4) stated that they do not have sufficient hardware and software throughout their whole organisation to expand the current use of BIM.

Finally, one respondents (C7) explained that the advanced IT equipment of his organisations allows them to better explore the potential benefits and applications of BIM through, for example, virtual-reality glasses or a high-tech BIM collaboration room.

Table 11 provides an overview of the driving forces and obstacles identified among the public clients under consideration in terms of IT infrastructure.

Table 11 – Overview IT infrastructure

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Driving forces															
Advanced IT infrastructure													x		1
Obstacles															
Lacking or inadequate IT infrastructure		x		x					x	x	x				5

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

Financial resources

The respondents of all public clients basically agreed that BIM adoption is associated with high investments in the long-term with regard to the internal change process, purchase of IT equipment, but

also the tendering of BIM services in projects, and therefore conclude that additional financial resources are fundamentally beneficial.

The respondents (C2, C5, C6, C10, C14) from five public clients indicated that a certain level of available financial resources is indeed a basic requirement for the adoption of BIM, and that they also have limited resources, but that this is not a major problem for the current BIM adoption in their organisation. They added that the crucial problem in this context is rather the lack of personnel and time capacities. They remain the crucial factor without which they would not be able to better promote the adoption of BIM, even if more financial resources were available.

Respondents (C8, C9, C11, C12) of four organisations that can be assigned to the reserved late adopters explained that they generally lack the financial resources for the initial investments needed to provide sufficient conditions for an organisation-wide BIM adoption. Two respondents of public clients that can be assigned to the progressive adopters (C3, C4) stated that their financial resources are not sufficient in order to continue to push BIM adoption as strongly as before and to further promote the whole organisation-wide rollout of BIM. Against this background, these organisations are waiting for more financial resources from the state government on the one hand and additional financial support from the Federal Government with regard to the BIM mandate on the other.

The representatives of the three public clients that can be assigned to the progressive early adopters (C1, C7, C13) explained that their adequate financial resources give them more opportunities to explore and test BIM as well as to accelerate their internal change process. Two of these respondents (C7, C13) emphasized the good financial support from their state governments as a key factor for their adequate financial opportunities.

Table 12 provides an overview of the driving forces and obstacles identified among the public clients considered in terms of financial resources.

Table 12 – Overview financial resources

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Driving forces															
Adequate financial resources											x		x	x	3
Obstacles															
Lacking or inadequate financial resources			x	x	x	x				x		x			6

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

Personnel resources

The respondents from 11 public client organisations across all identified adopter categories indicated that they generally lack sufficient personnel resources. In this context, they explained that BIM is currently adopted alongside the daily business of employees. As a result, there is a lack of time capacity both for employees who are responsible for organisation-wide BIM adoption and for employees who are already working in BIM projects or want to work in BIM projects in the future. On the one hand, this slows down the development of BIM strategies, concepts and training programs and thus the overall organisation-wide adoption process from the perspective of those currently responsible for BIM adoption. On the other hand, for project staff who are already working at full capacity, this leads to a situation where they are less or not able to deal with BIM at all. As a result, it is not enough time for project staff to familiarize themselves with BIM and receive training in BIM, which ultimately leads to

fewer employees who show interest in BIM and are able to or want to voluntarily carry out projects in BIM.

Table 13 provides an overview of the identified driving forces and obstacles among the public clients considered in terms of personal resources.

Table 13 – Overview personnel resources

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Obstacles															
Lacking or inadequate personnel resources	x	x	x	x	x	x	x		x	x			x	x	11

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

BIM strategy

The respondents (C8, C9, C11, C12, C10) from five organisations that can all be assigned to the reserved adopters indicated that their organisations are not currently working on an own BIM strategy and that accordingly none will be implemented in the near future. As a result, there is a lack of a holistic organisational approach to promote BIM adoption. In this context, these representatives mentioned that they lack the resources and expertise to develop a strategy themselves. One respondent (C11) indicated that the adoption of BIM at the organisational level and, accordingly, the development of a BIM strategy has not yet been given high priority. Furthermore, these respondents explained that they lack orientation for the development and implementation of a strategy because of missing detailed specifications from the Federal Government with regard to the planned BIM mandate. And since the BIM adoption is initiated by the Federal Government anyway, they are waiting for further specifications or guidelines from the Federal Government in order to take the next steps in adopting BIM.

The respondents from four organisations, three of them reserved late adopters (C5, C6, C14) and one progressive late adopter (C2), indicated that they already have an organisational approach and are currently in the process of developing and implementing a BIM strategy. However, they have not yet fully implemented it. Accordingly, these respondents explained that the process is very cumbersome due to limited capacities, especially in terms of time and personnel, and has therefore been delayed for some time.

The respondents from five organisations, four of them progressive early adopters (C1, C3, C7, C13) and one progressive late adopter (C4), stated that they already have a BIM strategy in place that drives and guides the BIM adoption of their organisation. The respondents made it clear that an officially communicated BIM strategy is important for organisation-wide BIM acceptance among employees. Thus, a strategy shows that BIM has a certain priority within the organisation and communicates the path of BIM adoption. In this context, a BIM strategy is important to define clear measures such as the development of a BIM training program and is essential to achieve the goal of BIM use in regular operations. Two of the respondents (C7, C13) made it clear that support from their state government, in particular measures such as a context setting BIM strategy development at the state level have a positive influence on their own strategy development.

Table 14 provides an overview of the driving forces and obstacles identified among the public clients considered in terms of BIM strategy.

Table 14 – Overview BIM strategy

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Driving forces															
Guiding BIM strategy										x	x	x	x	x	5
Obstacles															
Lack of a guiding BIM strategy			x	x	x	x		x							5

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

Organisational culture

On the one hand, the respondents of ten public client organisations stated that they have so far noted a restrained interest and demand for BIM on the part of the vast majority of employees including management personnel like department heads and a lot of persuasion still needs to be done. On the other hand, the respondents indicated that mostly very small groups or individual employees with a high level of commitment and interest drive BIM adoption on a voluntary basis. These dedicated employees often undertake BIM training on their own initiative and usually assume this responsibility in addition to their actual main task and often without any real organisational backing. In addition, respondents from these organisations indicated that most of the employees in their organisations still lack BIM awareness, such as knowledge of the added value of BIM, practical experience and time capacities in order to develop real BIM interest and demand. A few representatives from the organisations considered (C6, C8, C11) stated that BIM interest is seen mainly among young employees and that, in this context, the high age structure in public authorities, especially among superiors, may inhibit BIM adoption.

The respondents (C1, C3, C4, C13) from four public client organisations that can be assigned to the progressive adopters stated that they can already observe a high level of interest among employees and that a certain internal BIM demand has developed over time. They explained that in this context, BIM projects, BIM training programs and communicated priority within the organisation play key roles in creating awareness and interest in BIM among employees. However, two of these respondents (C3, C4) also indicated that small groups of highly committed employees are mainly driving the adoption of BIM.

Table 15 provides an overview of the driving forces and obstacles identified among the public clients under consideration in terms of organisational culture.

Table 15 – Overview of organisational culture

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Driving forces															
Small groups of highly committed employees	x	x	x	x	x	x	x	x	x	x		x	x		12
High internal interest and demand										x	x	x		x	4
Obstacles															
Lack of major internal interest and demand	x	x	x	x	x	x	x	x	x				x		10

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

5.3.2.3 Organisational structure

On the one hand, respondents (C2, C4, C6, C8, C9, C11, C12) from seven public client organisations indicated that slow, inflexible and very hierarchical administrative structures, typical for a public authority, inhibit and slow down BIM adoption. They argued that decision-making processes, procurement processes and definitions of the further course of action, are usually complicated, take a long time and involve many internal approvals. These inflexible and rigid procedures delay individual steps in the adoption process and ultimately inhibit BIM adoption. In addition, the rigid line hierarchies of public clients mean that coordination or exchange between employees of different departments often have to be agreed with superiors. This also hinders smaller steps in the BIM adoption process and often a lot of persuasion is needed with superiors, which leads to frustration among employees who want get involved in BIM adoption.

On the other hand, the respondents of ten public clients indicated a lack of official departments and employees specialised in BIM and responsible for adopting BIM in their organisation. According to the respondents, many of the public clients have no official BIM staff at all and lack clear responsibilities with regard to organisation-wide BIM adoption. Although some of these public clients have one or a few officially communicated BIM representatives who take responsibility for organisation-wide BIM adoption, these respondents also stated that they do not belong to a specialized organisational BIM department, accordingly do not have sufficient organisational resources and do this beside their main job. In this context, their very limited capacities are not sufficient to roll out BIM organisation-wide.

