MSc Thesis Report

Improving the collaboration in BIM teams in the design phase of BIM-enabled infrastructure projects

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Cover picture: Digital roadmap (Richard Prowse, 2019)

MSc. Thesis

Improving the collaboration in BIM teams in the design phase of BIM-enabled infrastructure projects

by

SUJITH MAHADEVAN

in partial fulfillment of the requirements for the degree of

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PREFACE

This report marks the final step of my graduation research project as a part of the MSc program in Construction Management and Engineering at TU Delft, The Netherlands. The research project have been carried out for a period of seven months from February – August 2021 in collaboration with Witteveen+Bos, an international engineering and construction consultancy firm headquartered in Deventer, The Netherlands. I am passionate about Building Information Modelling (BIM) and wanted to conduct a research in this field to improve the implementation rate in the AEC industry. This was the starting point and narrowing the scope was an interesting challenge for me. After reading many journal papers, I realised the importance of collaboration in BIM teams and decided to focus on this topic. Looking back at this journey, I am really happy to have gained extensive knowledge that will definitely help me in my future endeavours.

This would have been impossible without the support of my graduation committee. First and foremost, I would like to thank my company supervisor Ir. Maarten Visser for giving me the opportunity to conduct this research at Witteveen+Bos, arranging every resources that I needed instantly and providing me constant guidance throughout the process. I would like to thank my graduation chair Prof. Hans Bakker for his constructive feedback in this journey. He helped to improve the quality of this research by providing meticulous comments for every part of the research. I would like to thank Dr. Yan Liu for helping me shape the research scope with his knowledge on BIM and being there for whenever I needed guidance. I would like to thank Dr. Rutger van Bergem for providing insights from a layperson's perspective thereby giving a strong foundation on basics.

I would further like to thank the interviewees who shared their knowledge, experience and their valuable time for contributing to this research. It was an absolute pleasure working with people from Witteveen+Bos. Last but not least, I would like to thank my family and friends for giving me the mental support to achieve this success in my life.

I hope you enjoy reading this thesis.

Sujith Mahadevan
Delft, August 2021

EXECUTIVE SUMMARY

Introduction

The Architecture, Engineering, and Construction (AEC) industry is undergoing digital transformation to improve project performance and Building Information Modelling (BIM) is helping to achieve this objective. BIM teams are formed for every project to execute the BIM tasks and collaboration among them has been problematic resulting in misunderstandings, misinterpretation of data, and increased rework. This is especially high in the design phase of infrastructure projects. This gives the necessity to address the barriers hindering collaboration in BIM teams.

Research objective and question

The purpose of this research is to address the most critical barrier to collaboration in BIM teams in the design phase of BIM-enabled infrastructure projects and create strategies to avoid the barrier in future projects. The most critical barrier in this research is defined as "the main issue that causes the occurrence of problems resulting in undesired outcomes".

To achieve the research objective, the main research question (MRQ) is framed as follows:

***MRQ*: How can the most critical barrier to collaboration in BIM teams in the design phase of BIM-enabled infrastructure projects be addressed to improve the collaboration in future projects?**

Research design

The research is divided into six phases: Literature review, case studies, cross-case analysis, strategy creation, qualitative validation, and conclusion. The barriers to collaboration in BIM teams are identified from the literature and checked for presence in case studies. Three infrastructure projects were chosen for this purpose and studied to identify the barriers to collaboration in BIM teams. For this research, data were collected through conducting interviews with BIM teams and studying the BIM documents. The case study findings are compared with the literature and the most critical barrier is identified by asking why questions to the problems until the reasoning is sufficient to identify the main problem. After identifying the most critical barrier, strategies are developed to avoid the problem in the future projects. The created strategies are qualitatively validated with BIM teams to check the applicability in practice.

Research Findings

From the literature, 26 barriers have been identified hindering the collaboration in BIM teams. In the analysed cases, 14 barriers were observed. Out of which, 7 were observed in all the cases. These 7 barriers were studied further to find the main cause for the poor collaboration in BIM teams. From the analysis, it was found that lack of guidelines and standards was the most critical barrier to collaboration in BIM teams.

Strategy creation

To avoid the problem of lack of guidelines and standards in future projects, two strategies were proposed: [1] Improving the design process by integrating best practices and [2] Automating the process. With the 1st strategy, an improved process map for the design phase was created according to ISO 19650, a global standard for information management in civil projects and integrating the best practices (success stories) from past projects. This was required because members in BIM teams were less skilled and unaware of the process. The improved process map can help in understanding the design process of the entire project. To enable better collaboration in BIM teams, the 2nd strategy

from this research was to automate the processes. In this research, the improved design process is automated using business process management (BPM) software.

Qualitative validation

The strategies created from the research (process maps, automated process maps) were validated with BIM teams to check for applicability in practice. The interviewees acknowledged that the proposed strategies from the research can be a good attempt to solve the lack of standards and guidelines within the organisation.

Research limitations

Boundaries were set to stay within the scope of the research and these limitations should be considered while evaluating the findings

- Focus is given only to Dutch context and infrastructure projects.
- Barriers are biased with three Dutch infrastructure projects
- Barriers are analysed only in the design phase
- Results are validated qualitatively with BIM practitioners from Witteveen+Bos

Recommendations for practice

From this research, a set of recommendations are provided to Witteveen+Bos for improving the collaboration in BIM teams in future projects.

- Check the organisational quality standards and align the process maps accordingly.
- Provide a walkthrough of the process maps created from this research to the BIM practitioners.
- Appoint lessons learned team at every project to take responsibility in analysing the lessons learned capture and providing recommendations for reuse.
- Encourage members in BIM teams to join relevant software community
- Give high priority in creating guideline documents for the projects.
- Like this research, more BIM projects can be studied within the organisations, success stories should be found and the process should be improved.

Recommendations for future research

Future researches are required for

- Studying more projects of a similar type to check the quality of findings
- Analysing if the strategies from this research can be applied to other types of projects
- Comparing to which countries the proposed strategies can be applied.
- Studying the importance of the client's role in collaboration with BIM teams.
- Validating the research findings in a pilot project.
- Exploring the integration of project leaders with BIM processes.
- Performing research at other companies to check if this is company-specific or industry-specific problem.
- Providing more strategies to address lack of guidelines and standards.

Structure of the report

Chapter 1 presents an introduction to the research explaining the research problem. Chapter 2 explains the findings from the literature. To highlight, the barriers to collaboration in BIM teams. Chapter 3 describes the case study research involving three Dutch infrastructure projects. Chapter 4 discusses the similarities and differences among the researched cases and compares the findings with the literature. The most critical barrier to collaboration in BIM teams is found in this chapter. Chapter 5 provides possible strategies to address the most critical barrier. Chapter 6 discusses the applicability of the proposed strategies through qualitative validation with BIM teams from Witteveen+Bos. Chapter 7 concludes the research by answering the main research question, providing recommendations for practice and future research. The thesis is concluded with the personal reflection from the researcher.

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1. Introduction

The Architecture Engineering and Construction (AEC) industry is still in its much-anticipated move from tradition to automation. It has been dependent on 2D drawings and paper based documents which often causes problems leading to cost and time overruns in construction projects. Building Information Modelling (BIM) presents significant and promising changes to the digital transformation of AEC industry (Alizadehsalehi et al., 2020). BIM is defined as a modeling technology and an associated set of processes to produce, communicate, and analyse building models (Sacks et al., 2018). In easy words, "BIM is a comprehensive digital representation of a built facility with great information depth" (Borrmann et al., 2018). BIM is becoming popular as it gives project benefits in terms of time reduction, coordination improvement, reduced costs, and less re-work (Azhar, 2011). The implementation of BIM had significant impacts on the current practices, contractual policy, business models and reshaped the organisations (Al-Ashmori et al., 2020).

The AEC industry is project-based (Liu et al., 2017) and construction projects enabled by BIM are typically delivered through deploying BIM teams (Mignone et al., 2016) comprising members from specialist organisations contracted to execute BIM-related works (Grilo & Jardim-Goncalves, 2013). Collaboration between them is seen as a prerequisite for BIM success (Cao et al., 2017). Collaboration refers to an agreement among several specialists to share their capabilities, including available data, information, and knowledge, in completing particular tasks, to achieve the project's broader objectives, as defined by their client, or stakeholders (Hughes et al., 2012).

1.1 Problem analysis

Poor collaboration in BIM-enabled projects

BIM fosters collaboration across the construction supply chain (Howard et al., 2017) however the benefits of collaboration are realised only in a relatively small number of BIM-enabled projects (Cao et al., 2015). Poor collaboration continues to be one of the major risks affecting BIM-enabled projects (Zhao et al., 2017) with misunderstandings, misinterpretation of data, and increased rework (Nikas et al., 2007). BIM tasks are executed by deploying BIM teams and maintaining collaboration between them has proved problematic (Matthews et al., 2018). The most significant barrier in achieving effective collaboration in BIM teams is the failure to adjust intra – and inter-organisational processes and working arrangements with different sources of data (Vass & Gustavsson, 2017). Barriers hindering the collaboration in BIM-enabled projects should be found and strategies should be developed.

High efforts in design phase:

The MacLeamy curve in figure 1 shows that BIM processes require high efforts in the design phase of a construction project. The early stages of architectural design are accepted as the weakest point of BIM systems (Cavusoglu, 2015) as the members in the BIM teams should collaborate to communicate ideas, drawings, design specifications, and other disciplinary outputs required to develop models (Lee & Jeong, 2012). This creates denser and highly interdependent interactions among them and makes the design phase challenging (Jaradat et al., 2013). Hence, barriers to collaboration will be high in this phase. They need to be identified and strategies should be developed to optimise the design phase to enable better collaboration in BIM teams.

Lack of standardised processes

BIM suffers from a lack of standardisation (Santos et al., 2017). BIM standardisation plays an important role in enhancing collaboration and fostering interoperability (Turk, 2016) by smoothening the information exchange between different actors in BIM-enabled projects (Hooper, 2015). ISO19650 is a new set of international standards inspired from the UK1192 series for information management in buildings and civil engineering works. A survey conducted by Dadmehr & Coates (2019) has revealed that ISO19650 is the first official document related to information management for most countries around the world and guidance is needed for practitioners in using this standard. ISO19650 has its processes which the industry needs to adopt but the process is general and needs to be developed in detail to help practitioners in using the technology

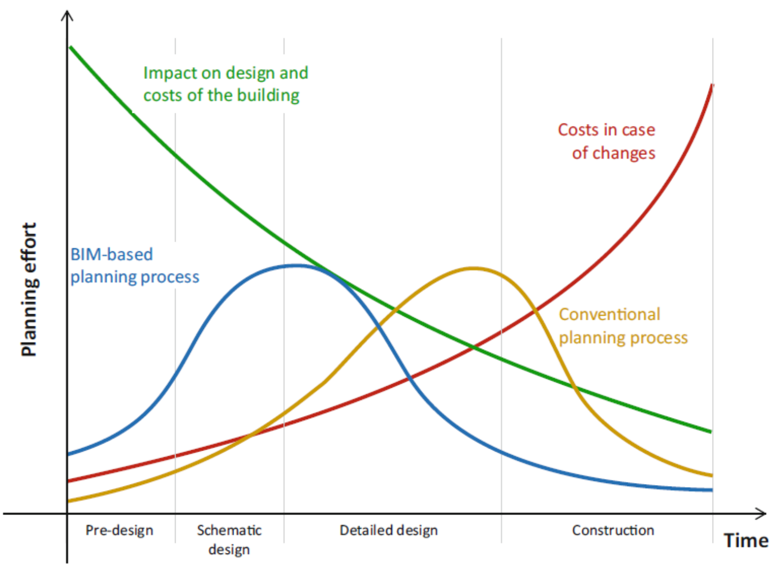

Figure 1 MacLeamy curve of conventional and BIM-based planning process (Borrmann et al., 2018)

1.2 Research relevance

1.2.1 Scientific relevance

A previous study by Oraee et al. (2019) identified the barriers to collaboration in BIM teams by performing a systematic literature review and developing an integrated conceptual model of the barriers. The barriers were divided into five categories: Process, Actor, Context, Team, and Task. Oraee et al. (2019) pointed out that the findings from the study need to be validated through exposure to real-life data and future studies are required to find remedial strategies for these barriers.

As mentioned earlier, there is a lack of attention to standardisation of BIM. In the previous researches, efforts were taken to standardise BIM processes for improving collaboration in different use-cases such as integrating design and cost estimation (Kharoubi, 2019), drill-and-blast process of tunnel projects (Sharafat et al., 2021), green building project delivery (Wu & Issa, 2013), 3D modeling (Tsai et al., 2014), 4D modeling (Marzouk et al., 2010) environmental impact assessment (van Eldik et al., 2020). An overview is provided in Appendix A. As mentioned earlier, ISO 19650 is new to the industry and paid less attention in the academic researches. It is important to enable standardisation of BIM according to ISO 19650 standards. To the best of the researcher's knowledge, the design phase of BIM-enabled infrastructure projects according to ISO 19650 standards is an unexplored area and studies are needed for improvements.

1.2.2 Practical relevance

This research is practically relevant as the AEC industry is digitising its project management practices which gives the necessity to develop standardised techniques, tools, and technologies that will revolutionize the construction project management practices (Alizadehsalehi et al., 2020). This research is performed at Witteveen+Bos (founded in 1946), an international consultancy and engineering firm that provides services in the fields of water, infrastructure, environment, and construction. Witteveen+Bos envisions to have a high level of BIM knowledge and implementation by promoting and developing the BIM culture in delivering high-quality processes and products. They need more standard templates/processes required to guide their employees with the technology. This is confirmed from the survey conducted for BIM acceleration within Witteveen+Bos to which around 80 BIM practitioners responded. The industry is bound by time pressures with the projects and there is very little opportunity to focus on improvements. Hence, it will be helpful for the organisations to use the end deliverables from this research in their project management practices.

1.3 Research objective and question

The purpose of this research is to address the most critical barrier to collaboration in BIM teams in the design phase of BIM-enabled infrastructure projects and create strategies to avoid the barrier in future projects. The most critical barrier in this research is defined as "the main issue that causes the occurrence of problems resulting in undesired outcomes".

To achieve the research objective, the main research question (MRQ) is framed as follows:

<u>MRQ</u>: How can the most critical barrier to collaboration in BIM teams in the design phase of BIM-enabled infrastructure projects be addressed to improve the collaboration in future projects?

To answer the main research question, sub-research questions are framed as follows:

<u>SRQ1</u>: What is the most critical barrier to the collaboration in BIM teams in the design phase of BIM-enabled infrastructure projects?

<u>SRQ2</u>: What are the possible strategies to address the most critical barrier to collaboration in BIM teams in the design phase of BIM-enabled infrastructure projects?

1.4 Research design

The research is divided into phases and shown in figure 2

Phase-1: Literature review

The first step of this research is to perform a literature review to identify the scientific relevance and the barriers to collaboration in BIM teams. The data for the literature study is collected from journals, scientific papers, research studies, and technical reports to collect the barriers to collaboration in BIM teams. This enables the researcher to enhance the knowledge on collaboration barriers before analysing the case studies.

Phase-2 Case studies

The identified barriers from the literature study are checked in the case studies. A set of criteria is developed in choosing the case studies for the research. Three infrastructure projects were chosen for this purpose and studied to identify the barriers to collaboration in BIM teams. For this research, data were collected through conducting interviews with BIM teams and studying the BIM documents.

Phase – 3 Cross-case analysis

The data collected is analysed by performing a cross-case synthesis. No two cases are similar and this technique is performed to see to what extent the individual cases can be sufficiently compared. The cross-case analysis then is compared with the literature. The most critical barrier is identified by asking why questions to the problems until the reasoning is sufficient to identify the main problem.

Sub-research question-1 is answered

Phase - 4 Strategy creation

After identifying the most critical barrier, strategies are developed to avoid the problem in future projects.

Sub-research question-2 is answered

Phase-5 Qualitative validation

The created strategies are qualitatively validated with BIM teams to check the applicability in practice.

Phase – 6 Conclusion

The research limitations, conclusion, recommendations for practice and future research are given.

Main research question is answered.