Respondents (C1, C3, C13) from three organisations that can be assigned to the progressive early adopters indicated that they have a clear structural orientation towards BIM adoption in their organisations in form of specialist departments and employees responsible for BIM.

Table 16 provides an overview of the driving forces and obstacles identified among the public clients considered in terms of organisational structure.

Table 16 – Overview organisational structure

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Driving forces															
Structural orientation of the organisation											x	x		x	3
Obstacles															
Inhibiting administrative processes		x	x	x	x	x			x	x					7
Lack of structural orientation of the organisation	x	x	x	x	x	x	x	x	x	x					10

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

5.3.2.4 Communication behaviour

A majority of the respondents from ten public client organisations considered across all identified adopter categories pointed out that they have a value-adding supportive network and that BIM exchange with external actors is enriching for their BIM adoption.

All public client respondents mentioned BIM conferences and working groups, which are set up by the Federal Government as important exchange platforms. The conferences take place at regular intervals, with participants from the federal ministry, the state ministries and representatives of public client

organisations to coordinate BIM adoption in the course of the Federal Government's BIM initiative. The representatives of the public clients who stated that they have a good network, however, made it clear that the close and value-adding exchange with other public clients is organised bilateral and based on own initiative. The BIM conferences are more of a platform for establishing contacts with other public clients. The respondents explained that this exchange with other public clients is important to learn from each other and share experiences in terms of BIM use in projects and organisation-wide BIM adoption (i.e. developing training programs or strategies). Against this background, more BIM advanced organisations pass on knowledge, developed templates or concepts such as object catalogues to less advanced organisations for mutual support.

Furthermore, many respondents from public client organisations with a good network, compared to the others, indicated that they show a high level of personal individual commitment in associations, industrial clubs and in BIM clusters with actors of the private sector. In this context, they stated that this has a positive influence on the BIM adoption of their organisation, as the input from potential trading partners like engineering firms or contractors is also important for the orientation of their BIM adoption and learning curve.

Moreover, two respondents of the most advanced public clients (C3, C7) that can be assigned to the progressive early adopters explained that they also have close cooperation with external parties such as universities. For example, one pubic client (C3), together with six other organisations and with the backing of their state government, including other public sector clients from the state with other responsibilities, but also from the construction sector, and a university, has launched its own BIM initiative. Within this initiative, problems are solved together and solutions for standards, guidelines, BIM training or templates are developed. The other progressive early adopter (C7) initiated very close cooperation with a university and has BIM projects and organisation-wide BIM adoption accompanied by this university. In this way, both sides benefit, as the university offers recommendation and support and the public client in turn serves as a field study for research.

Three respondents (C9, C11, C12) stated that they do not have a value-adding network and indicated that they simply are not yet actively networking due to limited time capacities, unclear responsibilities and lack of initiative. In addition, that they were unable to participate well in existing exchange platforms due to a lack of time, experience and knowledge about BIM and thus could not yet generate any real added value from this. One respondent (C10) pointed out that although his organisation participates in several exchange platforms, they can only generate limited added value because the topics of interest to them are too specific and the exchange is too superficial (e.g. in terms of specific software issues or problems occurring in the individual projects' environment).

Table 17 provides an overview of the driving forces and obstacles identified among the public clients considered in terms of communication behaviour.

Table 17 – Overview communication behaviour

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Driving forces															
Value-adding supportive network	x	x	x				x		x	x	x	x	x	x	10

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

5.3.2.5 Summary organisation context

Table 18 shows a summary of driving forces and obstacles for BIM adoption in the organisation context identified among the public clients considered.

Table 18 – Summary organisation context

Adopter category* / Case no.	RL 5	RL 6	RL 8	RL 9	RL 11	RL 12	RL 14	RE 10	PL 2	PL 4	PE 1	PE 3	PE 7	PE 13	
Driving forces															
Small groups of highly committed employees	x	x	x	x	x	x	x	x	x	x		x	x		12
Value-adding supportive network	x	x	x				x		x	x	x	x	x	x	10
Guiding BIM strategy										x	x	x	x	x	5
Top management support											x	x	x	x	4
High internal interest and demand										x	x	x		x	4
Adequate BIM expertise											x	x		x	3
Adequate financial resources											x		x	x	3
Structural orientation of the organisation											x	x		x	3
Advanced IT infrastructure													x		1
Obstacles															
Lack of BIM expertise	x	x	x	x	x	x	x	x	x	x			x		11
Lacking or inadequate personnel resources	x	x	x	x	x	x	x		x	x			x	x	11
Lack of structural orientation of the organisation	x	x	x	x	x	x	x	x	x	x					10
Lack of major internal interest and demand	x	x	x	x	x	x	x	x	x				x		10
Inhibiting administrative processes		x	x	x	x	x			x	x					7
Lacking or inadequate financial resources			x	x	x	x				x		x			6
Lacking or inadequate IT infrastructure		x		x					x	x	x				5
Lack of a guiding BIM strategy			x	x	x	x		x							5
Lack of top management support	x			x	x										3

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

5.3.3 Environment context

5.3.3.1 Governmental policies

Governmental policies with regard to the adoption of BIM by public clients in the German road infrastructure sector involves three factors. Firstly, the *Federal Government's BIM initiative* is involved, whereby the Federal Government attempts to push public clients of the federal states to adopt BIM in the course of order administration for federal projects in the respective states. Secondly, the *Framework conditions set by the respective state governments* in which BIM adoption of public clients takes place is involved. This is relevant because although the BIM initiative originates from the Federal Government and refers to federal projects, the public clients are assigned to the ministries and governments of the individual states in the hierarchy of the German road administration. Finally, the *BIM guidelines published by the Federal Government* are involved.

BIM initiative of the Federal Government

One the one hand, all representatives of the fourteen organisations surveyed mentioned the Federal Government's BIM initiative consisting of the step-by-step plan and the planned BIM mandate as the impetus for the adoption of BIM. In this context, they indicated that the start of the BIM adoption in their organisation was a reaction to the BIM initiative of the Federal Government. On the other hand, seven respondents (C2, C6, C8, C9, C10, C11, C12) also stated that the lack of further and detailed specifications from the Federal Government with regard to the initiative is hindering the current adoption of BIM in their organisation. In this context, missing specifications are understood as information that defines in which federal projects BIM is to be used for which BIM applications and to what extent, and how exactly BIM is to be implemented and demanded within the framework of the planned BIM mandate.

In general, the respondents indicated that the BIM step-by-step plan published in 2015 has created an initial BIM awareness in their organisations and that the planned BIM mandate conveys the message that BIM must be used at a certain point, which is perceived as a pressure to adopt BIM.

Three respondents (C3, C7, C13) of the four progressive early adopters reported that after creating a strong early BIM awareness, the BIM initiative stimulated their own organisational BIM interest and motivation. In this context, they explained that the BIM initiative represents an official framework for BIM adoption, for example in the sense of BIM conferences or workshops organised at federal level or the general communication that BIM adoption has now a certain priority, which has a positive effect on their BIM adoption. Within this framework, however, they promote BIM adoption quite independently of the Federal Government together with their state governments. According to the respondents, further BIM specifications of the Federal Government of course affect their BIM adoption, but they do not consider missing specifications as an obstacle as they are promoting BIM on their own initiative.

The respondents from the late adopters, made it clear that the interest in BIM from their organisation was limited at the beginning when the step-by-step plan was published, and therefore they only started with first BIM projects later. The representatives of five reserved late adopters (C6, C8, C9, C11, C12) made it clear that the planned BIM mandate for federal projects of the Federal Government is still the main reason for their BIM adoption. They are waiting for binding and implementable specification and then want to adopt them one-to-one. Although they stated that the BIM initiative has defined a rough timeline in form of the step-by-step plan and a target in form of the planned BIM mandate, it is not clear how exactly this target of mandatory BIM use could be achieved. Against the background of their own limited possibilities, these respondents stated that they lack orientation and that they are not clear about the direction in which they should steer their BIM adoption. Therefore, they wait and see before committing intensive resources and capacities in order to take next own steps in adopting BIM, such as the development of BIM strategies, training programs or the start of a large number of new BIM projects.

One of the interviewees (C 11) indicated that he expects great progress in the adoption of BIM in his organisation only if the Federal Government in general exerts even more pressure on his state governments and his organisation to adopt BIM. Another representative (C2) responsible for BIM adoption in his organisation pointed out that they are waiting for political decisions and binding specification in order to be able to exert more pressure internally to promote BIM adoption.

One respondent (C10) explained that his organisation is deliberately waiting for further specifications from the Federal Government. Firstly, because they do not have the skills and resources to carry out all the necessary steps of an organisation-wide BIM adoption (e.g. development of a strategy, training

programme or standardised processes) themselves, and secondly, because they do not consider it reasonable for each state and public client to develop its own approach. In the long run, this only leads to confusion and fragmentation among public clients and to disadvantages for trading partners in the market.

Table 19 provides an overview of the driving forces and obstacles identified among the public clients considered in terms of the Federal Government's BIM initiative.

Table 19 – Overview BIM initiative of Federal Government

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Driving forces															
Federal Government's BIM initiative	x	x	x	x	x	x	x	x	x	x	x	x	x	x	14
Obstacles															
Lack of detailed specifications from Federal Government		x	x	x	x	x		x	x						7

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

Framework conditions set by the state governments

The majority of respondents from the public clients considered indicated that their state governments have so far played a rather passive role in BIM adoption. Against this background, the state governments are aware of the federal BIM initiative, but do not actively promote BIM adoption or define own BIM specifications or policies. Consequently, they do not actively address BIM, but they do not strictly reject it either and simply pass on the specifications of the Federal Government's BIM initiative to the public clients.

The respondents (C3, C7, C13) of three progressive early adopters explained that their state governments are not only aware of the federal BIM initiative, but also actively support the adoption of BIM, demand BIM in projects and that there is a close exchange about BIM. This active support is characterised by the fact that the state governments publicly commit themselves to BIM, develop state BIM strategies, which also promote the use of BIM in state projects (which is not part of the planned BIM mandate), thus showing that BIM also has a certain priority on state level. According to the respondents, the respective ministries also have certain employees responsible for BIM, which shows that BIM is not taken up as a marginal issue at the political level in their state. Moreover, the respective state governments support the adoption of BIM in public client organisations with additional financial resources, which allows more freedom in starting new BIM projects, exploring BIM and accelerate the organisational adoption of BIM. This may include the purchase of IT equipment, such as technology for a BIM collaboration room, or investments as part of the internal change process as setting up a BIM competence centre or developing BIM training.

The respondents from two public clients (C2, C11) indicated that the lack of commitment from their state governments and the associated low priority of BIM has inhibiting influence on the adoption of BIM. This reticent attitude and the passive treatment of BIM as a marginal phenomenon at political level extends to the organisations of public clients and inhibits the adoption of BIM.

Table 20 provides an overview of the driving forces and obstacles identified among the public clients considered in terms of framework conditions set by state governments.

Table 20 – Overview framework conditions set by state governments

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Driving forces															
Support from federal state government											n/a	x	x	x	3
Obstacles															
Lack of support from federal state government					x				x		n/a				2

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

BIM guidelines published by the Federal Government

The representatives of nine organisations explained that the published guidelines are an important initial aid and orientation for employees who are dealing with BIM for the first time. This is particularly helpful in conveying a uniform understanding of BIM among employees. Accordingly, the guidelines are a great help, especially at the beginning of the BIM adoption when the relevant organisations do not yet have similar support and guidance for their employees themselves. In addition, the respondents indicated that the guidelines serve as a template for developing own BIM guidelines, concepts and strategies.

The representatives of some other organisations stated that they generally consider the guidelines to be helpful, but that their help is very limited to them. On the one hand, the guidelines were published too late to be relevant to them and, on the other, they are not specific enough to be really helpful. These public clients indicated that they had started their BIM projects before the first guidelines were published and had already developed own procedures accordingly. Furthermore, the guidelines are too generic, need to be adapted to the specific organisational contexts of the public clients and are therefore not directly applicable. In turn, this adaptation involves a lot of additional work and already requires own know-how.

Table 21 provides an overview of the driving forces and obstacles identified among the public clients considered in terms of BIM guidelines published by the Federal Governments.

Table 21 – Overview BIM guidelines published by Federal Government

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Driving forces															
BIM guidelines published by Federal Government		x	x	x	x		x		x	x	x			x	9

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

5.3.3.2 BIM adoption of trading partners

BIM adoption of trading partners involves two factors namely *BIM adoption level of trading partners* and *collaboration with trading partners in BIM projects*.

BIM adoption level of trading partners

According to the statements of the interviewees, on the one hand there are trading partners such as engineering firms or contractors that are already very intensively involved in BIM and on the other hand there are trade partners who are not yet BIM ready. The respondents indicated that because of the fact

that they are still in the pilot phase, which is characterized by a relatively small share of BIM projects in the total of all projects, trading partners that are not yet BIM capable do not pose a major problem. However, many respondents noted that the low level of BIM adoption seen in small enterprises will be a challenge for future BIM use in regular operations. In this context, public clients are not allowed to always work with the same companies under public procurement rules in regular operations. Accordingly, small companies with low BIM readiness must also be considered in the future. However, suitable procedures for the awarding process based on BIM qualifications as well as references while considering these companies are not yet clear.

Based on the conducted interviews it becomes clear, that the BIM adoption level by trading partners cannot be identified as a clear driving force or a clear obstacle for the current BIM adoption among the public clients considered.

Collaboration with trading partners projects

Respondents from eight public client organisations indicated the collaboration with trading partners in their BIM projects as an enrichment for their BIM adoption. Accordingly, the interviewees reported that collaboration in BIM pilot projects has so far been characterised less by adversarial behaviour and more by mutual trust, joint learning and a good team spirit. This collaboration characterized by a productive exchange of know-how and experience pushes their own BIM adoption.

However, some of the respondents noted that this good collaboration compared to other projects could possibly be a phenomenon at the beginning of the BIM adoption. As in pilot projects, all parties would benefit from each other during the learning process in a specific project environment. In future standard operations, this could possibly change and the adversarial behaviour could again dominate. In addition, a few interviewees mentioned that despite the good collaboration in terms of BIM, financial issues are still being discussed among project participants, as many trading partners still associate BIM with additional effort compared to traditional methods, which should be remunerated.

Table 22 provides an overview of the driving forces and obstacles identified among the public clients considered in terms of collaboration with trading partners in BIM projects.

Table 22 – Overview collaboration with trading partners in projects

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Driving forces															
Collaboration with trading partners in projects			x		x		x			x	x	x	x	x	8

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

5.3.3.3 Standards, norms and regulations

Standards, norms and regulations with regard to the BIM adoption of public clients involves *BIM compatibility of existing norms and regulations* (i.e. legislation, codes and HOAI) and the existence or lack of *BIM standards*.

BIM compatibility of existing norms and regulations

A majority of respondents from eight public client organisations indicated that existing norms and regulations have no significant influence on their BIM adoption. Six of the interviewed representatives (C8, C11, C12, C1, C7 and C13) of public clients across all identified adopter categories perceive a lack

of BIM compatibility as an obstacle for their BIM adoption. However, all respondents agreed that the current norms and regulations do not really address BIM and that there is a need to adapt them in the future to really reflect and facilitate the use of BIM. Accordingly, the public clients considered differ in their perception of the impact of the lack of adaptation of norms and regulations. On the one hand, some of the respondents stated that all norms and regulations are generally method neutral and, since BIM is a method, they do not see any reasons that fundamentally impede or hinder the adoption of BIM. On the other hand, other respondents indicated that the lack of adaptation leads to ambiguity in the use of BIM, which complicates the adoption of BIM.

Table 23 provides an overview of the driving forces and obstacles identified among the public clients considered in terms of BIM compatibility of existing norms and regulations.

Table 23 – Overview BIM compatibility of existing norms and regulations

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Obstacles															
Lack of compatibility of existing norms and regulations			x		x	x					x		x	x	6

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

BIM standards

The respondents from all 14 public client organisations perceived the lack of BIM standards as an obstacle for BIM adoption. In this context, the respondents referred to the lack of standards for the execution of BIM projects. The lack of standards means that every public client must develop its own procedures for implementing BIM in projects. Often, even each project has its own procedures and approaches developed, as there are always different project participants involved. According to the statements of the interviewees, this requires a certain amount of know-how on the client side, especially at the beginning of the BIM adoption, which is currently only available to a limited extent. In addition, the development of individual procedures for each project requires an enormous amount of time and additional effort and thus hinders BIM adoption. Furthermore, the interviewees agreed that the lack of nationwide BIM standards and the resulting development of BIM standards in individual federal states or by individual public clients leads to inconsistent fragmentation and different understanding of how to execute BIM projects, which makes it difficult for trading partners operating nationwide to maintain an overview. As a result of this fragmentation, trading partners would always have to meet different requirements and adopt different practices. This would further hinder the adoption and acceptance of BIM in the market.

Table 24 provides an overview of the driving forces and obstacles identified among the public clients considered in terms of BIM standards.