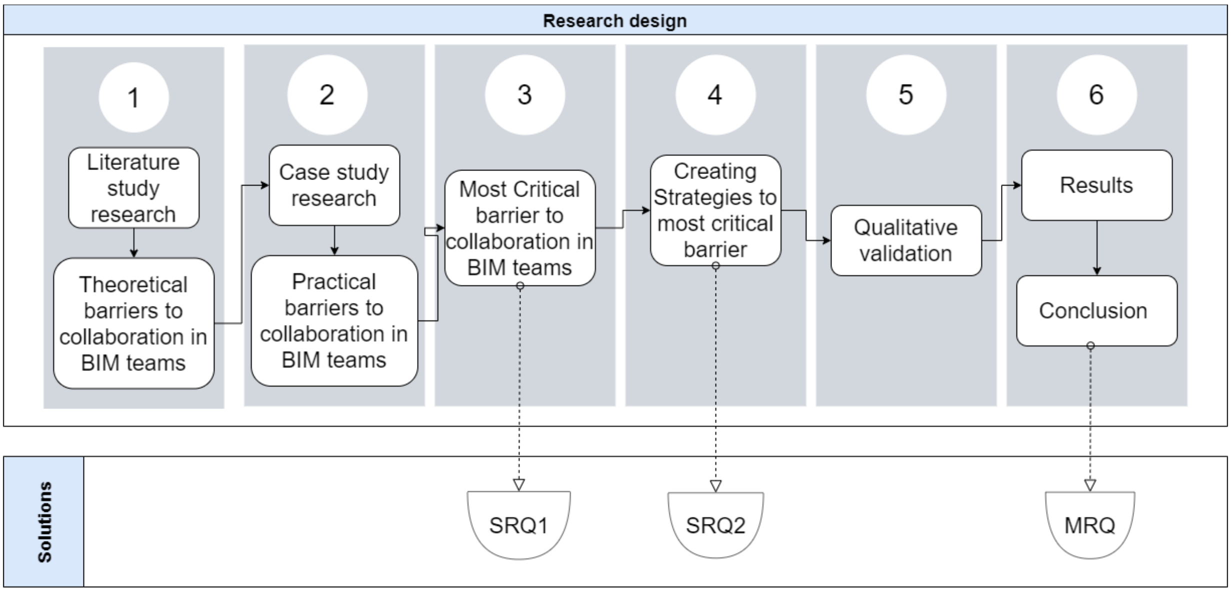

Figure 2 Research design

1.5 Research motivation

The researcher was motivated to perform research on this topic because of three reasons: [1] Importance of BIM in the construction industry, [2] Course from the master's curriculum [3] Working with BIM in the future.

BIM is rapidly growing but the implementation has been much slower than anticipated (Saka & Chan, 2020). The construction industry is transforming its construction management practices to digitisation and BIM is highly important in the present and future.

The researcher learned the foundations and importance of BIM and life cycle information systems in construction projects and organisations from the course “CIE4120 – Information systems for the construction industry”. For practical work, the researcher created numerous BIM models for a real-life project in India.

The researcher would like to work in the field of BIM contributing the knowledge and expertise obtained from the educational curriculum and this research. In the future, BIM will no longer be an exception and skilled employees will be required to execute the BIM tasks.

2. Literature study

2.1 Impacts of BIM in AEC industry

BIM is defined as a modeling technology and an associated set of processes to produce, communicate, and analyse building models (Sacks et al., 2018). In easy words, “BIM is a comprehensive digital representation of a built facility with great information depth” (Borrmann et al., 2018). The benefits include better communication, early collaboration, error-free design, less rework, better predictability, saved cost, and improved productivity (Lu et al., 2014). The implementation of BIM has significant impacts on the current practices, contractual policy, and business models and reshapes the organisations (Al-Ashmori et al., 2020).

The introduction of BIM has forced the AEC industry to change its work methods requiring collaboration among multiple parties (Liu et al., 2017). The new work methods accompany complex working relationships and interrelations (Bresnen et al., 2004). Collective working of hundreds of individuals is required in a large infrastructure project to achieve the BIM goals (Lee & Jeong, 2012). BIM goals are mostly 3D and 4D modeling and the usage is high in the design phase (Liu et al., 2017). To execute the BIM tasks, a BIM team is formed as the decision-making in projects is interdependent and requires a collaborative effort with different disciplines (Benne, 2005). It focuses on achieving the BIM goals in the project.

The important roles in a BIM team are BIM manager, BIM coordinator and BIM modeller (Borrmann et al., 2018). An overview of their responsibilities is provided in figure 3. BIM manager is a strategic role in the company responsible for guiding the transition towards digital practices and for developing guidelines regarding workflows, model contents, and best practices (Borrmann et al., 2018). BIM coordinator acts as a supporting role for the project manager and is responsible for technical issues regarding BIM (Liu et al., 2017). The BIM coordinator is also responsible for coordinating the specialist disciplines, merging sub-models, checking model contents, and applying quality control to meet the client’s demands. The BIM modeller is an engineer or architect responsible for developing the BIM models (Borrmann et al., 2018).

	Strategic						Management				Production	
Role	Corporate Objectives	Research	Process + Workflow	Standards	Implementation	Training	Execution Plan	Model Audit	Model Coordination	Content Creation	Modelling	Drawing Production
BIM Manager	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N
BIM Coordinator	N	N	N	N	N	Y	Y	Y	Y	Y	Y	N
BIM Modeler	N	N	N	N	N	N	N	N	N	Y	Y	Y

Figure 3 Responsibilities of members in BIM teams (Borrmann et al, 2018).

2.2 BIM-based design process

The construction project can be executed digitally from the initial stages and allowing to analyse the structure as well as the construction process in detail (Borrmann et al., 2018). An in-depth understanding of the construction project is obtained by implementing interactive visualisation of the asset in 3D models. In addition to this, new visualisation possibilities have emerged to support design coordination and control errors in planning which are clash detection and 4D construction process animation (Borrmann et al., 2018).

3D BIM:

Developing a 3D model is the most common BIM application (Eadie et al., 2015). The first level of BIM is the creation of 3D models. It represents the geographical structure of a planned asset. Before BIM, the structures were detailed in paper drawings which is time-consuming and error-prone. The possibility to check the traditional drawings is limited. The introduction of 3D BIM Models helps to visualise the planned asset, improve communications, and decision-making by analysing the options (Sacks et al., 2018). Software such as Revit, AutoCAD 3D, Civil 3D, SketchUp is used for this purpose (Sacks et al., 2018).

Clash detection

Clash detection ensures quality in a BIM model and can also be called BIM validation, clash detection, design coordination, and code checking (Ciribini et al., 2016). The design coordination ensures the geometric feasibility of the building's final status as well as a logical sequence of the construction processes (Borrmann et al., 2018). With the new possibilities in design coordination, considerable value is added to the project by early fault prevention and improving the planning of the construction. This is a rule-based framework to validate design according to various validation domains (Zhang et al., 2013). Before BIM, identifying physical conflicts was manually laborious and identified by overlaying 2D drawings which led to the situation that most of the errors were found during the construction phase resulting in cost and time overruns (Sacks et al., 2018). With the application of clash detection in BIM, the design validation is made easier but reactive. This process is also repetitive as different individual models are checked for clashes to develop an integral 3D model. Software such as Autodesk Navisworks Manage, Solibri Model Checker, and RIB iTWO can be used to perform the clash detection (Sacks et al., 2018).

4D BIM:

A 4D BIM model is created by linking the 3D model to construction activities defined in a schedule in a Building Information Model (Koo & Fischer, 2000). The main applications of 4D modeling are communication, planning and scheduling, safety issues, legal claims and dispute resolution (Platt, 2007). Before BIM, gantt charts were used for the project planning and it was difficult to find the critical path of the project. The implementation of 4D BIM improved communication as the project evolution can be observed giving room to solve disputes and discuss opportunities for improvements. The construction planning and scheduling of the projects are improved by presenting complex information more easily. Some of the software which has been used in 4D BIM modeling is: Microsoft Project, Primavera P6, and Vico Office Schedule Planner (Sacks et al., 2018).

2.3 Collaboration barriers in BIM teams/BIM-based construction networks (BbCNs)

Though BIM is considered as the ultimate solution for collaboration problems across the construction supply chain (Howard et al., 2017), the poor collaboration continues to be one of the major risks affecting BIM-enabled projects (Zhao et al., 2017) with misunderstandings, misinterpretation of data and increased rework (Nikas et al., 2007). BIM teams can also be referred as BIM-based construction networks and 26 barriers to collaboration in BIM teams are identified and placed in five categories such as process, actor, context, team and task (Oraee et al., 2019). This is shown in figure 4.

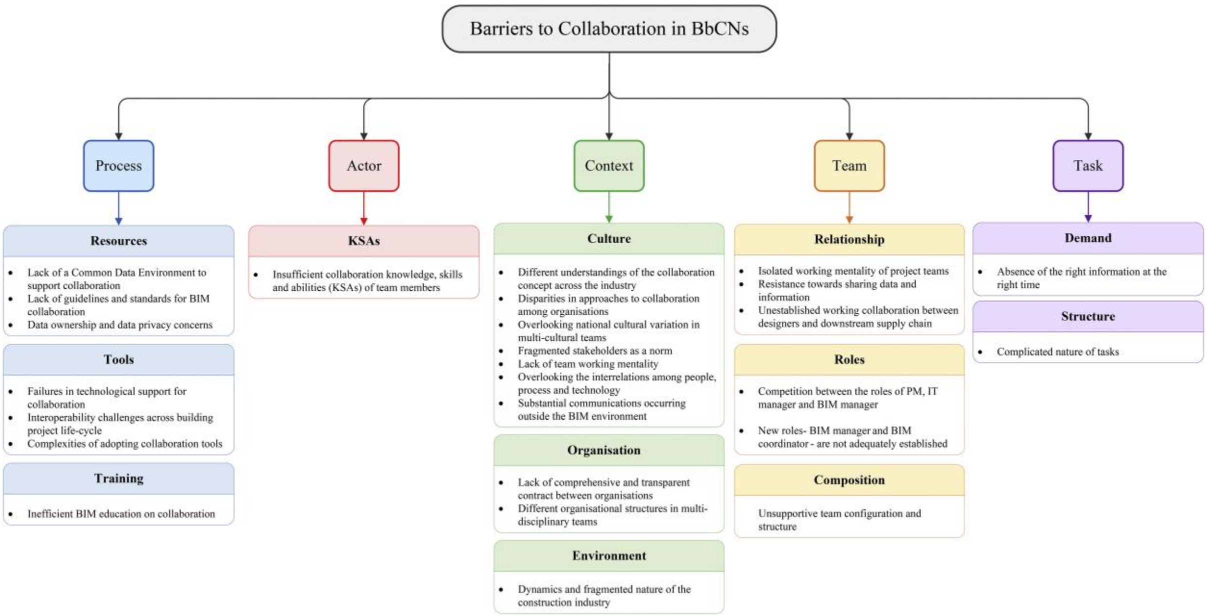

Figure 4 Barriers to collaboration in BIM teams/ BIM-based Construction Networks (Oraee et al., 2019).

Process barriers cover essential tools, necessary resources, and professional training for collaboration. Tools refer to the relevant software and technologies and their compatibility, capabilities, and specifications to collaborate in BIM-enabled projects. Appropriate resources such as physical space and equipment are required for efficient collaboration. Professional training regarding the technology is required to understand the processes and improve project performance. The largest group of process barriers were associated with tools, followed by resources which were followed by training.

- Resources: There is a lack of understanding on what resources in terms of enablers and organisational forces are needed to be in place for effective collaboration (Dossick & Neff, 2010). Industry professional bodies allocate a significant amount of resources to enhance collaboration among BIM teams and the best examples include the ISO19650 series and the UK1192 series. From the literature, BIM suffers from the lack of standardisation (Santos et al., 2017) and has been considered as a serious barrier to collaboration in BIM teams (Merschbrock & Munkvold, 2014). A process is standardised when it is predefined by executing it in the same way every time to produce the same output (Hooper, 2015). BIM standardisation enhances collaboration and fosters interoperability by enabling easy data exchange in the BIM teams (Hooper, 2015).
- Tools: Interoperability through BIM tools and software is regarded as a major barrier to collaboration in BIM-based construction networks (Hu et al., 2016; Lee et al., 2015). The problem of interoperability comes from two reasons: information loss during transfer and the software market (Criminale & Langar, 2017). There are numerous software available for each purpose and it is highly possible that they are not compatible with each other. Stakeholders have their preference for software and they might not be familiar with the software that was used to design the model. Incompatibilities were reported by practitioners when different versions or different configurations of the same software were used by users (Saluja, 2009).
- Training: Education and training in handling BIM technology for experienced personnel is lacking as a new generation of BIM technology-savvy engineers is still growing (Borrmann et al., 2018). Educating the BIM teams with training requires time and costs which is considered a serious barrier (Criminale & Langar, 2017). This has discouraged many professionals in the AEC industry from practicing it (Koptsopoulou, 2020). The problem of collaboration in BIM teams has its roots in human behaviour (Grilo & Jardim-Goncalves et al., 2010). In the present scenario, BIM training is being attended by young staff and this can lead to a trend where experienced veterans should

rely on them to operate BIM functions (Oraee et al., 2019). Organisational training has been highlighted as the best way for delivering continuous transformation in collaborative BIM processes (Oraee et al., 2019).

Actor barriers were concerned with the knowledge, skills, and abilities (KSA) of the members in BIM teams. Practitioners lack the necessary skills and collaboration competencies have not been improved to match BIM developments (Kokkonen & Alin, 2016). A study by Ahmed (2018) has shown that resistance to change is the most critical factor for BIM implementation. Construction practitioners show resistance to modify their existing ways of working and learning new technologies. They may feel intimidated by the new technology and think about the impacts of affecting their jobs negatively (Barlish & Sullivan, 2012). Not only the practitioners, the organisations also lack awareness of BIM contributing to the daily work of their employees (Siebelink et al., 2020). Organisations currently implementing BIM find difficulties in training their employees with the required BIM skills to manage and collaborate (Kokkonen & Alin, 2016). In the present scenario, there are managers unsure if BIM's benefits will outweigh the investments (Lambermon, 2020). Though the practitioners are aware of the BIM advantages, they are unaware of the economic effects and outcomes of BIM (Mehran, 2016).

Context barriers cover the specific environment in which the above-mentioned factors are set. Shades of the above-mentioned barriers are visible in the context barriers. Context barriers are divided into environment, organisation, and culture. The environment of the construction industry is fragmented in nature. The companies and supply chain components are dispersed in different locations, cities, and countries. Team members may differ in age, culture, gender, education, experience, roles, and attitudes which lead to cultural barriers. This was significant in BIM teams' collaboration and various communication attitudes between team members lead to ineffective collaboration (Oraee et al., 2019). The most important context-based barriers were associated with organisations. From the literature findings, the most influential organisational barriers included the lack of contractual standards on BIM models, different collaboration approaches to BIM by different organisations, and lack of appropriate inter-organisational BIM processes.

Team barriers cover the challenges including the composition, relationships, and knowledge sharing in BIM teams. Construction activities are inherently contingent upon collaboration among team members (Greenwood & Wu, 2012), and collaboration between them is seen as a prerequisite for BIM success (Cao et al., 2017).

- <u>Relationship:</u> The isolated working mentality disrupts the relationships and interfaces and leads to ineffective collaboration (Akponeware & Adamu, 2017). Willingness to share information among project stakeholders is critical and BIM should include the capability to transmit and re-use the information embedded in the graphical model (Liu et al., 2015). Designers may be reluctant to share their work due to liability concerns, unauthorized intellectual properties reuse, and risk misinterpretation (Liu et al., 2017). Sharing information with project stakeholders and supply chain partners will result in efficient collaboration.
- <u>Roles:</u> The introduction of BIM has resulted in new roles and responsibilities for the management and coordination of building information models (Borrmann et al., 2018). The roles and responsibilities need to be well-defined for better collaboration between diverse and interdependent tasks and activities (Zanni et al., 2017). The roles of BIM manager and BIM coordinator are not adequately established and the lack of centrality between these roles hinders the collaboration in BIM teams.
- <u>Composition:</u> Unsupportive team configuration and structure has been seen as a barrier to BIM teams. Team composition is mainly structured in traditional forms that support BIM tasks. The

changing role of the actors in the network, contractual, and organisational relationships and configuration of processes among the actors hinders collaboration in BIM teams (Mignone et al., 2016). Team composition greatly affects the attitudes of BIM teams (O'Leary & Mortensen, 2010) because the information from diverse sources has to be integrated hindering the collaboration in BIM teams (Wu & Hsieh, 2012).

Task barriers are the least influential barriers to collaboration in BIM teams (Oraee et al., 2019). They cover the demand and structure of BIM tasks. Task demand depends on the work situations and the unavailability of the required information at the right time for executing the tasks is a significant barrier for efficient collaboration (Zanni et al., 2017). Task structure is affected by complexities in projects. In large BIM teams, tasks are generally complicated and can yield diminished collaboration (Mignone et al., 2016).

The trends in barriers to BIM teams are shown in figure 5. From the figure, it is evident that the process barriers are most identified in the literature and dominates the barriers to collaboration in BIM teams. This gives the necessity to focus on addressing the process barriers. It is highlighted that BIM research should be paying attention to people, process, and their overarching interaction with technology and a better understanding of the collaboration process could lead to better BIM technologies (Liu et al., 2017).

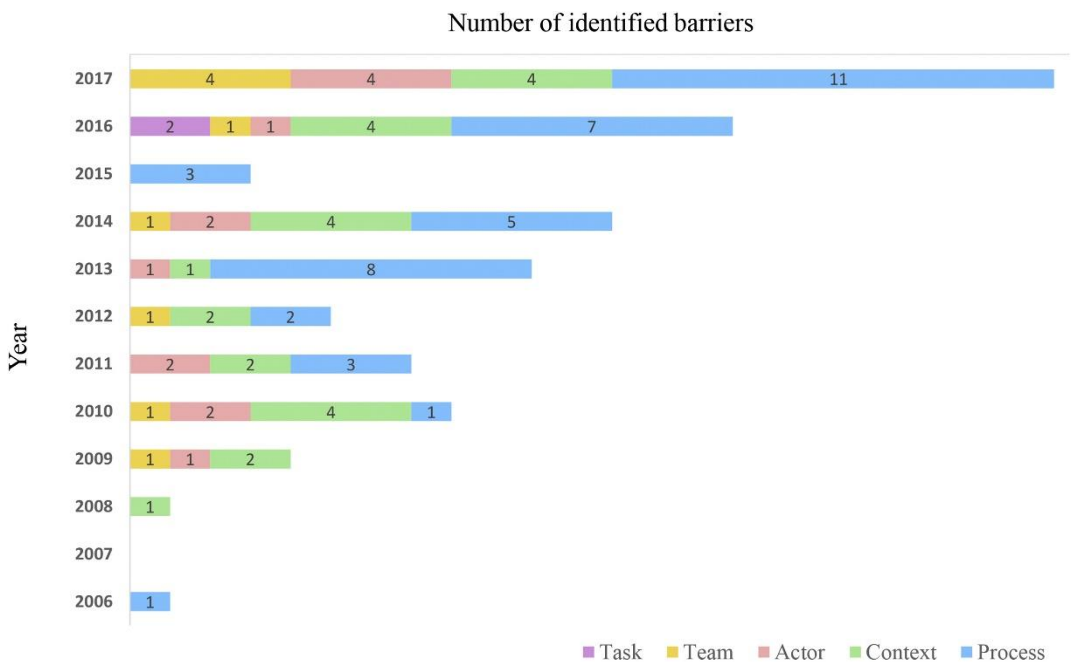

Figure 5 Trend in barriers to collaboration in BIM teams (Oraee et al., 2019)

3. Case study research

This chapter involves analysing real-life project cases to compare the identified barriers from the literature to collaboration in BIM teams. The case study research was done by choosing three projects with a certain set of criteria (section 3.1). The selected cases for this research (3.2) and the protocol for conducting the case studies are explained (3.3). The chosen cases for this research are explained in sections 3.4, 3.5 and 3.6 respectively.

3.1 Case selection criteria

The cases are selected such that they were similar in scope and complexity aspects. For this research, cases were chosen in which the project scope was to re-design existing infrastructure. The additional criteria are described as follows:

1. Large interdisciplinary infrastructure projects in which BIM is used.

Large infrastructure projects are highly uncertain, complex, and involve a large number of stakeholders including political parties (Clegg et al., 2002). Large infrastructure projects generally tend to result in cost and time overruns because of the uncertainties and technical complexities (Luo et al., 2017). In interdisciplinary projects, different disciplines are involved resulting in collaboration with numerous teams. The higher the number of people involved in the project, more perspectives on barriers to collaboration in BIM teams can be studied.

2. Witteveen+Bos is the lead appointed party

Witteveen+Bos is directly appointed by the client and becomes the main contractor to execute the design requirements for the project. This is because the lead appointed party takes responsibility in creating the BIM plan and models and much information about the collaboration issues can be extracted.

3. The design phase of the projects are almost or recently completed.

The reason to choose design phase is that most of the construction projects used BIM widely in the design phase with the application of creating 3D/4D models (Hartmann et al., 2008). The experiences of working with BIM can be easily collected when the projects are recently completed or under progress.

4. BIM documentation is available.

To observe the processes and plan of approach, BIM documentation for the project should be available. The documents should be accessible for getting a clear picture of BIM in the project.

5. Interviews are possible with BIM teams.

Interviewing the members of BIM teams enables the researcher to observe the challenges of implementing BIM in real-life projects. People in different roles such as BIM managers, BIM modelers, BIM coordinators should be interviewed to collect their experiences with BIM.

3.2 Selected cases for this research:

Three cases were selected matching the criteria with projects at Witteveen+Bos. The identified cases were discussed with the company supervisor to check the feasibility of studying these cases for this research. Data was collected by studying the documents related to BIM and conducting interviews with BIM teams.

3.3 Case study protocol

A protocol was developed following a set of guidelines to perform the case study research. The documents related to BIM for the chosen case studies were collected prior to the interviews thereby understanding the plan of approach for the project. To conduct the interviews, interviewees were selected based on their roles, involvement with the project, and familiarity with BIM. To understand the barriers to collaboration with BIM, BIM managers, BIM modellers, BIM coordinators and 4D planners were interviewed. Only the people who worked on the project were interviewed. In total, 10 interviews were planned and out of which 9 were conducted. Interview with BIM-coordinator of case-C was not possible due to unavailability.

The interviews were conducted in English. The identified barriers from the literature study were not shown on purpose hence strengthening the empirical evidence (Yin, 2002). The nature of the interviews was a blend of semi-structured and open questions. A questionnaire was prepared and sent to the interviewees before the interview (Appendix B). The questions were divided into four categories: self-introduction, process-based, issue-based, and solution-based. In addition, the research background including the objectives was sent via email. At the start of the interview, permission was sought to tape the interview to aid the transcription of the conversation and each interview lasted an hour. During the interview, a brief introduction of the researcher and the research was given through a presentation. It was followed by answering the prepared questionnaire. The questions were asked further based on the responses from the interviewees. At the end of the interview, additional documents relevant to the research were requested. Permission was sought from the interviewees if the input from the interview could be used for the research.

3.4 Case – A

Case A is a large infrastructure project to re-design the existing highway by expanding the road lanes, constructing bridges and underpasses in the Netherlands. The project objective is to reduce road congestion in the coming years and improve accessibility, road safety, and quality of life. The cost of the project is >1 billion euros and the entire project is divided in three parts. The design started in June 2020 and 90% of the works are completed. The BIM uses of the project include 3D modeling, clash detection, 4D modeling, and quantity estimation. The design process of this project is explained in Appendix C

3.4.1 Data collection:

1. Documents studied: BIM Execution Plan (BEP) and the BIM use cases of 4D and clash detection were studied. The purpose and scope of BIM, project organisation, goals, planning, and information management were documented in BEP. The model and object coding were mentioned in the document which helped the readers to understand the naming structure to be followed. The BEP was half complete resulting in incompletions in some sections of the document including the collaboration procedure. On studying the BIM use cases of 4D and clash detection, the process of obtaining the model was clearly outlined. The input, preparation, workflow, software to be used was highlighted and gave the readers an easy understanding of the process. The BIM use-case documents for other applications like developing 3D models and quantity estimation were not written yet.

2. Interviews: For this project, three interviews were conducted. An overview of the interviewees is given in Table 1 below and the transcripts can be found in the appendices mentioned in table 1.

Interviewee	Role	Educational background	Experience with BIM
A1 (Appendix D1)	BIM Modeller	Bachelors in Civil Engineering	First time working for infrastructure projects as lead designer
A2 (Appendix D2)	BIM Coordinator	Civil Engineering (Specialisation in BIM)	Started career with W+B as designer using AutoCAD. 5+ years of BIM experience
A3 (Appendix D3)	4D planner	Construction Management and Engineering	First time working with BIM.

Table 1 Interviewee information for case-A

3.4.2 Barriers to collaboration for BIM teams:

Bringing everybody on the same page including the clients, external parties, and explaining BIM processes was challenging in this project. Road design works were given to a third party and they were looking for other opportunities in altering the design. This resulted in 2 months delay which created a snowball effect in delaying the tasks dependent on them. In addition, contacting the external parties for modifications to the BIM models was difficult as the agreement was not well-defined at the start.

The roles and responsibilities were not clear for everybody and teams were not sure about their tasks. The project was understaffed such that there were only three BIM-modellers in the initial stages of the design process. It later expanded to six modelers but it was still understaffed because of the complicated nature of the tasks and the time pressure (Interviewee – A1). There was a huge workload in executing the BIM tasks for the project. For instance, the number of clashes when a clash test was performed. There were thousands of clashes in some situations and analysis of those clashes was complex (Interviewee – A2).

Procedures on how to work with software were not established. These were required to know the file format exchanges, level of detail, object coding, etc. Interviewee – A3 was new to the industry and felt more time was required to understand the process and work methodology. This was not established because of the time pressure and deadlines which resulted in costing additional time and efforts for the BIM teams to understand the process. The required information in the BIM models was not achieved because of this reason (Interviewee – A1).

The level of detail required was not defined properly which lead to misunderstandings and rework. For instance, getting the input for planning. Sometimes, there was new information received from the client during the project. Generally, the client outsourced BIM works to specialist organisations and has little knowledge of BIM. Their experience and education with BIM were an issue with this project. Lack of knowledge with BIM was another barrier in which construction practitioners believed that BIM is a 3D model and not a process (Interviewee – A1).

3.4.3 Best practices to improve collaboration in BIM teams:

1. Standardised workflows: Having a pre-defined workflow of who delivers what and when can be an ideal solution to improve collaboration in BIM teams (Interviewee – A3). Standardised workflows have to be developed and standardised throughout the organisation.

2. Structured roles & responsibilities: BIM is still people's work and what they need to do, how and when must be defined adequately (Interviewee – A2). Having well established roles gives the sources of input needed for the execution and the contact person when there is more information required (Interviewee – A3).

3. Well-defined information requirements: During the start of the project, information requirements must be defined. If the data is provided correctly, execution won't be a problem (Interviewee – A2).

3.4.4 Observations on case-A

Case-A was understaffed and had many inexperienced actors in the BIM team. This required additional time and effort for them to understand the BIM work methodology and bringing everybody on the same page to explain the BIM process was challenging in this project. In addition, the documents like BEP and the BIM use-cases were half-written. This didn't enable the members in the BIM teams to understand what information was required to be developed in the BIM models. Work procedures on how to do BIM were not established. When analysing case-A, these barriers resulted because of three reasons: [1] Practitioners experience with BIM, [2] Lack of standards and guidelines, [3] Insufficient knowledge with BIM teams. Interviewee-A2 highlighted that it is common to have inexperienced members in BIM teams as the skilled practitioners are scarce and having good leadership will avoid this problem. Guidelines and standards were not developed because of the human resource capabilities and time pressure of working with deadlines.

3.5 Case – B

Case B is a large infrastructure project to re-design the existing infrastructure by widening and constructing new roads and tunnels in Belgium. The cost of the project is >500 million euros and the conceptual design phase of the project is completed at the present date. The project objective is to have fewer traffic jams, fewer accidents, and a better quality of life surrounding the region. Several organisations like BAM, Sweco, Royal Haskoning DHV, Tractebel collaborate to work on this project. The design process of this project is explained in Appendix E.

3.5.1 Data collection:

1. Documents studied: BIM documentation was good in this project. The data was collected by studying BIM protocol, BIM execution plan (BEP), BIM360 coordination process map, BIM models validation process map. These documents gave the researcher a general overview of the approach to BIM in the project. The BIM Protocol and BEP were incomplete in some sections. A significant characteristic of this project is the creation of a knowledge platform (internally called WIKI). The procedures and guidelines to be followed by BIM teams is clearly explained in this online environment. The researcher saw the organisation of the WIKI page during the interview with the BIM coordinator through screen sharing.

2. Interviews: Four interviews were conducted with members in BIM teams including BIM modeller, BIM coordinator, BIM manager, and 4D planner. An overview of the interviewees is given in table 2 below:

Interviewee	Role	Educational background	Experience with BIM
B1 (Appendix F1)	BIM modeller	Bachelors in Civil Engineering	3+ years. Started as designer for this project.
B2 (Appendix F2)	BIM coordinator	Masters in Project Management of Civil structures and infrastructures (Specialisation in BIM)	15+ years. Started as designer using CAD.
B3 (Appendix F3)	BIM manager	Bachelors in Civil Engineering	6+ years. Started as designer with North-South Lane (NSL)

			project. Provide education to other schools on using Revit.
B4 (Appendix F4)	BIM modeller – 4D	Masters in Civil Engineering.	20+ years. Previous experiences include BIM coordinator for NSL.

Table 2 Interviewee information for case-B

3.5.2 Barriers to collaboration in BIM teams:

The failure of Common Data Environment (CDE) was an issue because of three reasons: [1] Initially BIM Xtra was used as the CDE for the project and later it was changed to BIM360 as the organisation did not want to take a risk with BIM Xtra as it was made by a small company, [2] Changing the CDE was itself a problem as getting activation license was challenging. This had to be discussed with the organisation as it was not the official CDE of the organisation, [3] the CDE workflow was changed as the project involved more than 200 models and information management was complex.

Integrating project leaders and BIM teams with the process was challenging and sharing information with project teams was difficult. Practitioners were not interested to work with BIM as 2D is considered as deliverables and other goals had to be achieved. BIM was considered as an additional task to do. Construction practitioners were not aware of the BIM technology and thought of BIM as 3D models and not as a process. Interviewees B2 and B4 felt that there was a lack of training on working with BIM. The organisation was not used to working with BIM methodology but some people realised the benefits of BIM. Time and efforts to understand the BIM process were challenging and there were people new who struggled to understand the BIM processes (Interviewee – B4).

The roles and responsibilities were not structured. Organogram was planned to be created but not done yet. This lead to issues of contacting the concerned person for approving the model. The project involved collaborating with numerous organisations and in some situations, specialists from other organisations had to be contacted to approve the models and there was uncertainty on finding the concerned person.

BIM documentation was done over different stages of the project and was not available at the start. The requirements on the information that BIM models should contain was not defined which lead to rework (Interviewee – B1, B3, B4). As a result, missing objects, physical codes, no good described demands were observed in the project. For instance, the demands from the client were changed such that the double-deck tunnel had to be changed to side-by-side tunnels. This gave a huge impact delaying the design works.

3.5.3 Best practices to improve collaboration in BIM teams:

1. Developing WIKI-page: The online knowledge platform tool helped the members in BIM teams to understand what they need to do. This helped practitioners who were new to working with BIM to understand the process (Interviewee – B1, B2, B3, B4).

2. Standardised workflows: Having a pre-defined workflow of who delivers what and when can be an ideal solution to improve collaboration in BIM teams (Interviewee – B3). Following ISO19650 standards is beneficial for improving collaboration and information management (Interviewee – B4).

3. Educating the BIM value to clients: The client is generally not aware of BIM and the benefits that can be realised with implementing this technology. They need to be educated to have a smooth workflow during the project (Interviewee – B4).

4. Well-defined information requirements: A decision on information requirements has to be made at the start. More information can be added to the top of the existing information but the existing information should not be removed/modified.

5. Organogram: An organogram should be created for each project clearly describing the structure of the organisation. The roles of the members in different teams must be outlined in form of a chart (Interviewee – B3).

3.5.4 Observations on case – B:

The theoretical way of working with BIM deviated in practice. Case – B had good BIM documentation for explaining the procedures and guidelines through the creation of a knowledge- sharing platform (internally called WIKI). This was a good practice which other projects can follow. This was done over different stages of the project and was not done at the start because the work methodology was not familiar. In the BIM protocol, it was mentioned that a BIM organogram was created for the project. The interview with the BIM manager (Interviewee – B3) confirmed that there was no organogram developed for this project. From this, it can be concluded that BIM documentation deviated from the planned approach. The documents are half-written which was also observed in case-A. When analysing case-B, the barriers resulted because of three reasons: [1] Lack of standards and guidelines for working with CDE, [2] Absence of the right information at the right time, and [3] Unfamiliarity with BIM work methodology.