Table 24 – Overview BIM standards

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Obstacles															
Lack of BIM standards	x	x	x	x	x	x	x	x	x	x	x	x	x	x	14

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

5.3.3.4 Summary environment context

Table 25 shows a summary of driving forces and obstacles for BIM adoption in the environment context identified among the public clients considered.

Table 25 – Summary environment context

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Driving forces															
Federal Government's BIM initiative	x	x	x	x	x	x	x	x	x	x	x	x	x	x	14
BIM guidelines published by Federal Government		x	x	x	x		x		x	x	x			x	9
Collaboration with trading partners in projects			x		x		x			x	x	x	x	x	8
Support from federal state government												x	x	x	3
Obstacles															
Lack of BIM standards	x	x	x	x	x	x	x	x	x	x	x	x	x	x	14
Lack of detailed specifications from Federal Government		x	x	x	x	x		x	x						7
Lack of compatibility of existing norms and regulations			x		x	x					x		x	x	6
Lack of support from federal state government					x				x		n/a				2

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

5.3.4 Summary of driving forces and obstacles

Table 26 shows a summary of all driving forces for BIM adoption identified among the public clients considered. The BIM initiative of the Federal Government and testing BIM in pilot projects could be identified as driving forces for all public clients, regardless of the adopter category. The belief that BIM is more advantageous than traditional working methods could be identified as the third most common driving force. However, it should be noted that the relative advantage of BIM is not a driving force for some reserved late adopters. The fourth most frequent and fifth most frequent driving force could be identified in the organisation context of public clients and also involves all adopter categories. These are small groups of highly committed employees and the existence of a value-adding, supportive network. For some reserved late adopters, however, a supportive network does not represent a driving force.

Furthermore, it can be noted that certain identified driving forces could only be observed among progressive early adopters. This is particularly true in the organisation context. With the exception of one progressive late adopter (C4), a guiding BIM strategy, top management support, high internal interest and demand, adequate BIM expertise, adequate financial resources, structural orientation and advanced IT infrastructure could only be identified as driving forces among progressive early adopters. In addition, tangible BIM benefits in practice and support from the state government could also only be identified as a driving force for progressive early adopters.

BIM guidelines published by Federal Government and collaboration with trading partners in projects are also perceived as driving forces by the majority of public clients. However, it could be observed that the BIM guidelines are perceived as a driving force predominantly by the late adopters and that collaboration with trading partners is perceived as a driving force above all by the progressive adopters.

Table 26 – Summary of driving forces

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Innovation and technology context															
Testing BIM in pilot projects	x	x	x	x	x	x	x	x	x	x	x	x	x	x	14
Believe that BIM is advantageous	x	x			x		x	x	x	x	x	x	x	x	11
Tangible BIM benefits										x	x	x		x	4
Organisation context															
Small groups of highly committed employees	x	x	x	x	x	x	x	x	x	x		x	x		12
Value-adding supportive network	x	x	x				x		x	x	x	x	x	x	10
Guiding BIM strategy										x	x	x	x	x	5
Top management support											x	x	x	x	4
High internal interest and demand										x	x	x		x	4
Adequate BIM expertise											x	x		x	3
Adequate financial resources											x		x	x	3
Structural orientation of the organisation											x	x		x	3
Advanced IT infrastructure													x		1
Environment context															
Federal Government's BIM initiative	x	x	x	x	x	x	x	x	x	x	x	x	x	x	14
BIM guidelines published by Federal Government		x	x	x	x		x		x	x	x			x	9
Collaboration with trading partners in projects			x		x		x			x	x	x	x	x	8
Support from federal state government											n/a	x	x	x	3

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

Table 27 shows a summary of all obstacles for BIM adoption identified among the public clients considered. The insights gained indicate that the high complexity of BIM, particularly with regard to the internal change process, and a lack of BIM standards are obstacles for all public client organisations, regardless of the identified adopter categories. A lack of BIM expertise and lacking or inadequate personnel resources could be identified as second most common obstacles among all public clients. The third most common obstacles are the lack of structural orientation of the organisation towards BIM and the lack of major internal interest and demand. However, it should be noted that these two are not obstacles for the progressive early adopters.

In addition, it can be noted that certain identified obstacles could not be observed among the progressive early adopters at all. These obstacles are lack of clarity and evidence of the benefits of BIM, the conviction that BIM does not provide clear benefits, lack of structural orientation of the organisation, inhibiting administrative processes, lack of a guiding BIM strategy, lack of support from top management and lack of detailed specifications from the Federal Government.

Furthermore, it can be stated that certain obstacles could only be identified among the reserved late adopters. These are lack of clarity and evidence of the benefits of BIM, the belief that BIM does not provide clear benefits and lack of top management support. The obstacle of a lack of a guiding BIM strategy could only be identified among the reserved adopters. A lack of detailed specifications from the Federal Government, with the exception of one progressive late adopter (C2), could also be observed mainly among the reserved adopters.

Missing or insufficient financial resources as well as missing or insufficient IT infrastructure could, except for the one reserved early adopter, be identified as an obstacle among all adopter categories, but only at a significantly lower frequency than the most common obstacles identified.

Table 27 – Summary of obstacles

Adopter category*	RL	RL	RL	RL	RL	RL	RL	RE	PL	PL	PE	PE	PE	PE	
Case no.	5	6	8	9	11	12	14	10	2	4	1	3	7	13	
Innovation and technology context															
BIM adoption is complex	x	x	x	x	x	x	x	x	x	x	x	x	x	x	14
Lack of clarity and evidence of BIM benefits		x	x	x		x									4
Believe that BIM does not give clear advantages				x		x									2
Organisation context															
Lack of BIM expertise	x	x	x	x	x	x	x	x	x	x			x		11
Lacking or inadequate personnel resources	x	x	x	x	x	x	x		x	x			x	x	11
Lack of structural orientation of the organisation	x	x	x	x	x	x	x	x	x	x					10
Lack of major internal interest and demand	x	x	x	x	x	x	x	x	x				x		10
Inhibiting administrative processes		x	x	x	x	x			x	x					7
Lacking or inadequate financial resources			x	x	x	x				x		x			6
Lacking or inadequate IT infrastructure		x		x					x	x	x				5
Lack of a guiding BIM strategy			x	x	x	x		x							5
Lack of top management support	x			x	x										3
Environment context															
Lack of BIM standards	x	x	x	x	x	x	x	x	x	x	x	x	x	x	14
Lack of detailed specifications from Federal Government		x	x	x	x	x		x	x						7
Lack of compatibility of existing norms and regulations			x		x	x					x		x	x	6
Lack of support from federal state government					x				x		n/a				2

** RL is short for reserved late, RE is short for reserved early, PL is short for progressive late, PE is short for progressive early.*

Chapter 6 Discussion

This chapter provides a discussion of the main results, explains the limitations of this study and proposes directions for future research.

6.1 Discussion of results

From previous research a need to explore the BIM adoption of public client organisation was identified. The conducted exploratory cross-case study, which involved 14 public clients in the German road infrastructure sector, aimed to provide insights into why and how public clients adopt BIM and what driving forces and obstacles they face. The results of this study contribute to a deeper understanding of BIM adoption of public clients on an organisational level. Policy makers or practitioners can use these insights to develop measures to promote and stimulate the BIM adoption of public client organisations, thereby strengthening them in their potential role as drivers for industrial change towards BIM.

The preliminary investigation of the current state of BIM adoption and future expected state of BIM adoption gave a first insight into the current adoption dynamics among the considered public client organisations, thus provided a first overview on how public have adopted BIM and helped to classify the public clients based on different adoption states. Consequently, this first step represented the point of departure and set the contextual frame for the subsequent examination of the driving forces and obstacles among the public clients. The exploration of driving forces and obstacles among the public clients was based on the theoretical model underlying this study using the TOE framework (Tornatzky et al., 1990), DOI theory (Rogers, 1982) and constructs of the UBAT (Ahmed & Kassem, 2018). In the following, the most interesting key findings of this research are discussed.