3.6 Case – C

Case - C is a large infrastructure project to re-design the existing infrastructure by widening the existing roads, constructing new roads, and a bridge (2.5 kilometres long) in the Netherlands. The cost of the project is >1 billion euros and the project objective is to find robust strategies for the increasing traffic situation. The BIM uses for this project include 3D modelling, clash detection, 4D modelling, quantities, digital inspection, and serious gaming to use a simulator ride along the path. Numerous organisations such as Dura Vermeer, BESIX, Hochtief, and Van Oord collaborate to execute the project tasks. The design process of the project is explained in Appendix G

3.6.1 Data collection:

1. Documents studied: BIM was well-documented in this project. BIM protocol, BIM – use cases, BIM posters, BIM roadmap, modeling guidelines for worksheet exchange process, clash detection, and data information were studied. The plan of approach for executing BIM tasks was well organised and the procedures and guidelines to develop BIM models were outlined in the worksheet documents.

2. Interviews: Three interviews were planned to collect the experience of the members of BIM teams. The third interview with the BIM coordinator was not possible as the person was on leave for an indefinite period on personal grounds. An overview of the interviewees is given in table 3 below:

Interviewee	Role	Educational background	Experience with BIM
C1 (Appendix H1)	BIM modeller	Civil Engineering (Specialisation in Structural)	8+ years. Involved in other large infrastructure projects as BIM modeller.
C2 (Appendix H2)	BIM manager	Civil Engineering (HBO)	5+ years. Previously worked with 3D, 4D and 5D.
C3	BIM coordinator	Interview was not conducted	

Table 3 Interviewee information for case-C

3.6.2 Barriers to collaboration in BIM teams:

The workflow for BIM360 was changed because of the change of the BIM manager. The new person reorganised the working methodology which lead to start the process again renaming the objects and models. Every project begins with a new process based on BIM manager's preference thereby resulting in a lack of standardised workflows in the organisation

Interviewee C2 highlighted that BIM was not integrated with the project plan and was not given the priority it deserved. The project teams considered BIM as an additional task and bringing them on the same page was challenging. The team was understaffed and the capacity was not sufficient to execute the BIM tasks. BIM was underestimated in this project and working with time pressures was challenging (Interviewee – C1). The template models were created to set a baseline for further BIM models. This was created easily as it was a basic version and the time required to develop BIM models was estimated based on the time required for template models.

The BIM documentation for this project was perfectly done but the reality was different due to the complicated nature of the tasks of working with time pressure and less priority. Coding of the models was mostly done at the end of the project whereas it was supposed to be established in the earlier stages of the project and applied to 3D models at the earliest.

The BIM experience within the client and other project teams was minimal and explaining the BIM process took additional time and effort. The existing team had members with less BIM experience. They did not have sufficient knowledge of BIM. Though manuals were available to refer to the work procedures, time pressure with the deadlines did not allow study the documents. Information requirements were not clearly defined at the start and in some situations, new information was received from the client during the project.

3.6.3 Best practices to improve collaboration in BIM teams:

1. Standardising workflows: The workflows must be standardised and used throughout the organisation. This is observed from the responses of the interviewee – C2 as it was mentioned that every project begins with a new process.

2. Creating template models: Sample projects which give the starting points for the BIM modelers to work on is a good practice that can be followed in other projects (Interviewee – C1).

3. Experienced Leaders: Interviewee – C2 believed that an inexperienced team is not problematic in projects when leaders are experienced. BIM is relatively new to the organisation and an inexperienced team is obvious in the AEC industry. The issue of an inexperienced team can be solved when leaders have good knowledge about BIM and give the right directions to the team members.

3.6.4 Observations on case – C

Case – C had a good start with documenting BIM in the project. But, working with time pressure was intense and lead to deviations from the plan. Creating template models helped the BIM modelers to understand the information required in the models that should be created thereby improving collaboration. This was a good practice which other projects could follow. Collaboration was poor because of a lack of BIM knowledge and experience with practitioners, underestimating the value of BIM, and change in workflows. This could have been avoided if the BIM manager was not changed and the required effort for BIM was optimistically estimated.

4. Cross case analysis

This chapter compares the barriers among the studied cases. In section 4.1, the barriers from the analysed three cases are combined. Section 4.2 links the barriers from the theory (literature) and practice (case study findings). Section 4.3 explains the similarities and differences in the observed cases through cross-case analysis. Section 4.4 outlines the most critical barrier to collaboration in BIM teams thereby answering SRQ1.

SRQ1: What is the most critical barrier to collaboration in BIM teams in the design phase of BIM-enabled infrastructure projects?

4.1 Combined barriers from all the cases

The exact statements given by the interviewees from the analysed three case studies were combined by marking their occurrence in each case. Figure 6 shows the overview of the barriers observed in the case studies. These were later confirmed with them via email.

Barriers observed from case studies	Case-A	Case-B	Case-C
Changes in workflows		x	x
Additional time and efforts to understand the process	x	x	
Insufficient BIM education with the client and BIM teams	x	x	x
Unused to this kind of working methodology		x	
Every project there is a new process		x	x
CDE was changed to a different software. It was not official CDE environment and had to be discussed with the company		x	
Lack of knowledge on how to use software	x		
Level of detail required was not sufficient	x	x	
Getting input for planning was delayed	x		
Amount of clashes to be solved was complex	x		
Coding models and objects was not defined at the start		x	x
No good described demands from the client		x	
Underestimation of time to execute BIM activities		x	x
Information was not updated in the BIM models		x	x
Corona crisis made everything completely digital	x		
BIM was not given priority and was considered as additional task		x	x
Design change by external party after completion	x		
Bringing everybody on the same page was challenging	x	x	x
BIM process was not integrated with the project plan			x
Communication of responsibilities was done through mail & weekly meetings	x		
Lack of knowledge with BIM	x	x	x
Inexperienced team	x	x	x
Conflicts with the project teams. Integrating Project leader and design leader with the BIM process is challenging		x	
Understaffing	x		x
No organogram. Contacting concerned person was challenging. Roles & responsibilities was not structured		x	x
Connecting different models to check the progress. It was given only after completed and had to be checked for correctness			x

Figure 6 Case study findings

4.2 Linking the barriers from the case studies to the theory

The barriers from figure 6 are matched with the theory and shown in figure 7. This is done by referring to the definition of the barrier from Appendix C and matching the causes from the theory with the effects in practice. The matching is self-explanatory in most cases. For instance, Insufficient BIM education with the client and BIM teams can be directly linked to inefficient BIM education on collaboration. Another instance, changes in workflows is the effect of lack of guidelines and standards. In this way, the barriers obtained from the theory and practice are matched.

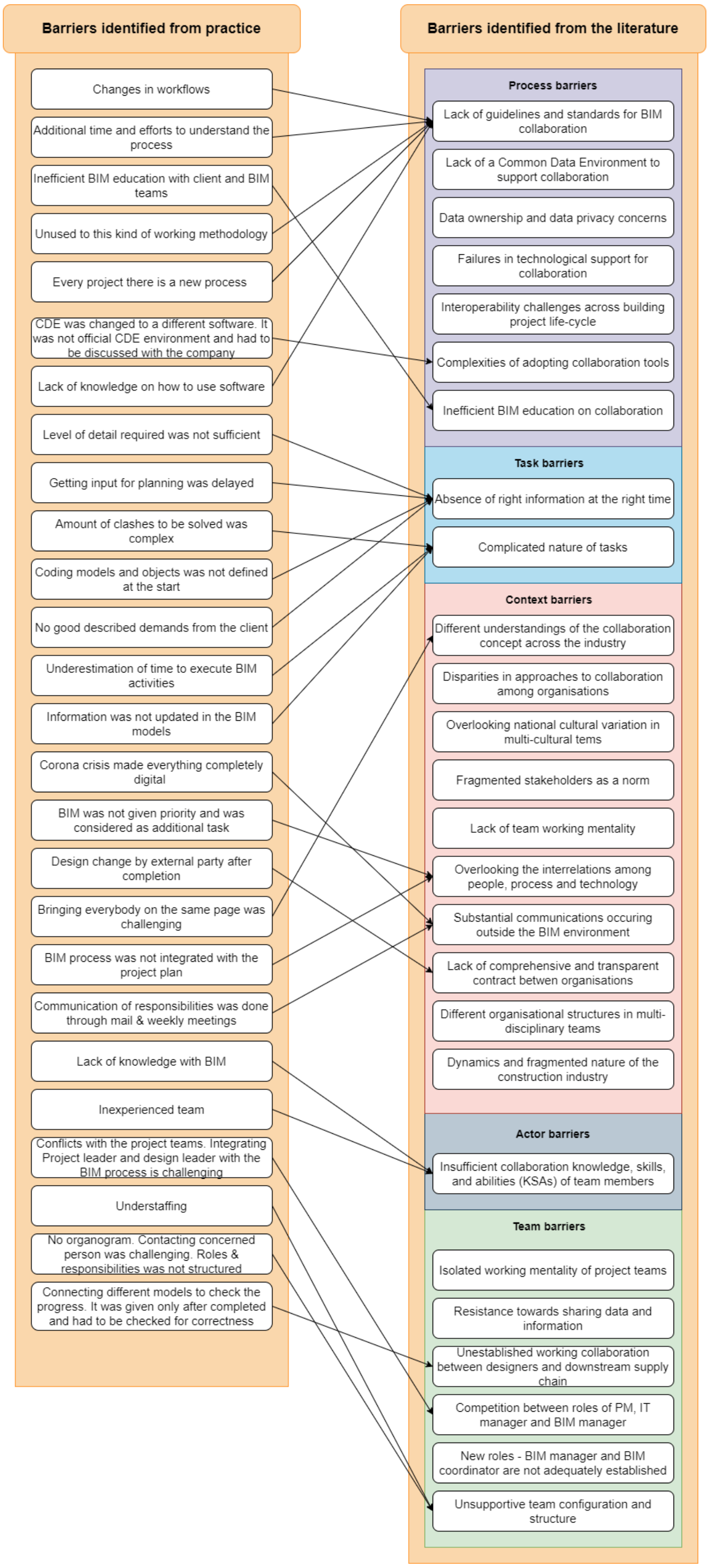

Figure 7 Matching the barriers from case study and literature

After marking the presence of barriers from all three cases (Figure 6) and matching the barriers observed from the theory and practice (Figure 7) these are integrated to analyse the observed barriers to collaboration in BIM teams as shown in figure 8. 14 barriers from the literature have been identified in the case studies. Out of which, 7 are observed in all three cases (highlighted in green) and the other barriers are case-specific. 12 barriers from the literature were not observed in practice and the reasoning is provided in Appendix I.

	Case - A	Case - B	Case - C
Lack of guidelines and standards	x	x	x
Complexities of adopting collaboration tools		x	
Inefficient BIM education	x	x	x
Absence of right information at the right time	x	x	x
Complicated nature of BIM tasks	x	x	x
Substantial communications	x		
Overlooking interrelations		x	x
Different understandings of collaboration concept	x	x	x
Lack of contractual standards	x		
Insufficient KSA	x	x	x
Competition between PM, BIM manager		x	
Unsupportive team configuration	x	x	x
Unestablished working collaboration			x
New roles - BIM manager and coordinator are not adequately established			x

Figure 8 Matched barriers presence across cases

4.3 Findings from cross-case analysis

Barriers observed in all cases:

1. Lack of guidelines and standards

Case-A did not have adequate guidelines established for the project at the start whereas case-B and case-C comparatively performed better. Case-B had some guidelines established at the start of the project and remaining throughout the project. Incompletion in guideline documents was observed in case-A and case-B. Case-C had the perfect approach to establish guidelines as worksheets were developed for every BIM application and software. However, the guidelines had to be changed in case-C because of the appointment of a new BIM manager. Similarly in case-B, the guidelines had to be changed as BIM in practice was different from theory. It was difficult for the practitioners to understand the process because: [1] Every project had a different process, [2] Practitioner having less knowledge on BIM, [3] Less priority for BIM, [4] Time pressure for working with deadlines, and [5] Changing workflows required additional time and efforts.

2. Inefficient BIM education on collaboration

In all the analysed cases, BIM education was minimal. Training was not established to educate the members in BIM teams. In addition, inefficient BIM education was also observed with the client. They were not properly educated with the BIM approach in the observed case studies. This lead to not providing information at the right time and missing demands throughout the project.

3. Absence of right information at the right time

In case-A and case-B, the level of detail required to be achieved in the BIM models was not well-defined beforehand because of the inadequate discussion with the client. This resulted in reworks delaying the process. It was not observed in case-C as early checks were made to check the level of detail in BIM models. This is linked to the lack of guidelines and standards as the absence of information in guidelines affected this issue. Coding models and objects was problematic in case-B and case-C because the information management was complex. Case-A gave utmost attention to coding the models and objects to avoid problems in later stages of the project.

4. Complicated nature of BIM tasks

Case-A had complications with solving the number of clashes observed in 3D models. This was because design and coordination were done by different organisations. Case-B and case-C did not experience this issue because design and coordination were done internally. Case-B and case-C experienced underestimation of time to execute BIM activities as the time required was predicted based on draft models. Case-A did not experience this barrier because of working in design loops. Updating the information in BIM models was not done in case-B and case-C as the project involved numerous models and tracing the information was complex. Case-A gave utmost attention to this aspect and did not experience this issue

5. Different understandings of the collaboration concept

BIM was perceived differently by the practitioners in the studied cases. They perceived BIM as a 3D model and not as a process. This barrier is linked to inefficient BIM education on collaboration. The inefficiency of BIM education with the client and BIM teams made it challenging to explain the BIM process to bring everybody on the same page.

6. Insufficient KSA

BIM was relatively new to the organisation and the practitioners were not used to this kind of working methodology. This resulted in having an inexperienced team in all the analysed cases. Actors with insufficient skills was observed only with BIM modelers. The BIM manager in all the cases was at least 5+ years of experienced with BIM. They provided good guidance for the modellers and coordinators in executing the BIM tasks.

7. Unsupportive team configuration

This barrier was observed for two reasons: [1] Understaffing and [2] Structuring roles and responsibilities. Case-B was sufficiently staffed whereas case-A and case-C were understaffed with a lack of BIM modellers. Structuring the roles and responsibilities was problematic in case-B and case-C. Case-A established the organisational structure and this was missing in case-B and case-C. The problem occurred as contacting the concerned person was challenging.

<u>Case-specific barriers:</u>

8. Complexities of adopting collaboration tools

Case-B changed the Common Data Environment (CDE) software during the project. Much time was spent in decision-making and acquiring the licenses thereby delaying the process. Case-A and case-C made the right decision in choosing the software and did not make changes to it.

9. Substantial communications occurring outside the BIM environment

COVID-19 situation made the communications completely digital. Though this barrier can apply to all three cases, it was perceived as a barrier only to case-A. This is because case-A was started during the COVID-19 situation. The entire communication happened through phone calls and emails and it was complex. Case-B and case-C were started before the COVID-19 situation and did not experience this barrier.

10. Overlooking interrelations among people, process and technology

In case-B and case-C, BIM was not given the priority it deserved. Process and people integration was challenging as BIM was considered as additional tasks to do. This barrier was not observed in case-A as BIM was given high importance.

11. Lack of contractual standards around BIM models

Case-A did not have a BIM-friendly contract with the party responsible for road design on the level of developments and requirements for BIM models. This was problematic as contacting the external party in the later stages of the project to modify the BIM models was challenging.

12. Competition between PM and BIM manager

Case-B had issues with integrating the project leader in the BIM process. Getting the information required from the project leader for developing BIM models was challenging as the focus was given to the primary deliverables and other goals to be achieved in the project.

13. Unestablished working collaboration between designers and downstream supply chain

Case-B involved collaborating with many organisations in a consortium and a proper working collaboration between designers was not established. The models were not shared before completion and obtaining approvals. This resulted in delaying the process and increased rework.

14. New roles – BIM manager and BIM coordinator – are not adequately established

Case-A did not have a BIM manager and the roles and responsibilities were taken over by the BIM coordinator. This barrier did not affect the project performance as the tasks required were executed.