Current and future expected state of BIM adoption among public clients

First of all, when considering the results on current and future expected BIM adoption state, the study revealed that although the Federal Government's BIM initiative was launched as early as 2015, the majority of public clients started adopting BIM after a delay and have only recently started using BIM in a few initial BIM projects. In addition, the findings showed that most public clients, despite an originally planned BIM mandate from the end of 2020, do not yet have precise expectations and ideas about the frequency and extent of BIM use in the near future. This indicates that the originally defined objectives of the Federal Government's BIM initiative differ from the current practical implementation. Thereby, suggesting that there may be a mismatch between expectations and beliefs between political sphere and operational public client organisations. In this context, the picture gained in this study regarding the adoption behaviour of most organisations, which is characterised by reluctance based on relatively little experience and just a few BIM projects, suggests that public clients may still struggle with BIM adoption or may not show sufficient commitment to BIM adoption and that the short-term implementation of a comprehensive BIM mandate may be problematic. This indicates that the publication of a BIM initiative and the definition of a BIM mandate by the government alone may not necessarily mean that in practice all public clients can, want or will ultimately demand and actively support the use of BIM in public projects. These findings are line with previous research problematizing the assumption that public clients can act as drivers for change in industrial context towards BIM. Vass

& Gustavsson (2017) identified a certain mismatch between expectations and beliefs about the role of public clients and Lindblad (2019) noted that simply prescribing that public clients have to demand BIM in public projects is not sufficient to establish public clients as change agents for industry change towards BIM.

By also considering the extent of BIM use, the results showed that BIM has so far mainly been used for civil structures such as bridges. The use of BIM for road structures is still comparatively low. According to Costin et al. (2018), existing studies show contradictory findings about the frequency of BIM use for different types of transportation infrastructure, making it difficult to classify the results of this research accurately. However, there are studies in the literature reviewed by Costin et al. (2018) that confirm the trend towards more frequent use of BIM in bridge projects, albeit to a lesser extent than in this study (Jones & Laquidara-Carr, 2017). Furthermore, the study revealed that the BIM use is so far almost exclusively limited to the inventory phase, as well as the planning and design phase. There is a lack of BIM use in subsequent phases such as in the construction phase and in the maintenance and operation phase. In addition, the results on the expected future extent of BIM use also showed continued limited BIM use in the operation and maintenance phase. Accordingly, it is clear that public clients have so far used BIM only in parts of their field of activity and also expect to use it only to a limited extent, at least in the near future. One the one hand, this underlines the fact that the majority of public clients considered are still in the early stages of BIM adoption and do not yet have comprehensive practical experience in the full range of BIM applications. As a result, they have not yet been able to explore and assess the full potential of BIM, particularly in the operation and maintenance phase, which is considered to be the most beneficial for public clients in the infrastructure sector. On the other hand, this could indicate that most public clients may still struggle to involve all departments in the various fields of activity in the organisational BIM adoption process. This aspect was also identified by Vass & Gustavsson (2017), particularly with regard to the involvement of the maintenance department, as one of the intra-organisational challenges for public clients when implementing BIM. Against this background, it may also be the case that, for certain reasons, some public clients have not yet shown sufficient commitment to adopt BIM holistically in their organisations, or that the will to do so may not exist.

In addition, a closer look at the BIM adoption states identified among the public clients revealed a certain fragmentation and different BIM adoption behaviour. On the one hand, this fragmentation is characterized by the large majority of the late and reserved adopters mentioned above, but on the other hand, a few progressive early adopters have been identified who started relatively early with the adoption of BIM, are already using BIM in several projects, and to a greater extent. This raises the question of how to explain the phenomenon of identified fragmentation. Or rather, how can the reserved and late adoption behaviour of the majority of public clients be explained? And what are the possible reasons for the early and progressive adoption behaviour of a few public clients? In this context, there may be different driving forces or obstacles for BIM adoption in the respective organisations, which may explain the contrary adoption behaviour. Furthermore, these could be of different nature, have different degrees of impact or have a different relevance in the specific organisational contexts. The analysis of the driving forces and obstacles identified among the public clients considered provides insights that can be used to find answers to these questions.

Driving forces and obstacles for the adoption of BIM by public clients

In general, the investigation of the driving forces and obstacles showed that the BIM initiative of the Federal Government was the main reason for the adoption of BIM for all public clients, although, as mentioned above, it initially met with reluctance or is still met with reluctance by many public clients and it is questionable whether the originally set objectives will be achieved. It could be observed that

the start of the BIM adoption was as a reaction to the Federal Government's BIM initiative. On the one hand, this indicates that the adoption of BIM had a clear external impetus, was not initiated solely on the initiative of public client organisations, and was at least initially politically driven. On the other hand, this shows that governmental policies in general have a great influence on public clients and are more important, perhaps even necessary, to initiate BIM adoption in public client organisations. This finding is consistent with existing literature on innovation adoption by public clients, which shows that change processes in public client organisations are to a great extent politically driven (A. Hartmann et al., 2008).

Furthermore, the results on identified driving forces and obstacles draw a consistent picture of the BIM adoption among the majority of public clients considered. On the one hand, the study revealed that the most common driving forces originate from the technology and innovation context and the environment context, i.e. the Federal Government's BIM initiative, testing BIM in pilot projects, the believe that BIM is advantageous, published BIM guidelines and collaboration with trading partners. This highlights the importance of external drivers for BIM adoption of public clients. On the other hand, the most common obstacles originate from the organisation context. Against this background, the results clearly showed that the organisation context in terms of lacking expertise, lacking or inadequate personnel resources, lack of structural orientation of the organisation towards BIM and lack of major internal interest and demand is the main obstacle and critical bottleneck for the adoption of BIM for the majority of public clients. The organisation context as main issue for BIM adoption is further emphasised by the fact that the perceived high complexity of BIM adoption in the technology and innovation context also relates in particular to the internal change process and has been identified as an obstacle for all public clients considered. This indicates that the internal transformation process towards BIM may be the major challenge for public client organisations and that their limited internal capability for change may hinder the adoption of BIM. This is consistent with previous research which has shown that public client organisations are often characterised as large bureaucratic structures that seek stability and resist change and disruption (Borins, 2002). In this context, the findings of this study also reflect some of the intra-organisational challenges that Vass & Gustavsson (2017) have identified in implementing BIM for industry change in public client organisations, such as changing work practices, providing training and education or creating new roles. In addition, the most frequently obstacles identified in the organisation context confirm the findings of Siebelink, Voordijk, Endedijk, & Adriaanse (2020) on the dominance of barriers for BIM adoption on organisational level, which are linked to people's motivation to change to BIM, their competences in using BIM and their capacity to make and support the transition to BIM.

The finding that small groups of highly committed employees of public clients have been identified as the most common driving force in organisation context, and in many of the reserved and late adopting organisations even as one of only two or even the only driving force, further underpins the problematic role of the organisation context. Firstly, this suggests that the initiative of individual employees plays an important role in driving the adoption of BIM among the public clients. Above all, however, this shows that for the majority of public clients, the Federal Government's push for BIM adoption in the course of the BIM initiative is almost entirely carried by committed individuals or small groups without much organisational backing. Thereby, indicating that there may be a lack of holistic organisational approaches backing up the commitment and initiative of individual employees and that BIM may not yet be in organisational focus and of high priority in most public client organisations. These insights may contribute to explain why the majority of public clients started to adopt BIM relatively late and still show a rather reserved adoption behaviour.

However, a closer look at the organisation context reveals differences between the public clients considered which may contribute to explain the different adoption behaviour and states mentioned above. It is striking that significantly fewer obstacles and correspondingly more driving forces in the organisation context were identified among the few progressive early adopters than among the other clients considered. In this context, the factors such as a guiding BIM strategy, support from top management, internal interest and demand, BIM expertise, financial resources and the organisation's structural orientation towards BIM are not obstacles but driving forces for most or often all progressive early adopters compared to the other public clients. This suggests that progressive early adopters have already created an enabling environment for BIM adoption within the organisation context. Accordingly, this could be one reason explaining the early and relatively progressive adoption behaviour. In addition, it could be deduced from this that these factors may be enablers for a higher BIM adoption state. Against this background, it can also be noted that for the progressive early adopters, the most frequent obstacles compared to the majority of reserved and late adopters tend to originate from the environment context (lack of BIM standards and lack of compatibility of existing norms and regulations) and not form the organisation context. This may indicate that internal barriers tend to dominate at an early stage of BIM adoption, and external barriers may become more important as BIM adoption progresses. However, these insights again raise the question of how to explain the fact that progressive early adopters have already been able to create stimulating conditions for BIM within their organisations compared to the majority of public clients considered.