The above analysis is summarised in table 4 below:

<table>
<tr><th>S.No</th><th>Barrier</th><th>Case-A</th><th>Case-B</th><th>Case-C</th></tr>
<tr><td colspan="5">Barriers observed in all cases</td></tr>
<tr><td>1</td><td>Lack of guidelines and standards</td><td>Adequate guidelines were not established for the project at the start</td><td>Some guidelines established at the start of the project and remaining over the course of the project</td><td>Guidelines established including development of worksheets for every BIM application and software.</td></tr>
<tr><td>2</td><td>Inefficient BIM education on collaboration</td><td colspan="3">BIM education was minimal. Trainings were not established to educate the members in BIM teams and the client</td></tr>
<tr><td>3</td><td>Absence of right information at the right time</td><td colspan="2">Level of detail required to be achieved in the BIM models was not well-defined beforehand because of the inadequate discussion with the client</td><td>Early checks were made to check the level of detail in BIM models</td></tr>
<tr><td rowspan="3">4</td><td rowspan="3">Complicated nature of BIM tasks</td><td>Complications with solving clash detections</td><td>-</td><td>-</td></tr>
<tr><td>-</td><td colspan="2">Underestimation of time to execute BIM activities</td></tr>
<tr><td>-</td><td colspan="2">Project involved numerous models and tracing the information was complex</td></tr>
<tr><td>5</td><td>Different understandings of the collaboration concept</td><td colspan="3">Practitioners perceived BIM as 3D model and not as process and this is linked to inefficient BIM education on collaboration</td></tr>
</table>

6	Insufficient KSA	Actors with insufficient skills was observed only with BIM modellers. The BIM manager in all the cases were at least 5+ years experienced with BIM		
7	Unsupportive team configuration	Understaffed with lack of BIM modellers	-	Understaffed with lack of BIM modellers
		-	Organisational structure was not created	
Case-specific barriers				
8	Complexities of adopting collaboration tools	-	CDE was changed during the project	-
9	Substantial communications occurring outside the BIM environment	Project started during COVID-19 and communication was complex with emails and phone calls	-	-
10	Overlooking interrelations among people, process and technology	-	BIM was not given the priority it deserved. Process and people integration was challenging as BIM was considered as additional tasks to do	
11	Lack of contractual standards around BIM models	Contacting the external party in later stages of the project to modify the BIM models was challenging.	-	-
12	Competition between PM and BIM manager	-	Getting the information required from the project leader for developing BIM models was challenging	-
13	Unestablished working collaboration between designers and downstream supply chain	-	The models were not shared before completion and obtaining approvals.	-
14	New roles – BIM manager and BIM coordinator - are not adequately established	No BIM manager and responsibilities were taken over by BIM coordinator	-	-

Table 4 Summary of case study findings

4.4 Conclusion – Answering SRQ1

The most critical barrier in this research is defined as the main issue that causes the occurrence of problems resulting in undesired outcomes. Hence, the problem that is common to the observed projects should be identified. The 7 barriers which occurred in all the cases are analysed further to find the main issue that caused the occurrence of problems resulting in poor collaboration in BIM teams. Why questions are asked to find the root cause to find the most critical barrier to collaboration in BIM teams. From the analysis, it is found that lack of guidelines and standards is the most critical barrier to collaboration in BIM teams. This is visually presented in figure 9. The red boxes in this figure represent the critical issues in the project.

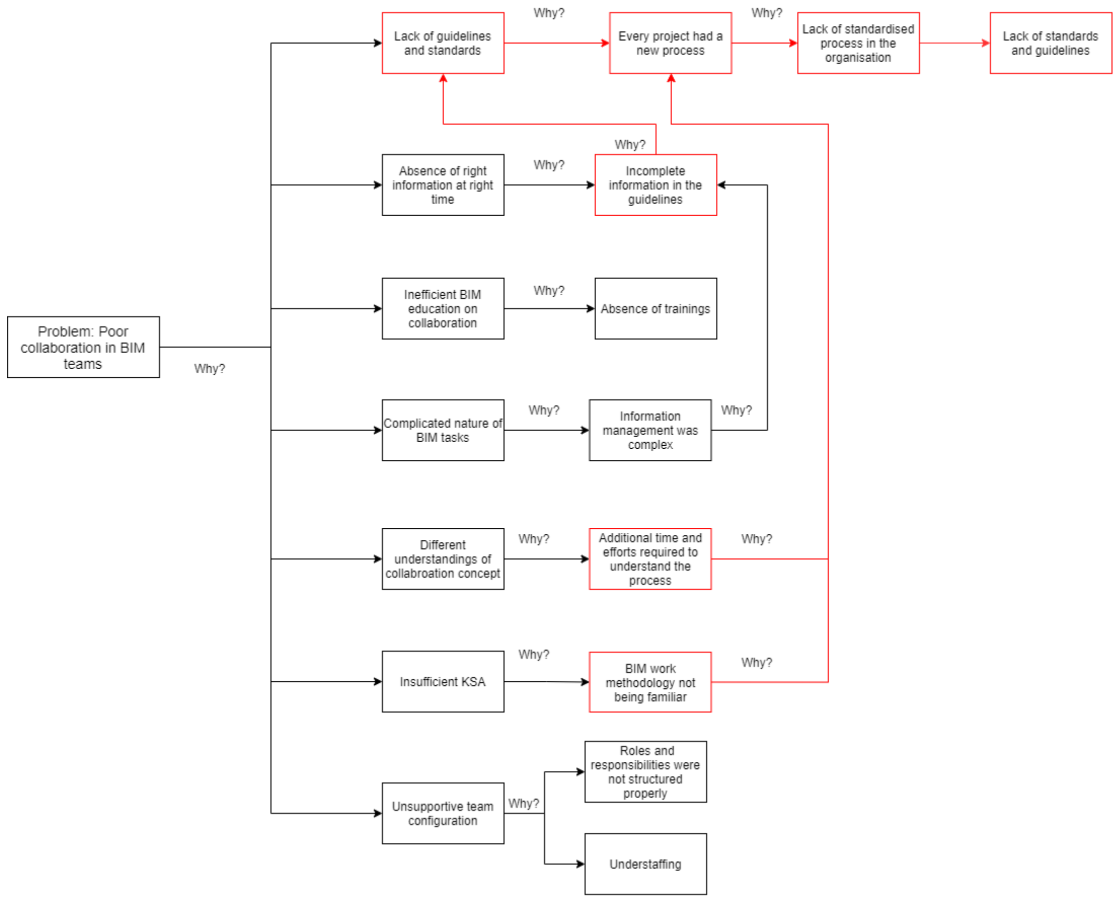

Figure 9 Analysis of barriers observed in all cases

Figure 9 showed the different reasons that caused lack of guidelines and standards. Understanding the sequence that lead to the lack of guidelines and standards was required to avoid this problem in future projects (shown in Figure 10). The poor collaboration in BIM teams occurred because the information in the guidelines was incomplete. Which information was required was not identified because of the unfamiliarity with BIM work methodology. Practitioners were not familiar with BIM work methodology because it required additional time and effort to understand the BIM process. This happened because every project had a new process which leads to the conclusion of a lack of standardised processes in the organisation. This issue lead to the problem of poor collaboration in BIM teams and hence concluded as the most critical barrier to collaboration in BIM teams.

In addition, lack of knowledge, experience, and education with BIM teams were other main causes for this problem. BIM was still new to the organisation and it was common to have practitioners inexperienced with BIM work methodology. Interviewees from the case study research highlighted that if the project has experienced BIM leadership, collaboration in BIM teams should not be a problem.

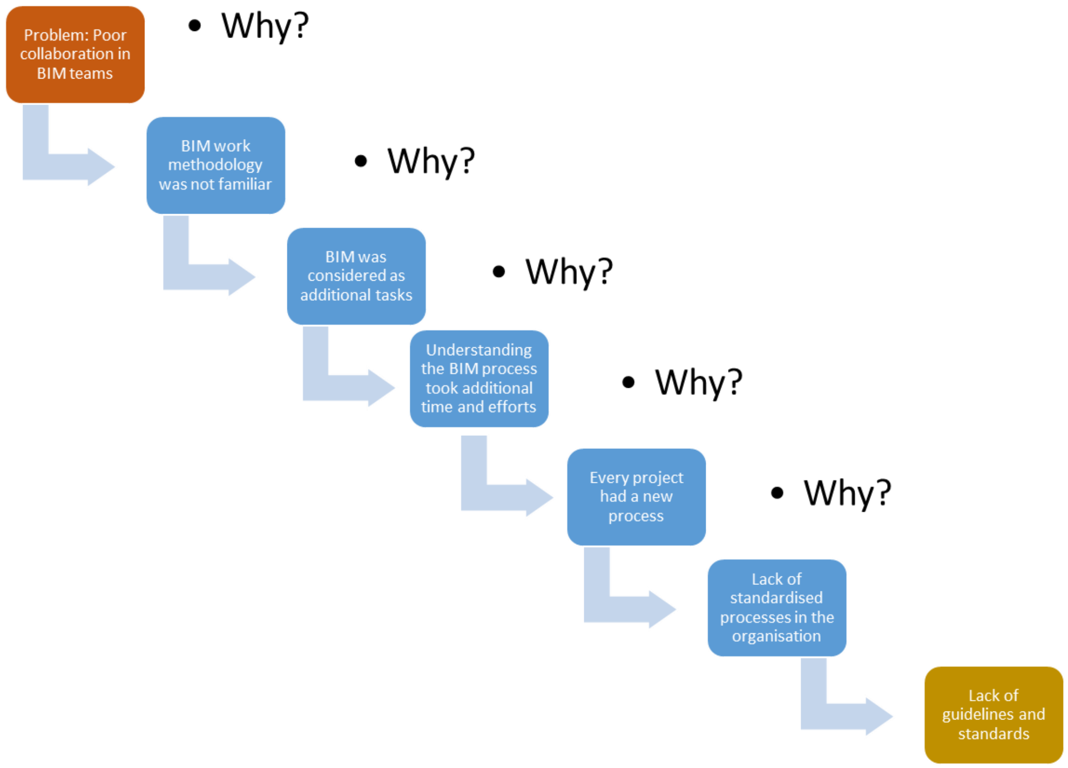

Figure 10 Sequence for the most critical barrier to collaboration in BIM teams

5. Possible strategies to address the most critical barrier

This chapter aims to provide the possible strategies for addressing the most critical barrier to collaboration in BIM teams. Two strategies are proposed in this research: [1] Improving the design process by integrating best practices (Section 5.1) and [2] Automating the process (Section 5.2). A conclusion is provided in section 5.3 and SRQ2 is answered in this chapter.

SRQ2: What are the possible strategies to address the most critical barrier to collaboration in BIM teams in the design phase of BIM-enabled infrastructure projects?

5.1 Improving the design process by integrating best practices

The existing BIM based design process should be improved to avoid reinventing the wheel for every new project. This can be achieved by integrating the best practices with the existing design process. The best practices in this context mean the success stories from past projects. These best practices can refine existing methods and offer innovative strategies to solve problems and complete tasks (Liu, 2021).

5.1.1 Observed best practices

From the observed three cases, the best practices unique to each project that improved collaboration are listed below:

1. **Creating master BIM model**: Case-C established a baseline model which acted as a catalyst to develop high-quality BIM models, avoid misunderstandings and reduce re-work. This was not realised in other projects because of three reasons: [1] The importance of a master BIM model was not recognised, [2] The BIM scope in the projects was not well-defined at the start, [3] The projects were under-staffed and capacity was not sufficient to create a master BIM model.

   Things to consider for creating a master BIM model: [1] The master BIM model should be a reference to other BIM models and the sole source for design validation. [2] It should be accessible for every actor involved in the project and usable to work directly online from the computer without additional requirements. [3] Responsibilities on creating and updating the master BIM model should be defined at the start of the project. [4] Any design change in aspect models should be reflected in the master BIM model and the process for making design changes should be established at the start of the project

2. **Interactive knowledge-sharing platform:** Case-B created an interactive webpage to share knowledge, guidelines, and standards on working with BIM for the project. Adopting a knowledge-sharing platform helped to transfer new knowledge to innovative practices. This practice was not popular because of the awareness and requirement of Information Technology professionals to set up the infrastructure.

   Things to consider for creating an interactive knowledge sharing platform: [1] All the BIM guideline documents for the project should be stored in the platform including BIM execution plan, BIM protocol, and BIM manuals. [2] Access for the BIM teams to this platform should be given so that they can obtain knowledge regarding BIM. [3] Having this done before the start of the project is highly advantageous to smoothen the project's performance.

In addition, some of the best practices from the literature that can improve collaboration is explained below:

3. **Efficient lessons learned capture:** A collaboration process capturing project experiences is crucial to benefit from past experiences and to avoid cost overruns and schedule delays in future construction projects (Aragao & El-Diraby, 2019). This practice is not popular because practitioners quickly move to other projects and don't convert the implicit knowledge (learned know-how) to explicit knowledge (documentation). Capturing frequent lessons learned leads to information overload and lessons should be captured at critical stages of the project. A lessons learned team should be formed to analyse the captured responses and suggest recommendations on re-using the lessons learned in future projects. The recommendations should be incorporated in the existing process to modify the work methodology.

   Things to consider for efficient lessons learned capture: For higher efficiency in capturing lessons learned, a baseline should be established which organisations should follow (Marlin, 2008). [1] Each lesson should be validated appropriately; [2] Lessons should focus on both successes and failures and how it can benefit future projects; [3] Lessons recorded should not finger-point or blame anyone; [4] Information is continuously updated in a database and easily searchable.

4. **Optimised BIM meetings with the client:** The client should be on board to exchange information, share knowledge and experience upfront leading to efficient designs and avoiding problems in later stages (Liao et al., 2018). The client must be involved in the following BIM meetings:

   <u>BIM kick-off meeting</u> is required to communicate the information required by each party in the project and make early decisions in the project. In this meeting, the project objectives, guidelines, standards, resources, restrictions, deadlines, and schedules for the project should be defined. This practice is beneficial to increase the commitment of the stakeholders (Papadonikolaki et al., 2016) and enable better collaboration among BIM teams.

   <u>Model Coordination meeting</u>: A coordination meeting is important for conflict resolution in the designed BIM models and repeated coordination meetings with too many participants lead to inefficiencies. A two-tiered coordination process is useful for making the right decisions by the right participants (Sacks et al., 2018). Tier-1 meetings are conducted to focus on major design errors and the direction of design development. Tier-2 meetings are conducted to focus on minor design errors and construction clashes. The client need not regularly participate in the tier-2 meetings but only in the crucial resolution meetings resulting in significant changes.

   <u>Constructability analysis/collaborative meeting</u>: In this meeting, the projects are visualised through 4D simulations and it is useful for the client to understand the construction process (Boton, 2018). However, it should be noted that involving the client in too many meetings is inefficient. To make it efficient, the client should be invited to important meetings and a schedule should be made and conveyed at the kick-off meeting.

5. **Software community:** BIM practitioners should stay involved with the software community to be active in discussions and update themselves with new information (Klaschka, 2019). Numerous communities were created within the organisation. However, this has to be restructured having an optimal number of software communities and during the start of every project, practitioners must be encouraged to join the relevant software community.

5.1.2 Improved design process

The process for the design phase of future BIM-enabled infrastructure projects is improved by integrating the strategies from 5.1.1 to the existing process. The existing process was found during the case study research through documents and interviews. This can be found in Appendix C, Appendix E and Appendix G. The improved process is created following ISO 19650 standards which the organisation is aiming to implement in their project management practices. ISO19650 is a new set of international standards inspired from the UK1192 series for information management in buildings and civil engineering works. A survey conducted by (Dadmehr & Coates, 2019) has revealed that ISO19650 is the first official document related to information management for most countries and guidance is needed for practitioners in using the standard. The ISO19650 is created in four parts for different purposes. The second part (ISO19650-2, 2018) focuses on the delivery phase of assets and is aligned with the research scope. The improved process is created for the three most important roles in BIM teams: BIM manager, BIM coordinator, and BIM modeller.

Process modeling can be done with techniques like IDEF0, Process Protocol II and Business Process Modelling Notation (BPMN). For this research, BPMN is used to map the processes because of three reasons (Saluja, 2009)

(1) It is a standard maintained by the Object Management Group (OMG) with a richer set of capabilities for modelling business process
(2) Usage of "swim lanes" helps to visualise the communication between actors
(3) Availability of fairly simple software (Oracle BPM, Visio, TIBCO, draw.io)

Business Process Modelling Notation (BPMN) is the best choice and the de-facto standard for representing the processes in an expressive graphical way (Chinosi, 2012). It is made up of a set of graphical elements which enables easy development of simple diagrams (White, 2004). Chinosi (2012) categorizes the graphical elements in four categories to build the diagrams: Flow objects, Connecting Objects, Swim lanes, and Artifacts. It is shown and explained in Appendix J.

According to ISO19650-2 (2018), the process of a construction project is divided into eight phases. The design phase of the construction projects is linked to the last 4 phases (mobilisation, collaborative production of information, Information model delivery and project close-out) of the ISO-19650-2. The mobilisation phase covers the project setup concerning the human and software resource availability. BIM kick-off meeting should be held in this phase of the project to discuss the plan of approach. The collaborative production of information phase is the crucial phase of the project. The BIM models are created and checked during this phase involving intense efforts from the BIM teams. The last two phases information model delivery and project close-out cover the approval from the client for the BIM models, archiving the BIM models, and capturing lessons learned. Capturing lessons learned at the end of the project can be inefficient as knowledge tends to fade away throughout the project. The lessons learned captured during different parts of the process should be compiled together to create a lessons learned report. The whole process is shown in figure 11 and divided into sub-processes (shown in figure 12). This helps to better understand the process map.

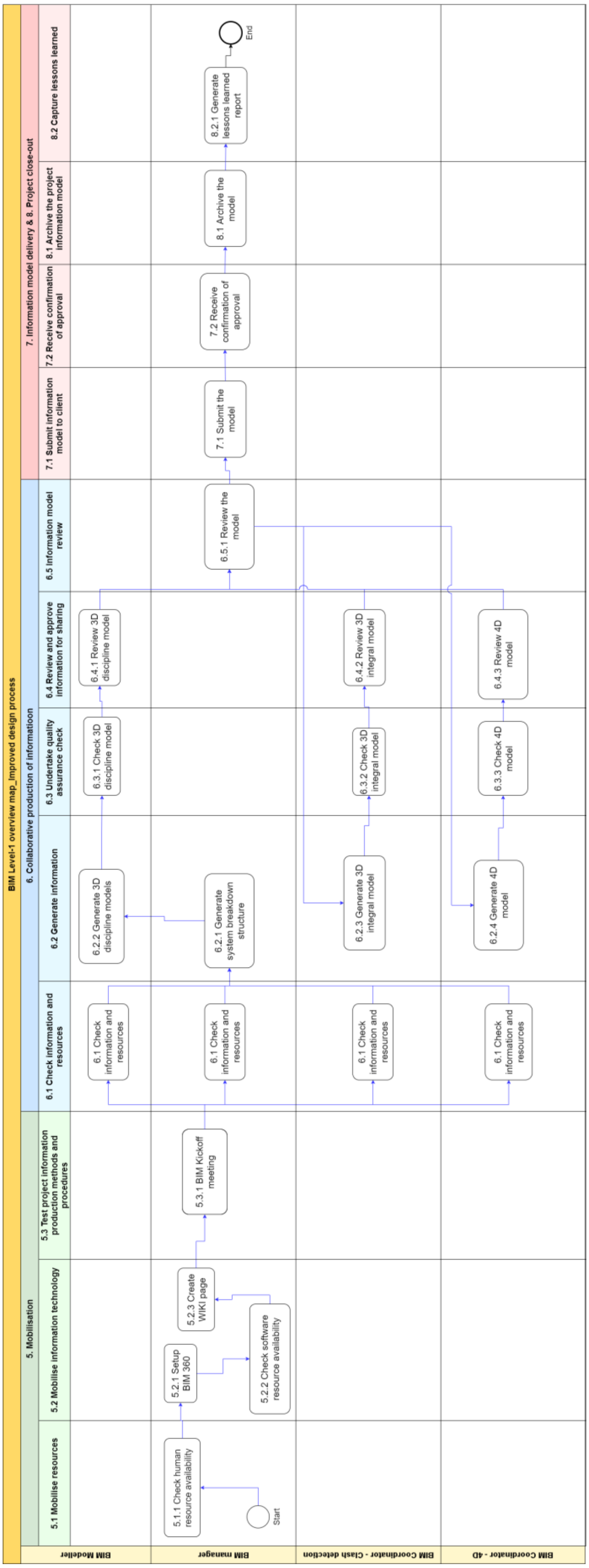

Figure 11 Improved process map for the design phase according to ISO 19650 standards

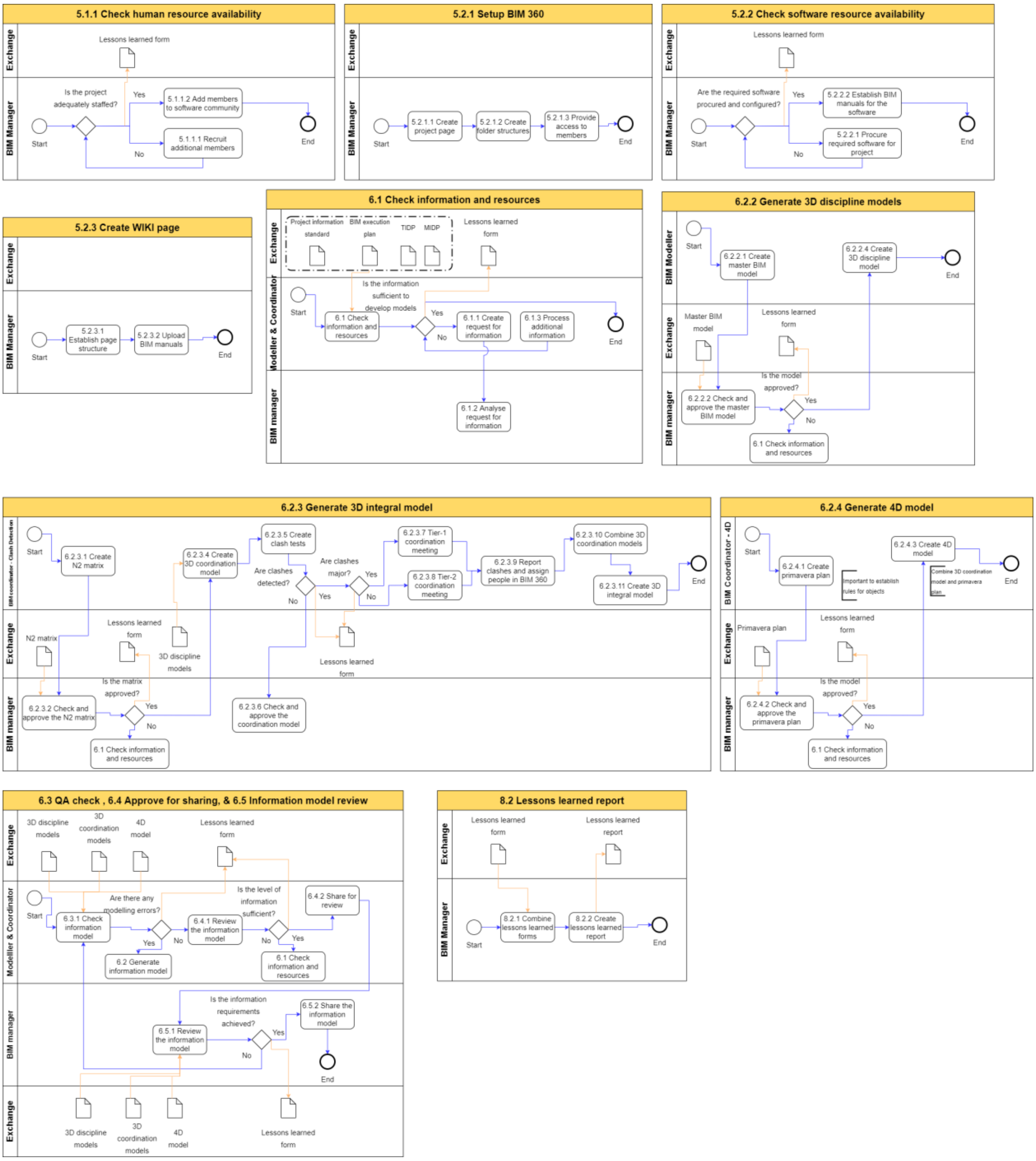

Figure 12 Sub-processes for the design phase

5.2 Automating the process

The construction industry is moving towards digital transformation and it becomes necessary for organisations to automate their processes enabling better productivity in project teams. Collaboration can be more efficient when the tasks are auto-assigned and live tracking the process is possible.

The process map can be automated in the following steps. First, it is important to register the members in BIM teams in the identity management section. A profile must be created for all the users including the email address. The users should be grouped according to their roles. This is shown in figure 13. Second, the process should be designed by creating events, activities, and gateways. The most used options are user task, exclusive gateway, and parallel gateway. The process from figure 11 and figure 12 is designed in this software (figure 14). For every task, it is important to create forms (figure 15) and assign users (figure 16). Forms are a set of controls that can be used depending on the task type. While assigning users, it is important to enabling email notifications as well. Third, the process should be checked for validation errors. In the absence of errors, the process setup is complete. The software offers a user-friendly interface to analyse the responses from practitioners (figure 17) and track the live progress (figure 18).

The automated process map is most useful for the BIM manager as it is the responsibility of the BIM manager to set up the process for the project. The BIM manager can live track the process and analyse the responses from the BIM teams. In addition, it can be helpful for BIM teams to reduce the work in analysing the process maps for the next steps. Moreover, it is useful for easy capture of lessons learned and re-using them in future projects. The experiences of the practitioners can be captured and stored in a single file. This can be evaluated at the end of project to see the pros and cons of a specific work methodology. The success stories can be modified to the process and can result in an improved process. Organisation should use this process map in future projects to improve their project management practices. Automating the process can reduce human errors, streamline the processes, and avoid the necessity to study the process maps for next steps.

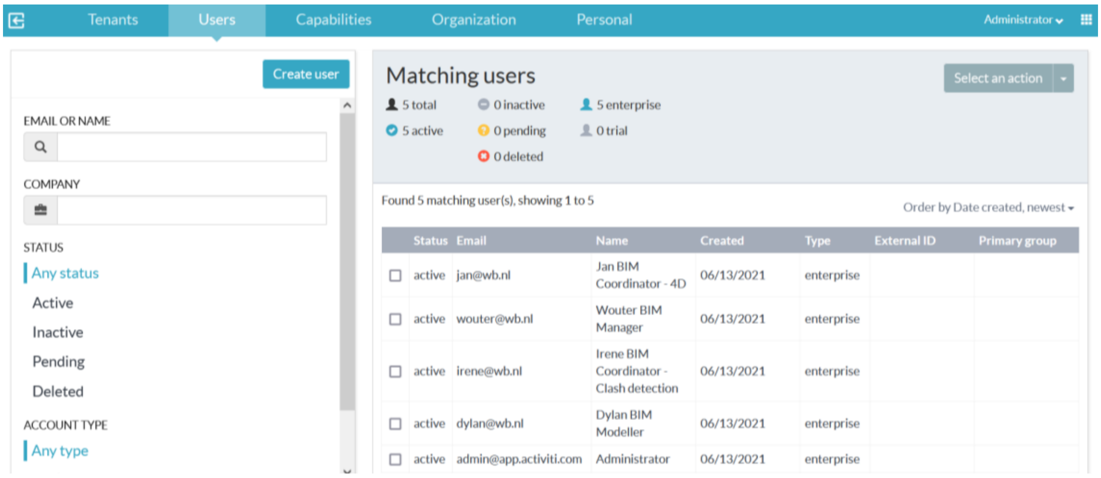

Figure 13 Profile overview of BIM teams

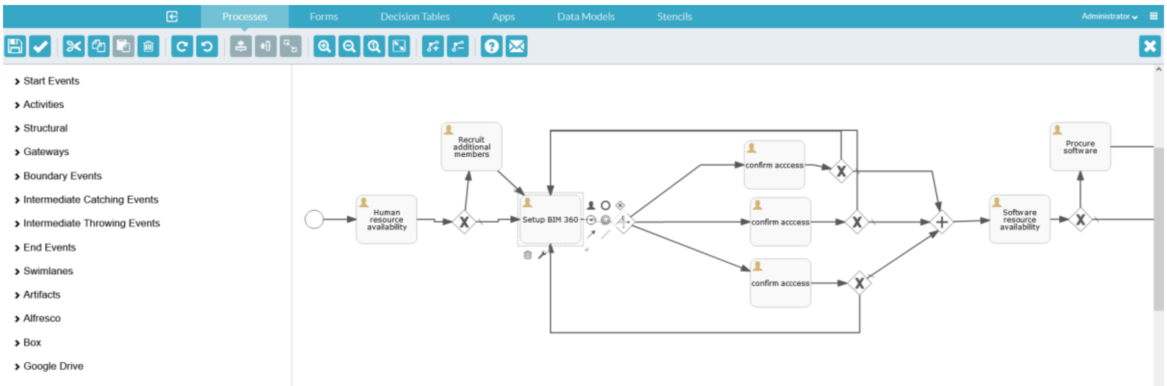

Figure 14 Process designing workspace

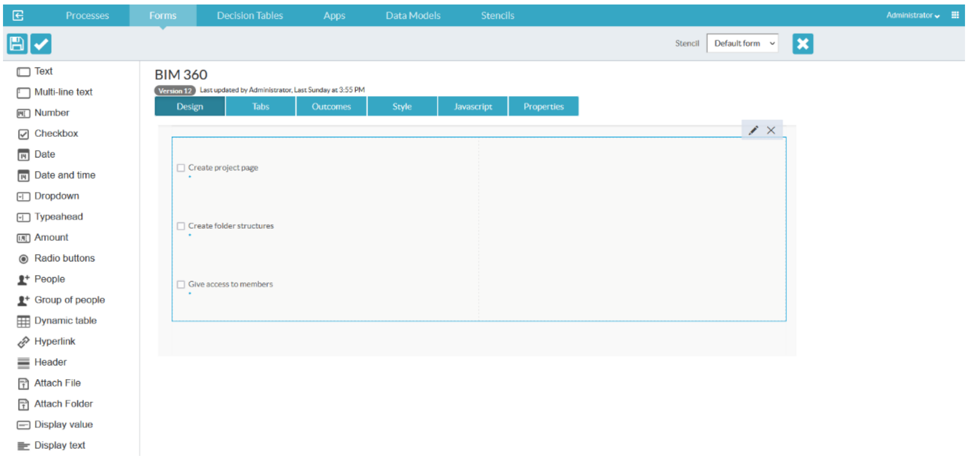

Figure 15 Form creation

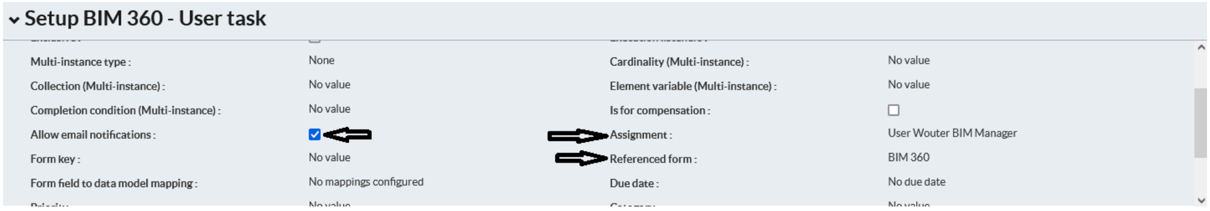

Figure 16 Assigning users

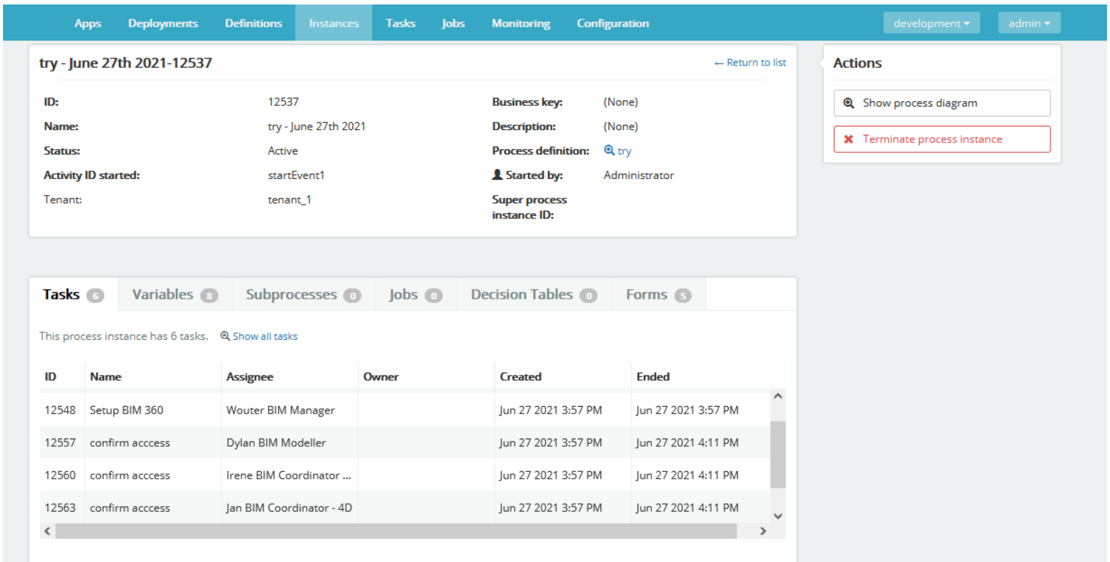

Figure 17 Admin's view

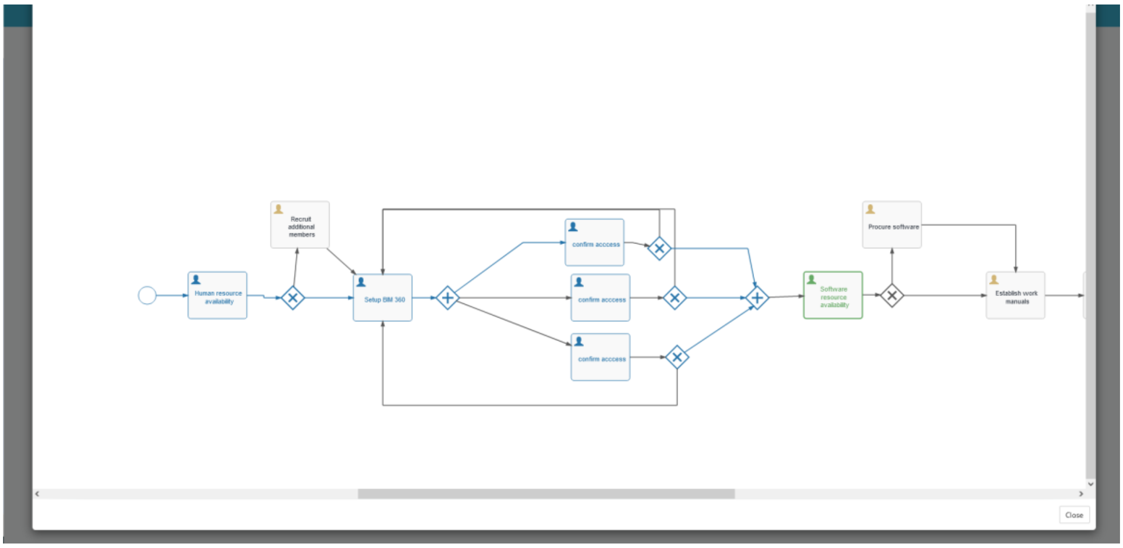

Figure 18 Process live tracking

5.3 Conclusion – Answering SRQ2

The possible strategies for addressing the lack of guidelines and standards are: [1] Improving the design process by integrating best practices, and [2] Automating the process. Best practices from case studies (two strategies), literature study (three strategies) are integrated to create an improved process map. This process map is created according to ISO 19650 standards which provides good information governance in construction projects. The design phase of construction projects according to ISO 19650 standards are divided into four phases and a process map covering these phases are created. To better improve the collaboration in BIM teams, [2] the process maps should be automated. Automating the process can reduce human errors, streamline the processes, and avoid the necessity to study the process maps for the next steps. These strategies are validated with BIM teams and will be discussed in the next chapter.