Against this background, the results of this study suggest that governmental policies in the sense of active support by state governments, originating from the environment context, has a decisive influence on the organisation context and could be one reason explaining the fragmentation among the public clients considered. This study revealed that most state governments have so far taken a rather passive role in the BIM adoption, although the public client organisations (except C1) are actually assigned to state governments. For the progressive early adopters, however, active support from the state government was identified as a driving force. In addition, the interviews conducted with respective representatives pointed out that the active support and the enabling framework conditions set by their state government have played a major role in achieving their progressive BIM adoption state and in creating an enabling environment for BIM adoption within their organisations. State governments can exert a positive influence on BIM adoption by communicating that BIM has also a priority at the state level, by providing adequate resources (i.e. financial resources) and by supporting strategy development in public client organisations through context setting BIM initiatives at state level, or ultimately by requesting BIM in state projects. Therefore, active support of state governments addresses many of the core obstacles in organisation context identified among the majority of public clients considered. This suggests, that active support from state government may be an important enabler for BIM adoption on organisational level, and that state governments are potentially in a key role in promoting the adoption of BIM. On a higher level, it can therefore be deduced that the interplay between the federal political system in Germany, consisting of one Federal Government, 16 individual and quite independent federal states with their own state governments, the complex and fragmented hierarchy in the German road administration and a planned BIM mandate exclusively for partial tasks and partial responsibilities of public clients (BIM mandate exclusively for federal projects) may be one underlaying factor that could explain the fragmentation among the public clients considered.

Furthermore, it can be observed that the ambivalent perception of the Federal Government's BIM initiative in relation to the organisational context may contribute to better understand the late and reserved adoption behaviour of the majority of public clients. As previously mentioned, the BIM initiative of the Federal Government was identified as the main driving force and reason for starting the

adoption of BIM. On the other hand, the lack of detailed specifications from the Federal Government in the course of the BIM initiative and the upcoming BIM mandate was identified as an obstacle for the majority of reserved public clients. In this context, it can be deduced that the BIM initiative of the Federal Government may not be as stimulating for public clients who lack driving forces and face lots of obstacles in the organisation context and do not yet receive active support from their state governments as it is for public clients such as the progressive early adopters. In the case of many reserved adopters, where the lack of detailed specifications from the Federal Government was identified as an obstacle, a sluggish "actio reactio" BIM adoption behaviour could be observed. Accordingly, these reserved public clients due to limited own initiative, readiness and resources or capabilities are waiting for new specifications from the Federal Government to take next own steps towards BIM adoption and tend to play the ball back to the Federal Government as they have not initiated the BIM adoption themselves. This points out that the previous specifications and mandates of the Federal Government alone have not yet encouraged many public clients to promote the adoption of BIM on their own.

6.2 Research limitations

There are several limitations to this study. First, there are limitations to the case study approach of this research. On the one hand, this study was based on a multiple case study of 14 different public clients, which represents a large number of organisations for an in-depth case study (Eisenhardt, 1989; Yin, 2009). However, the cross-case analysis benefited from the rather large number of case studies. On the other hand, the results of this study have limited generalizability due to the limited statistical evidence of the chosen case study approach. In this context, it should be mentioned, however, that due to the generally small number of organisations relevant to the research context, the study of 14 organisations already provides a meaningful overview. In addition, there is the possible limitation that the case organisations that agreed to participate in this study are already the more advanced public clients. Also, the fact that all of the organisations included in this study have already started to adopt BIM suggests this. Accordingly, public clients that have not yet addressed the issue of BIM adoption may have tended to not participate in the study and are not reflected in the results.

Second, there are limitations related to the data collection of this research. The main method of data collection was based on interviews, and in the context of this study it was only possible to interview one to a maximum of two representatives of each public client organisation in a limited time frame. Consequently, the results of this research could be significantly influenced by the personal perception and views of the individual respondents and the survey of several people from the individual organisations could possibly create a different picture than that reflected in this study. However, since this study placed emphasis on interviewing the respective BIM representatives of the public clients, an attempt was made to counteract this rather limited number of sources in the individual organisations as good as possible with the great knowledge of the single respondents in relation to the context relevant to this research. Furthermore, during the preparation of this study it also became clear that the number of potential respondents from the individual organisations was very limited, as most public clients are still in the early stages of BIM adoption and therefore a significantly higher number of reliable respondents would often not have been possible.

Third, there are limitations related to the level of detail of this study in terms of BIM uses, driving forces and obstacles. In this context, there are various differently defined BIM applications, benefits, driving forces and obstacles in the existing literature. To elaborate and present the results of this study, a level

of detail was chosen that is reasonable from the author's perspective with regard to the research context but could differ from other studies. For example, one identified obstacle to this research is lack of BIM expertise. In this study, this obstacle involves lack of BIM training programs, whereas in other studies, lack of training programs is a separate factor. This is similar to BIM uses and applications.

6.3 Future research

The findings and limitations of this research provide opportunities for future research. First, due to the limited depth of the cross-case study and the identification of the organisational context as the main sources of obstacles as well as the internal change process as the main challenge for BIM adoption, further research is recommended to delve even deeper into the organisation context of individual public clients. This would provide a more in-depth understanding of the structures, processes and phenomena at organisational level and their effects on BIM adoption. Thereby, enabling to make more specific recommendations for public clients in order to promote BIM adoption. In addition, governmental policies and political actors were identified as key aspects that have a strong influence on public client organisations and their BIM adoption. In this context, it is recommended on the one hand to examine BIM initiatives and mandates from governments in terms of mutual and shared motivation, expectations and requirements between policy makers and public client organisations in order to assess and improve the implementation, impact and effectiveness of such policies. On the other hand, it is recommended to take a closer look at the perspective of politicians and governments in order to explore which barriers and challenges they face. Based on these insights, measures could be developed to strengthen the role of political actors in supporting BIM adoption of public client organisations.

Chapter 7 Conclusion

This final chapter briefly summarises the main results of this study and provides the conclusions. Furthermore, based on the discussion of the findings in the last chapter, recommendations for promoting and stimulating the BIM adoption of public client organisations in the German road infrastructure sector are provided.

7.1 Conclusions

This study aimed to understand why and how public clients in the German road infrastructure sector adopt BIM and what driving forces and obstacle they face. To answer the underlaying research questions, a cross-case study approach was applied to explore the current and future expected BIM adoption state as well as the reasons, driving forces and obstacles for BIM adoption of 14 public client organisations. In this way, the results of this study contribute to a deeper understanding of the BIM adoption of public clients on an organisational level. Policy makers or practitioners can use these insights to develop measures to promote and stimulate the BIM adoption of public client organisations, thereby strengthening them in their potential role as drivers for industrial change towards BIM.

In order to fulfil the purpose of this study, four research questions were defined which are answered in the following. The first and second research question aimed to gain insights into how public clients in the German road infrastructure sector adopt BIM by looking at the current and expected future BIM adoption state in terms of BIM experience, frequency of BIM use and the extent of BIM use. In this way, a first understanding of the dynamics of BIM adoption and the BIM adoption behaviour of the public clients was provided. The third research question aimed to identify driving forces in order show what the reasons for BIM adoption are and which factors on the side of the public clients are perceived as beneficial and provides insights on aspects that are important for stimulating the BIM adoption and a further promotion. The fourth research question aimed to identify obstacles in order to show which problematic factors on the side of the public clients will have to be addressed in the future in order to promote BIM adoption.

(1) What is the current state of BIM adoption among public clients in the German road infrastructure sector?

This study revealed that all public clients considered have started to adopt BIM. However, a fragmentation could be identified. This fragmentation is characterised by a vast majority of public clients that show a reserved and late adoption behaviour and have only recently started to adopt BIM. Accordingly, most public clients have relatively little BIM experience and use BIM in a few projects. Only a few public clients could be identified that show a progressive and early adoption behaviour, and already have a certain degree of BIM experience, use BIM over a relatively long period of time and in several projects. The current share of BIM projects compared to traditionally executed projects among organisations is still low. Almost all public clients are in pilot use of BIM and, accordingly, have not yet implemented BIM in standard operations. In addition, the results indicated that BIM is used with a strong focus on civil structures and that the use of BIM for road structures is still comparatively low. The use of BIM is foremost limited to the inventory phase as well as the planning and design phase and

the corresponding applications in the area of visualization possibilities, design coordination, clash-detection, quantity take-off and cost estimation as well as planning. Except for very few of the progressive early adopters, there is a lack of BIM use in the subsequent phases such as the construction phase. Proper BIM usage in the operation and maintenance phase could not be observed at all.

(2) What is the future expected state of BIM adoption among public clients in the German road infrastructure sector?

The study showed that despite an originally planned BIM mandate from the end of 2020 onwards, most public client organisations considered lack a clear and specific expectation of future BIM adoption and use for the next 1 to 2 years. However, the results indicated that the frequency of BIM use is likely to increase in the next 1-2 years, but that the current fragmentation between reserved and progressive public clients will continue in the future. Concerning the future expected extent of BIM usage, the results indicated that, with few exceptions, the majority of the public clients will extend the current BIM usage in the inventory phase as well as planning and design phase up to the construction phase. First public clients, also expect to use BIM in the operation and maintenance phase, but this only affects a relatively small group and is therefore the exception. Furthermore, it could be observed that the majority of all public clients expect to extend the BIM applications to public relations, time and schedule simulation and construction progress monitoring.