6. Qualitative validation

This chapter explains the qualitative validation of proposed strategies in this research by discussing the opinion of BIM practitioners. Section 6.1 outlines the interview outline for validating the strategies. Section 6.2 discusses the opinion of BIM practitioners for the proposed strategies. Section 6.3 gives a conclusion to the chapter.

6.1 Interview outline

A focus group discussion and an additional interview were conducted to validate the research findings. For the focus group discussion, two interviewees were grouped along with the researcher in a conference room and this was arranged in the Witteveen+Bos office in Deventer. The additional interview was online with a project manager. Interviewees were selected based on their roles, involvement with the project, and familiarity with BIM. The interviewees to validate the research findings were not interviewed for the research earlier. An overview of the interviewees is presented in table 5. The transcripts are attached to Appendix K and Appendix L.

The interviews were based on semi-structured questions. A questionnaire was prepared and sent to the interviewees along with relevant documents before the interview. At the start of the interviews, permission was sought to tape the interview to aid the transcription of the conversation. During the interview, a brief introduction of the researcher and the research was given through a presentation. It was followed by answering the prepared questionnaire. Permission was sought from the interviewees whether the input from the interview could be used for the research.

Interviewee	Role	Educational background	Experience with BIM
Interviewee 1	BIM manager	Bachelors in Civil Engineering	Draftsman, 3D model expert and on daily basis leading a small group of BIM engineers.
Interviewee 2	BIM modeller	Bachelors in Mechanical Engineering	Started as a draftsman and a 3D model expert now.
Interviewee 3	Design leader – BIM	Masters in Structural Engineering	Design leader for 2 large infrastructure projects and group leader for BIM model development and coordination.

Table 5 Overview of interviewees for focus group discussion

<u>Questions discussed in the interviews:</u>

1. Did you experience the most critical barrier from this research in practice?
2. How would the proposed strategies from this research solve the most critical barrier?
3. How can the proposed strategies be implemented in future projects?

6.2 Discussions

1. Did you experience the most critical barrier from this research in practice?

Interviewees agreed that lack of guidelines and standards can be the most critical barrier to collaboration in BIM teams within the organisations. Interviewee-1 felt that this barrier could be the main cause for many other barriers to collaboration in BIM teams. Interviewee-2 observed this barrier more for collaborating with the client as information provided in the documents was not clear for them to understand the BIM approach and requirements. Interviewee-3 observed this barrier to be most critical at the start of projects as everybody working on getting the tender awarded and less focus is given to create guidelines.

2. How would the proposed strategies from this research solve the most critical barrier?

For strategy-1 (Improving the design process by integrating best practices), Interviewee-1 found the process map helpful to provide a direction for the BIM managers to standardise the work practices for future projects. For other roles, the process map complicated. He added that these workflows should be included in the post-award BIM execution plan. Initially, interviewee-2 felt the process map was complicated to understand. After an explanation was given during the interviews for Level-1 and Level-2 process maps, it was easy for him to understand the process. He added that the process is already in the heads of people but when it is presented in a visual diagram, it can help to unify the working methodology. Interviewee-3 felt this is a good start to provide a standardised way of working and can be beneficial within the organisation. But the applicability of this process map when collaborating with different companies can be a little challenging as companies have their own way of working. The researcher explained that the process map was created according to ISO 19650, a global standard of which every company is aware. He later concluded that this can be a much efficient method to improve a process but the applicability needs to be validated in a project.

For strategy-2 (automated process map), Interviewee-1 and interviewee-3 liked the tool very much. They felt this automation can help to be on top of things. Interviewee-2 highlighted that this tool can be very helpful when the project members are not aware of the standardised processes. Interviewee-1 was optimistic to use this tool in an upcoming project to test its applicability.

3. How can the proposed strategies be implemented in future projects?

For strategy-1, Interviewees highlighted that the process map can be a starting point in educating BIM teams with the BIM processes for the project. Creating a single master BIM model for an entire project can be challenging and multiple master BIM models for each discipline are required (Interviewee-1). A knowledge-sharing platform at the project level is not sufficient and creating an organisational level platform can accelerate BIM working (Interviewee-2). Infrastructure for the software community already exists in the organisation and the practitioners should be encouraged to join relevant communities (Interviewee-3). The client meetings can be less efficient for extracting information required for the project as they are generally less experienced but can be useful for discussing expectations and creating BIM awareness in the project.

For strategy-2, it is important to apply the tool in a Witteveen+Bos project. Organisational quality standards have to be checked and software licenses have to be purchased. This is an addition to the existing tools. In the future, strategies to integrate the existing tools can be encouraging. For example, Relatics and BIM 360.

6.3 Conclusion

The interviewees felt that the proposed strategies from the research can be a good attempt to solve the lack of standards and guidelines within the organisation. Most important is the explanation for the process map. That is required as the process map alone is difficult to understand. The BIM manager should provide a walkthrough session for the other members in BIM teams on reading the process map. They believed that these strategies should be tested in one of their projects for applicability. Challenges in integrating the best practices were observed with the master BIM model and optimised BIM meetings with the client. The interviewees felt that BIM education was very important in the organisation and the proposed strategies from the research can act as a starting point for educating the BIM teams. Other strategies to educate BIM teams are needed to improve collaboration in BIM teams. One of the interviewees is in a BIM managerial position and acknowledged that the proposed strategies from this research will be implemented in a pilot project.

7. Conclusion and Recommendations

This chapter concludes the research by answering the main research question in section 7.1. Then, the limitations to this research are outlined in section 7.2. The recommendations for practice are explained in section 7.3 and recommendations for future research in section 7.4. The final section of the final chapter (section 7.5) narrates the personal reflection of the researcher.

7.1 Research limitations

This section discusses the limitations of this research. These limitations should be considered while evaluating the findings.

1. The results of the barriers were obtained by studying only the Dutch infrastructure projects. The results from this research cannot be applicable for infrastructure projects from other countries.
2. Only infrastructure projects were studied and other types of projects were not studied in this research.
3. The research focused on analysing the barriers to collaboration in BIM teams only in the design phase. Other phases were not considered during this research.
4. The results from the research were validated qualitatively based on the perspective of three interviewees. Due to the long duration of infrastructure projects, the strategies from this research were not implemented in real-life projects.
5. Interviews were conducted only with the BIM teams from Witteveen+Bos. Client perspective on collaboration to BIM teams was not considered.

7.2 Conclusion

The objective of this research was to address the most critical barrier to collaboration in BIM teams in the design phase of BIM-enabled infrastructure projects and research questions were framed in section 1.3.

The conclusion to this research is formulated by answering the main research question in this section. The sub-research questions 1 & 2 have been answered in the previous chapters and will not be repeated in this chapter.

MRQ: How can the most critical barrier to poor collaboration in BIM teams in the design phase of BIM-enabled infrastructure projects be addressed to improve the collaboration in future projects?

To improve the collaboration in the BIM teams in the design phase of future BIM-enabled infrastructure projects, first the most critical barrier should be identified. Next, strategies should be created to address the most critical barrier and integrated in the existing practices to avoid the same mistakes.

In this research, barriers to collaboration in BIM teams were identified through a literature study. 26 barriers were identified which acted as the baseline for further steps of the research. These barriers were checked in the case studies to observe the presence in the practical world. From the comparison between cases and with the literature, the most critical barrier was identified, i.e., lack of guidelines and standards. This was identified by asking why questions until the reasoning is sufficient to develop strategies. To avoid this problem in future projects, following strategies were proposed: [1] Improve the design process by integrating best practices and [2] automate the process. The process is improved by integrating the best practices (success stories) that improved collaboration in BIM teams from case studies and literature. The process map is created according to last 4 phases (Mobilisation, Collaborative production of information, Information model delivery and Project close-out) of ISO 19650 standards. The created process map is automated to improve collaboration in BIM teams. This reduces human errors, streamlines the processes, and avoids the necessity to study the process maps for next steps. Moreover, it can help in easy capture and analysis of lessons learned. Handling vast information is complex and automation helps in reducing the complexity. The lessons learned are stored in a single file which can be analysed to study the pros and cons of the work methodology. The success stories (pros) can be added to the existing process enabling easy re-use of lessons learned.

These strategies can be implemented in the future projects and the BIM teams should be aware of this improved process before the automated process is implemented. They should be aware of the tasks beforehand. The BIM manager should take the responsibility in managing the automated process in the project. In conclusion, this research presents strategies to improve collaboration in the design phase of future BIM-enabled infrastructure projects.

7.3 Recommendations for Witteveen+Bos and for practice

Analysing the research, it can be concluded that there are lots of improvements required to improve collaboration in BIM teams within the organisation.

1. It is recommended to check the created improved process map and automated processes for quality approval at the company. These processes should then be validated in a pilot project before implementing in future projects. After validation, these processes can be recommended at the organisational level. This can be achieved by providing a workshop to the people at BIM managerial positions within the organisation.
2. It is highly recommended to provide a walkthrough of the process maps to the BIM teams. Without explanation, the process map can be difficult to interpret. A walkthrough for both the levels of the process map should be given. The master file for the process map enables easy tracking of the process flow by just clicking at the arrows.
3. It is recommended to appoint a lessons-learned team at every project who takes responsibility in analysing the lessons learned capture. Though multiple persons capture lessons learned throughout the project, responsibility should be given to the lessons learned team in analysing the responses, providing recommendations for future projects and updating the work methodology.
4. It is recommended to have the proposed additional system (Activiti) to automate the process. This has been widely used to automate the BPMN workflows and it is proven to be user-friendly and efficient. Consideration was given into integrating the automated process to the existing systems like BIM 360 and Relatics. To conclude, it was not efficient and not recommended to spend time in integrating into the existing systems.
5. It is recommended at the start of the project to encourage members to join the relevant software community. In the present scenario, the practitioners voluntarily join the software community but this should be indirectly forced to the software users. This helps to get guidance on using the software from users. It is recommended to optimise the number of software communities in the organisations. There were lots of communities and this has to be optimised.
6. It is recommended to give high priority to creating guidelines documents for the projects. This should be completed before the start of the design works in the projects.
7. It is recommended to study more BIM projects within the organisation, find the success stories and improve the process.

7.4 Recommendations for future research

This research does not give a full stop to the collaboration in BIM teams. Future research is required to take this research to the next steps and listed as follows:

1. Client collaboration plays an important role in providing the right information at the right time. This research did not consider the client's perspectives and future researches to analyse the collaboration to BIM teams from the client's perspective should be focused.
2. Researches are required to validate the proposed strategies in a pilot project to check the applicability in practice. The impacts of implementing the strategies from this research should be analysed. The pilot project should be a Dutch infrastructure project as the results are based on that aspect.
3. Integrating Project leaders with the BIM process was observed to be challenging. Research on why the problem exists and how that can be improved should be focused on.
4. The research analysed only three Dutch infrastructure projects. More projects of similar type can be analysed to check the changes in the barriers.
5. The strategies from this research were created for Dutch infrastructure projects. However, researches, if these strategies can be used in other types of projects can be an interesting topic for future research.
6. This research analysed the barriers in the design phase. Future research can be performed to analyse the barriers in other phases of the projects
7. The findings from this research can be validated in other companies to investigate if the barriers are company-specific or industry-specific problems.
8. The research proposed two strategies for addressing the lack of guidelines and standards. Future research can be performed to come up with more strategies to address this issue.

7.5 Personal reflection

Choosing a topic that I liked was the best thing that happened to me during this journey. I was driven to learn more about the topic thereby gaining knowledge and skills. Having an open mind enabled me to explore new topics and better scope down my thesis. I explored numerous topics on BIM and it was post progress-1 meeting that I finally chose a specific area of focus. Throughout the journey, I spent much time planning on how to do things rather than doing them. I categorised every information that I collected perfectly and created a master file which gave me the option to track and trace every information. Every paper that I read, I marked the unique elements that would be helpful for my thesis. I started executing things only after exploring all the possible options.

Performing the research at Witteveen+Bos was another good thing that happened during the journey. My company supervisor gave me the freedom to choose the area of focus. Initially, there were lots of changes and now it looks completely different from the start. This helped me to avoid stress. I enjoyed working with people from Witteveen+Bos. They were quick in responding to my emails and scheduling interviews. I got the opportunity to have a focus group discussion to validate my research findings which I thought would be difficult in this COVID situation. This company is focusing on the full acceleration of BIM and created a BIM task force. I volunteered to participate in the weekly meetings to exchange knowledge on BIM. This helped me to check the overlaps in my research and find what I can better provide to Witteveen+Bos from my research. On the other hand, I gave them knowledge on specific topics like CDE, education on BIM, etc.

COVID situation was favourable in my case. Living in the Hague, it would have been difficult for me to travel to university and offices if there was no COVID. I felt that this situation was productive to work on thesis and other things. To conclude my reflection, I strongly believe that the knowledge I gained from this research will help me in my future workspace as I am passionate about working in the BIM sector.