(3) What are the driving forces for the BIM adoption by public client organisations in the German road infrastructure sector?

First of all, the investigation of driving forces identified the Federal Government's BIM initiative as the main reason and external impetus for BIM adoption among the public client organisations considered. Thereby, indicating that BIM adoption was not initiated solely on the basis of own initiative and was at least initially politically driven. The most frequently driving forces identified are (1) the Federal Government's BIM initiative, (1) testing BIM in pilot projects, (2) small groups of highly committed employees, (3) the believe that BIM is more advantageous than traditional working methods, and (4) a value-adding, supportive network. When considering all driving forces identified, the findings indicated that the most frequent driving forces for BIM adoption originate from the environment context and innovation and technology context. This highlights the importance of external drivers and suggests that most public clients lack driving forces in the organisation context. In this context, the study revealed that, for the majority of reserved and late adopting public clients, the Federal Government's push towards BIM adoption is almost exclusively carried by small groups of highly committed employees without holistic organisational commitment and backing. However, significant differences between the few progressive early adopters and the rest of the public clients were identified, in terms of which driving forces are encountered and how many in total. With regard to the few progressive early adopters a BIM enabling organisation context can be observed characterised by a guiding BIM strategy, top management support, high internal interest and demand, adequate BIM expertise, adequate financial resources and structural orientation of the organisation towards BIM. Thereby, indicating that these factors are enablers for a higher BIM adoption state. Furthermore, the study revealed that active support from state government may be one reason that explains the significant difference between the majority of public clients and progressive early adopters in this respect. Therefore, suggesting that active support from state government may be an important enabler for a higher BIM adoption state that positively influences the organisation context and that state governments are potentially in a key role in promoting the adoption of BIM.

(4) What are the obstacles for the BIM adoption by public client organisations in the German road infrastructure sector?

The obstacles most frequently identified are (1) the lack of BIM standards, (1) the high complexity of BIM, in particular in terms of the internal change process and the related additional expenditure of time required, (2) the lack of BIM expertise, (2) the lack of or inadequate personnel resources, (3) the lack of structural orientation of the organisation towards BIM and (4) the lack of major internal interest and demand. When considering all obstacles identified, the findings indicated that the most frequently obstacles identified originate from the organisation context. This suggests that the organisation context is the critical bottleneck for the adoption of BIM and that the internal change process may the major challenge for most public clients. However, similar to the consideration of driving forces, significant differences between the few progressive early adopters and the rest of the public clients were identified, in terms of which obstacles are encountered and how many in total. The most obvious difference lies in the organisation context and relates to the same factors that have been mentioned before in terms of the driving forces, but which are accordingly perceived as obstacles in this consideration. More interestingly, this study found that the Federal Government's BIM initiative may not be as stimulating for public clients who lack driving forces and face many obstacles in the organisation context and do not yet receive active support from their state governments as it is for progressive early adopters. For many reserved public clients, the lack of detailed specifications by the Federal Government is perceived as an obstacle. Accordingly, in contrast to the progressive early adopters, who independently drive the adoption of BIM, a sluggish "actio reactio" adoption behaviour was observed among these clients, which tends to return the ball to the federal government and wait for detailed input and specifications before taking own next steps towards the adoption of BIM.

7.2 Recommendations

Based on the findings of this study three key recommendations can be made to promote and stimulate the adoption of BIM by public clients in the German road infrastructure sector:

(1) Political bodies should overcome political fragmentation between federal and state level and accordingly extend the Federal Government's BIM initiative for federal projects to federal states and state projects. This would encourage state governments to play a more active role by showing that BIM has a certain priority on state level, by creating supportive environments for the BIM adoption of public client organisations, and by demanding BIM for state projects.

(2) Policy makers should adapt the BIM initiative so that there is lower focus on exerting pressure and output-oriented targets in the sense of binding specifications and mandates, but rather a greater focus on showing the way to BIM adoption in order to enable public clients to drive BIM adoption themselves. This could be achieved by the development of measures in close collaboration with public clients which, on the one hand, activate the self-interest and motivation of public clients to adopt BIM and, on the other hand, actively support the adoption process enabling public clients to master the internal change process.

(3) If practitioners in organisations of public clients or policy makers want to promote BIM adoption, an important focus should be on creating a supportive and enabling environment for dedicated employees within the organisations. Thereby, this study recommends to address the general shortage of personnel in order to give employees sufficient time to familiarise themselves with

BIM, establishing or providing suitable BIM training programmes to generate BIM expertise and interest among the majority of employees, and aligning the organisational structure towards BIM by creating clear responsibilities for BIM adoption and capacities through specialised personnel with sufficient time and specialised departments.

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Appendix A

A.1 Specific BIM use cases in the German context

Against the specific German background, the "BIM 4 INFRA" initiative has defined 21 concrete potential use cases (UC) of BIM, which are already assigned to the standardized HOAI service delivery phases of a construction project typical for Germany which are presented in Table 28 (König & Feustel, 2018).

Table 28 – Specific BIM use cases in the German context acc. to HOAI phases

Source: (König & Feustel, 2018, p. 11)

No.	Use case	Service delivery phases acc. to HOAI									Operation phase
		1	2	3	4	5	6	7	8	9	
Inventory											
UC 1	Inventory	■	■								
Design and planning											
UC 2	Examination of the planning variants		■								
UC 3	Visualizations (public relations)		■	■	■						
UC 4	Design and verification			■	■	■					
UC 5	Coordination of disciplines			■		■					
UC 6	Progress monitoring of design and planning phase		■	■	■	■					
UC 7	Preparation of conceptual, approval and/or detailed design plans		■	■	■	■					
UC 8	Health and safety planning			■		■					
Permit and approval											
UC 9	Planning approval			■	■	■					
Tender and awarding											
UC 10	Cost estimation/calculation		■	■							
UC 11	Specifications, tendering and awarding						■	■			
Construction											
UC 12	Scheduling of execution			■		■			■		
UC 13	Logistic planning			■		■			■		
UC 14	Fabrication and assembly plans								■		
UC 15	Construction progress monitoring								■		
UC 16	Change management								■		
UC 17	Billing of construction services								■	■	
UC 18	Defect management								■	■	
Operation											
UC 20	Operation and maintenance										■
UC 21	Conditions monitoring										■

Appendix B

B.1 Interviews and questionnaire

The following questionnaire had to be filled out and returned by the interviewees before the interview. The filled-out questionnaire then served as a basis for the interviews and was used to facilitate the discussion. Accordingly, each public client organisation was interviewed following the same defined structure based on the questionnaire specifically built for the research. Furthermore, despite the given structure, the respondents had the possibility to set their own priorities beyond the questionnaire and add their own topics and aspects. In this way the questionnaire sensitized the interviewees to the topic before the interview and enabled a productive and prepared discussion. Furthermore, the questionnaire prevented miscommunication, misinterpretation and false mutual understanding. Due to the structured but nevertheless free methodology a high comparability was guaranteed which nevertheless made it possible to take up new aspects from the interviewees. The filled-out questionnaires supported the subsequent analysis process of the transcribed interviews and prevented possible mistakes.

In addition to the questions from the questionnaire, further and more in-depth questions were asked during the interviews, which are shown in blue colour and are added to the following questionnaire. In addition, the detailed questions asked with regard to points 13 and 15 of the questionnaire varied according to the thematic priorities set by the respondents.

Questionnaire

BIM adoption of public client organisations in the German road infrastructure sector.

This questionnaire is confidential and your data will be processed anonymously.

Please fill in the grey fields to answer the questionnaire.

(Can you introduce yourself and explain what role you play in BIM adoption in your organisation?)

1. Which of the following descriptions best corresponds to the understanding of BIM in your organisation? (please select one description)
   - ☐ BIM refers to **software** used for **2D CAD drafting**, with paper or electronic prints, or a mixture of both as the most likely data exchange mechanism.
   - ☐ BIM refers to any **software**, irrespective of **2D, 3D or 4D**, used for modelling the structural, architectural and mechanical components of a building for various visualization design, evaluation and management applications.
   - ☐ BIM is a **database**, (i.e. electronic data model), which can be created by different software, to provide input into different analyses required through the life cycle of a building.
   - ☐ BIM is the **process** of managing the essential building design and project data in a digital format throughout the building's life-cycle.
   - ☐ BIM is a digital **representation of the facility**, from which data appropriate to various users' needs can be extracted and analysed to generate information.

If your organisation does not yet use BIM, please continue with question 8.

2. In how many projects has your organisation used BIM so far? (including ongoing projects)
(What kind of projects are these and were there specific criteria for selecting projects to use BIM?)

3. What percentage of the ongoing projects in your organisation involve the use of BIM? (an estimate is also in order)

4. How long has your organisation been using BIM?
   - ☐ < 1 year
   - ☐ 1-2 years
   - ☐ 3-5 years
   - ☐ > 5 years

(What was the reason or impetus to start with BIM adoption at that time?)

5. What type of project has made up the majority of your BIM projects so far?
   - ☐ Civil engineering – i.e. bridges, tunnels
   - ☐ Roadway structures – i.e. highways, roads
   - ☐ Others (please specify)

(Why do these kinds of projects make up the majority so far?)

6. Which of the following applications of BIM have been or are used in projects in your organisation?
   - ☐ 3D Visualization
   - ☐ Design coordination
   - ☐ Environmental analysis
   - ☐ Logistic on site
   - ☐ Operations and maintenance
   - ☐ Quantity take-off
   - ☐ Cost estimation and cost planning
   - ☐ Clash control and detection
   - ☐ Time and schedule simulation
   - ☐ Public relations
   - ☐ Construction progress monitoring
   - ☐ Others (please specify)

(Why have these particular types of applications been used so far? / Why not the others?)

7. In which of the following phases is your organisation already using BIM?
   - ☐ Site inventory
   - ☐ Design and planning
   - ☐ Permit and approval
   - ☐ Tender and Awarding
   - ☐ Construction
   - ☐ Operation
   - ☐ Others (please specify)

(Why do you use BIM in these particular phases? / Why not in the others?)

8. How many percent of new projects in your organisation that will be added in the next 1 to 2 years will involve the use of BIM (an estimate is also ok)?

(How do you estimate or generally expect the future development of BIM adoption in your organisation?)

9. Which of the following BIM application(s) does your organisation expect to implement in projects over the next 2 years in addition to those already used?
   - ☐ 3D Visualization
   - ☐ Design coordination
   - ☐ Environmental analysis
   - ☐ Logistic on site
   - ☐ Operations and maintenance
   - ☐ Quantity take-off
   - ☐ Cost estimation and cost planning
   - ☐ Clash control and detection
   - ☐ Time and schedule simulation
   - ☐ Public relations
   - ☐ Construction progress monitoring
   - ☐ Others (please specify)

(Why do you expect to use these particular types of applications? / Why not the others?)

10. In which of the following phases does your organisation expect to implement BIM in projects over the next 2 years in addition to those already used?
    - ☐ Site inventory
    - ☐ Design and planning
    - ☐ Permit and approval
    - ☐ Tender and Awarding
    - ☐ Construction
    - ☐ Operation
    - ☐ Others (please specify)

(Why do you expect to use BIM in these particular phases? / Why not in the others?)

11. What do you believe are the biggest advantages of using BIM for your organisation, and are these advantages already visible in practice in your projects? (please rank the benefits relevant to you and assess whether they have been visible)

No. for rank	☒ for already visible	
	☐	Improve project quality
	☐	Better understanding of design
	☐	Provide life cycle data
	☐	Scope clarification
	☐	Speed up the design process
	☐	Reduce construction cost
	☐	Better cost estimates and control
	☐	Better construction planning and monitoring
	☐	More efficient communications

	☐	Reduce project duration
	☐	Improve safety performance
	☐	Enhance organisational image
	☐	Others (please specify)

12. What do you believe are the driving forces for the BIM adoption of your organisation? (please give a brief description)

13. Please indicate your reaction to the following statements by ticking the appropriate boxes, where: 1= agree, 2 = tend to agree, 3 = neutral, 4 = tend to disagree and 5 = strongly disagree.

(Detailed questions on this point varied according to the thematic priorities set by the respondents.)

	1	2	3	4	5
We expect BIM to be more advantageous than traditional working methods.	☐	☐	☐	☐	☐
Various software is available, which we are permitted to test in order to explore the BIM functionalities.	☐	☐	☐	☐	☐
Testing BIM in our pilot projects is successful and is driving our BIM adoption.	☐	☐	☐	☐	☐
We already see clear benefits of using BIM in our projects.	☐	☐	☐	☐	☐
We have enough internal competence to use BIM.	☐	☐	☐	☐	☐
We offer proper BIM training and guidance for our staff.	☐	☐	☐	☐	☐
We offer incentives when our employees apply or use BIM.	☐	☐	☐	☐	☐
We have a BIM strategy in place which guides our BIM adoption and enjoys high acceptance.	☐	☐	☐	☐	☐
We perceive a strong internal BIM interest and demand.	☐	☐	☐	☐	☐
BIM adoption is largely driven by our internal motivation.	☐	☐	☐	☐	☐
We have a good network of external actors who support our BIM adoption and which is characterized by value added exchange.	☐	☐	☐	☐	☐
We are pushing our BIM adoption, as BIM will become the standard anyway due to the BIM mandate of the BMVI.	☐	☐	☐	☐	☐
The published BIM handouts (handbooks) and guidelines initiated by the government help us with our BIM adoption.	☐	☐	☐	☐	☐
Government subsidies and extra financial support are very important for the success of our BIM adoption.	☐	☐	☐	☐	☐
Our federal state government supports us and creates favourable conditions for our BIM adoption.	☐	☐	☐	☐	☐
Our trading partners like designers, architects and contractors use BIM.	☐	☐	☐	☐	☐
The BIM collaboration in projects with our trading partners is enriching.	☐	☐	☐	☐	☐

14. What do you believe are the main barriers for the BIM adoption of your organisation? (give a short description)

15. Please indicate your reaction to the following statements by ticking the appropriate boxes, where: 1= agree, 2 = tend to agree, 3 = neutral, 4 = tend to disagree and 5 = strongly disagree.

(Detailed questions on this point varied according to the thematic priorities set by the respondents.)

	1	2	3	4	5
We are not sure for which applications BIM is really beneficial in practice.	☐	☐	☐	☐	☐
BIM adoption is technically very challenging for us (integration in systems, data interfaces, etc.).	☐	☐	☐	☐	☐
BIM adoption is very time consuming and causes a lot of additional work (i.e. due to internal change processes).	☐	☐	☐	☐	☐
Using BIM is very challenging for our employees and requires elaborate training.	☐	☐	☐	☐	☐
BIM adoption requires high investments (i.e. set up costs, running costs and training costs).	☐	☐	☐	☐	☐
We have a lack of internal BIM competence.	☐	☐	☐	☐	☐
It's difficult for us to employ new BIM specialists.	☐	☐	☐	☐	☐
We do not know what content to teach our staff in BIM trainings.	☐	☐	☐	☐	☐
We perceive a large knowledge gap between our BIM specialists and the operational staff who are supposed to initiate BIM projects.	☐	☐	☐	☐	☐
We have obsolete systems, hardware and software.	☐	☐	☐	☐	☐
Our inflexibility as an organisation hinders our BIM adoption (i.e. decision-making-, procurement processes, etc.).	☐	☐	☐	☐	☐
Our limited financial resources hinder our BIM adoption.	☐	☐	☐	☐	☐
Developing and implementing our own BIM strategy is/was very challenging for us.	☐	☐	☐	☐	☐
We perceive a high internal resistance regarding BIM.	☐	☐	☐	☐	☐
We lack a value-added network of external actors supporting our BIM adoption and are on our own.	☐	☐	☐	☐	☐
There is a lack of a uniform and common understanding of BIM in our organisation.	☐	☐	☐	☐	☐
The BIM initiaitive of the Federal Government and the BIM mandate of the BMVI are rather unclear and raise a lot of questions for us.	☐	☐	☐	☐	☐
The framework conditions set by the government of our federal state hinder our BIM adoption.	☐	☐	☐	☐	☐
The low BIM adoption level of our trading partners like designers, architects and contractors hinders our BIM adoption.	☐	☐	☐	☐	☐
We and our trading partners have a misaligned understanding of using BIM in projects.	☐	☐	☐	☐	☐
The lack of industry BIM standards hinders our BIM adoption.	☐	☐	☐	☐	☐
New BIM specifications like BAP and AIA are causing problems for us.	☐	☐	☐	☐	☐
Current regulation and norms are not compatible with BIM and hinder our BIM adoption.	☐	☐	☐	☐	☐

16. Please use the space below to provide any comments you wish to make:

Thank you for taking the time to fill out this questionnaire!