8. References

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Appendices

Appendix A: Previous efforts on standardising BIM processes

Author	Title	Findings	Remarks
(Saluja, 2009)	A process mapping procedure for planning building information modeling (BIM) execution on a building construction project.	BIM Process Mapping procedure can increase the level of planning for a project by familiarizing the team with strategies and processes of their team members to achieve a more informed and effective transition of information between responsible parties.	Created BIM process mapping procedure and process maps for certain BIM uses (3D modelling, 4D modelling, design coordination) in building projects.
(Kharoubi, 2019)	Towards 5D BIM: A Process Map for Effective Design and Cost Estimation Integration	The created process map provided a standard representation of objects, enhanced the communication between the designer and cost engineer, and involved the cost engineer earlier in the design. This process map is a stepping stone towards full automation.	Created process map for integrating design & cost estimation. The map was performed for cost engineer and designer.
(Sharafat et al., 2021)	BIM-Based Tunnel Information Modeling Framework for Visualization, Management, and Simulation of Drill-and-Blast Tunnelling Projects	Framework facilitates data sharing, information integration, data accessibility, design optimization, project communication, efficient project management, and visualization of tunnel design and construction processes.	Created process map for project manager, contractor and designer for drill-and-blast process of tunnelling projects.
(Wu & Issa, 2013)	Integrated process mapping for bim implementation in green building project delivery	Encouraging to observe that BPMN provides good integration with IFC, and more BIM software vendors are embracing IFC as a standard for BIM information exchange.	Created process map for green building project delivery.
(Tsai et al., 2014)	Workflow re-engineering of design-build projects using a BIM tool	With the framework, owner's satisfaction level strengthened teamwork among various departments, helped the company enter into more contracts, and consequently raised the company's competitiveness in the construction market.	The process map was not specific to any construction projects. No standards were used.
(Zou & Zhou, 2014)	A Model-based BIM Framework for Bridge Engineering	Framework can significantly facilitate integrating BIM tools and practices, and increase the collaboration and productivity throughout the whole process of a bridge.	General process map for project owner, planner, BIM team and construction developed UML and the framework is not validated.
(van Eldik et al., 2020)	BIM-based environmental impact assessment for infrastructure design projects	BIM environment is able to facilitate an automated and integrated EIA in infrastructure design projects; BIM based EIA is much faster than traditional EIA process; The visual	UML framework for BIM based automated environmental impact assessment of infrastructure projects.

		representation allows designers to easily pinpoint high contributing model elements to total Environmental Impact Score (ESI) and use it in decision-making process.	
(Marzouk et al., 2010)	On the use of building information modeling in infrastructure bridges	The paper described the method of implementing BIM on bridges' projects by forming Bridge Information Modeling project execution plan which requires four steps which are: identifying goals and uses; developing overview and detailed process maps; identifying information exchange requirements; and developing the infrastructure needed to support the implementation.	Used BPMN technique to create process map for infrastructure bridges for 4D and the created process map was not validated.
(Al Hattab & Hamzeh, 2013)	Information flow comparison between traditional and BIM-based projects in the design phase	Frameworks can boost connectivity between project players to give way to a free flow of information throughout the entire project life span, which transforms its delivery into a lean and waste free process	Traditional vs BIM based process is compared and general semantic model describing many BIM uses in the design phase for engineers was developed. It was not focused for managers.

Table. A Previous efforts on standardising BIM processes

Appendix B: Case study questionnaire

Self-introduction:

Please introduce with job role and experience with the company and project, educational background and experience with BIM.

Process-based:

- How would you sequence the process of arriving at 3D model/clash detection/4D model in chronological order?
- Who were the actors involved in this phase?
- What was the software used in this process?
- What was the input in this process?
- What is the output of this process? To whom is it communicated?

Issue-based:

- What were the issues faced during the process?
- What were the causes of delays?

Strategies-based:

- What could be the possible strategies for improving the collaboration in design phase?

Appendix C: Case -A BIM design process

The BIM uses for this project included 3D modeling, clash detection/design coordination and 4D modeling. The process for individual uses are explained below and the overall process of the project is outlined in figure D.

1. <u>3D modelling</u>: Before starting the model, existing information on drawings, locations has to be extracted from the available documents. It is important to analyse the information requirements for the overall model from the BIM Execution Plan (BEP) and individual models from the Relatics. Based on the requirements, 3D models are developed. The 3D models are uploaded in a collaborative working environment BIM360. Every Friday, the BIM modeller is required to upload the 3D models to the "Work In Progress" folder which the BIM coordinator uses for the clash detection. While developing the model, if more information is required, a "request for information" is issued by BIM modeller. It is important to note that BIM modellers must follow the naming structure for coding the models and objects in each models with utmost attention as improper coding will result in numerous mistakes in the clash detection. The process of developing 3D models is shown in figure A.

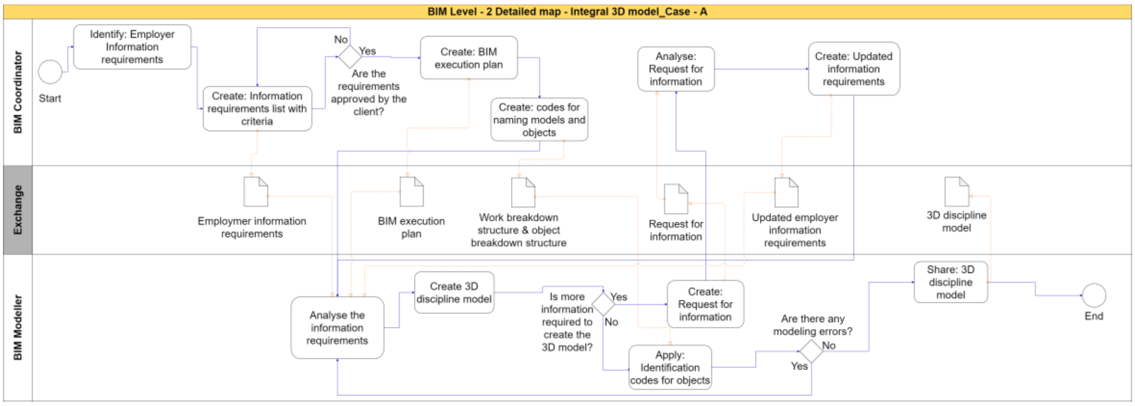


Figure. A Case-A 3D modelling process

2. <u>Clash detection</u>: The process starts with creating N2 matrix to analyse relationship between objects and determine which models must be clashed. In this project, N2 matrix was provided by the client (Rijkswaterstaat). The BIM coordinator updated the N2 matrix with relevance to this project. BIM Coordinator starts the clash detection process after receiving the 3D models from the BIM modeller by making a coordination model in the Navisworks. Before performing the clashes, it is important to check the object codes as they are the most frequent errors observed in clash detection. Having N2 matrix and 3D coordination models as inputs, clash detection is performed. When clashes are detected, Request for Information (RFI) is created in BIM360 environment and BIM modellers are notified with the errors. When they are resolved, the tests are performed again until there is no error observed. The output of this process is one integral 3D model which is uploaded to BIM360. The clash detection process is shown in figure B.

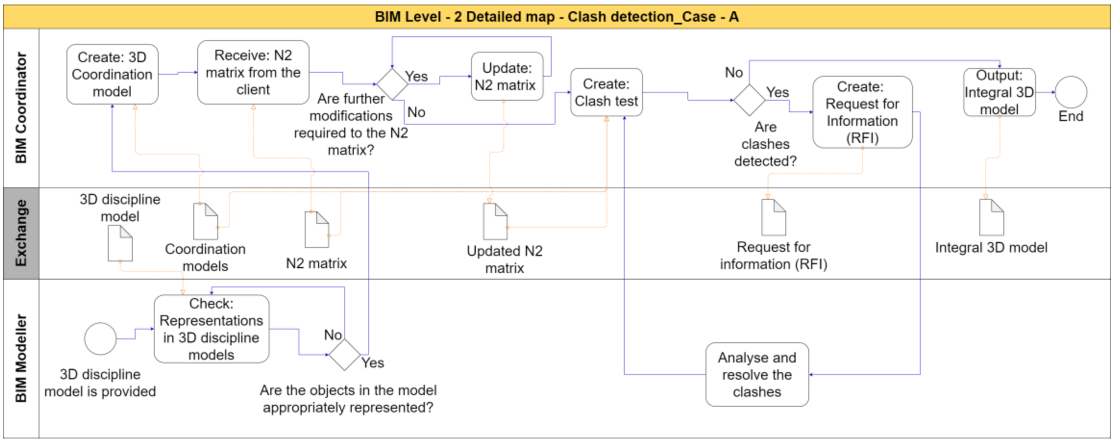


Figure. B Case – A Clash detection process

3. <u>4D modelling</u>: An implementation plan is created in the first place with Primavera. This is created along with BIM coordinator and planning expert from the client's side. The implementation plan is checked with the client for approval. In this plan, the identification codes for objects in the BIM models and activities in implementation plan must be the same. The integral 3D model and the implementation plan are exported to Synchro Pro environment. Before creating the 4D model, it is important to check both the input for unwanted elements or activities. In addition, the object codes has to be checked in both the files. In each 4D activity, filters should be created describing the phase of the project: construction, demolition, temporary or existing. Having done this, 4D model is created and the output of the process is an animation video showing the evolution of the project over time. This is shared to BIM360 platform. The 4D modeling process is shown in figure C.

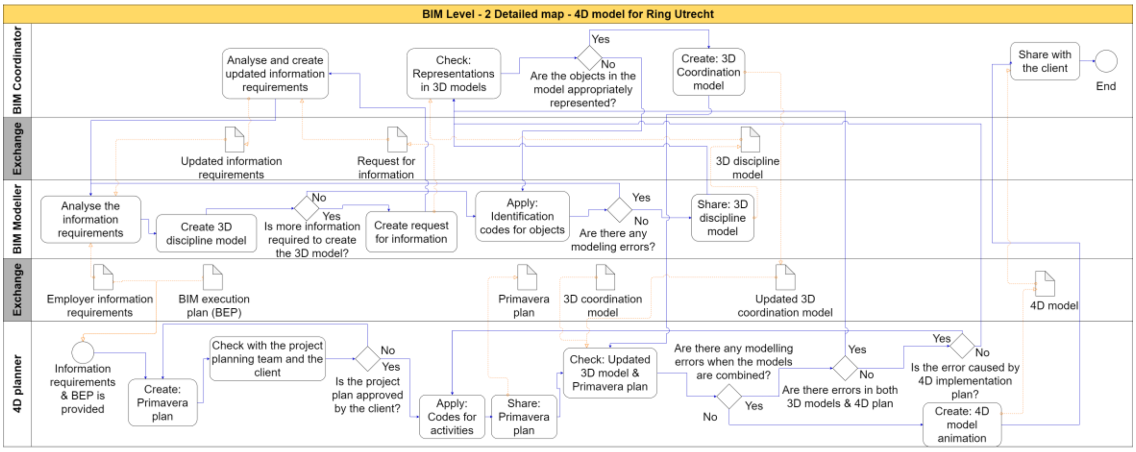


Figure. C Case – A – 4D modeling process

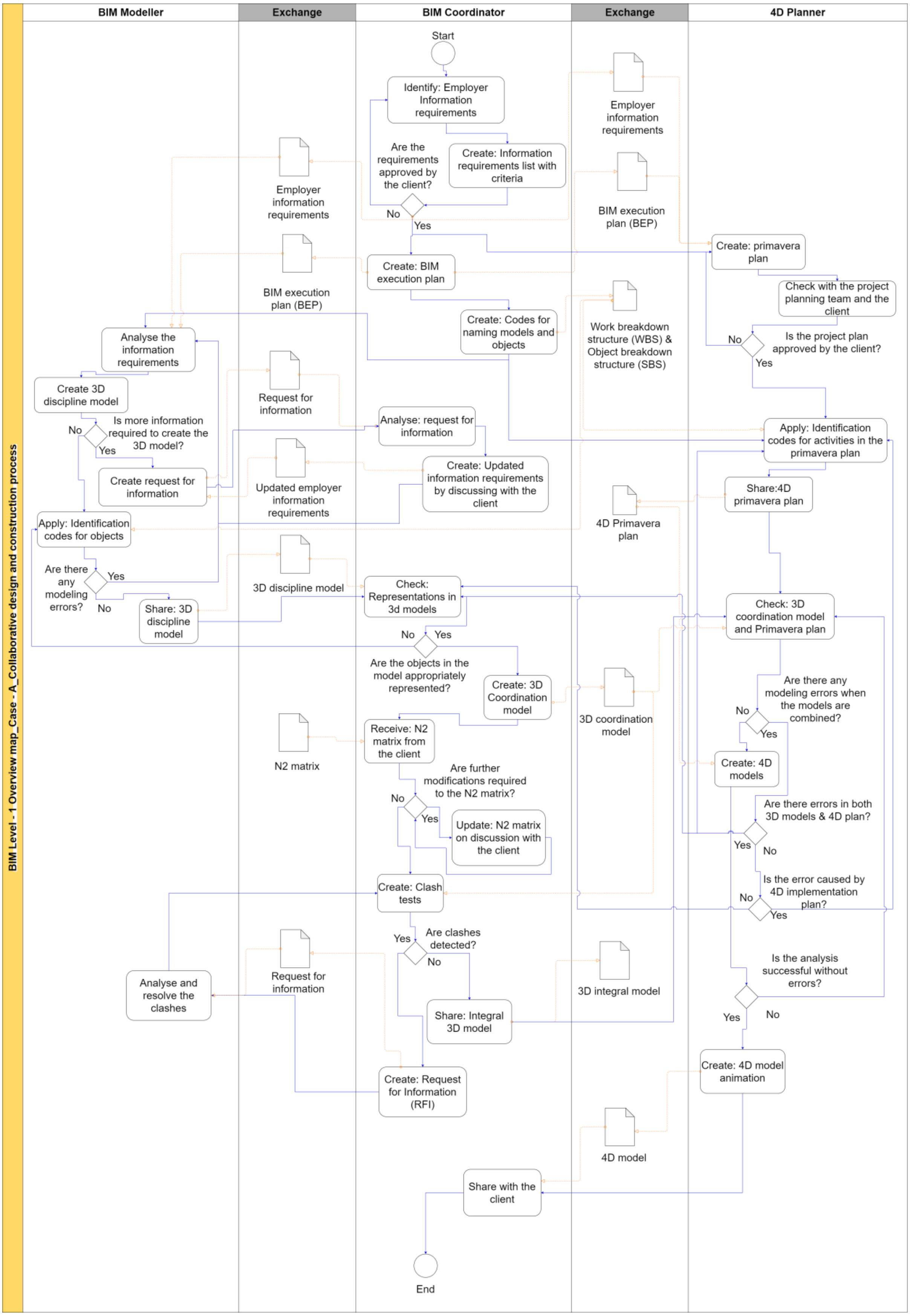


Figure. D Case-A overall BIM design process

Appendix D1: Transcripts of interviewee A1

Date: 19-Mar-21
Time: 09:00 – 10:00

Agenda

- Introduction
- View on BIM within W+B
- 3D Design & clash detection process
- Issues & delays
- Best practices

Minutes:

- Introduction
    - BIM Modeler in case - A
    - Educational background: Bachelors in Civil Engineering
    - Worked in water construction sector
    - First time working for infra projects as lead designer
    - Previous BIM experience: Data coordinator in another large infrastructure project
- View on BIM in W+B
    - Awareness is less. Most people think BIM is just a model but it is a process.
- 3D Design & clash detection process
    - Design process
        - Before starting the model:
            - Look at the information register (existing drawings, objects)
            - Location
        - During development:
            - Get information from Sharepoint
            - Process the model
            - If the information is missing, ask the client
            - Deliver the model to the client
        - Actors:
            - BIM Coordinator, Construction team, geotechnical team, road design team, project management team, client
        - Software:
            - Open Roads, Revit, AutoCAD, Navisworks, Recap (Point cloud), BIM360
        - Input:
            - Road design (dgn to civil 3D)
            - Client requirements (pdf and excel). Export to relatics
            - Plan of action
            - Geotechnical availability
        - Output:
            - One big 3D integral model in CDE created by W+B
    - Clash detection process
        - Partially involved.
        - Submit the models to BIM coordinator. He does the clash detection in BIM 360. Get back with the results
- Issues and delays
    - Issues

        - Dependencies on external parties. We had to depend on road design team for giving their models
        - Procedures for working with Revit. Information on naming the file, level of detail, exchange formats were required.
        - The project was understaffed.
        - Time pressure and conservative nature of the industry (Old School) was reasons for hindering BIM implementation. There were tight deadlines for this projects.
        - Other teams were not aware of BIM.
    - Delay:
        - External party – road design team. 2 months delay. They were looking for other opportunities
        - Level of detail required for the BIM models were not established beforehand
        - Inexperienced team. People were not aware of BIM methodology and they lacked knowledge in BIM.
    - Others
        - Communication of responsibilities was done through mail, weekly meetings.
        - Traditional drawings were still designed in the process as BIM was not made mandatory
- Best practice
    - Before the model, look at the existing drawings.
    - Check the available information
    - Check the BEP
    - Look the client requirements

Appendix D2: Transcripts of interviewee A2

Date: 31-Mar-21
Time: 09:00 – 10:00

Agenda

- Introduction
- Clash detection process
- Issues & delays
- Best practices

Minutes

- Introduction
    - Started my career with W+B as designer using AutoCAD
    - BIM Coordinator with Case-A
    - Education: Civil Engineering (Specialisation in BIM)
    - Client for the project: Rijkswaterstaat
    - Scope: Expansion of roads including construction of bridges, passes.
- Clash detection process
    - Before starting the model:
        - Aspect model: Separate models.
        - Integral model: Combined aspect models
        - First step is, you make the coordinates. Set out the elements. Extract the information from existing models.
        - Redesign the existing models and check with the pointcloud
        - BIM modeller makes new models and exports to BIM360 environment
        - BIM coordinator opens the 3d model in Navisworks and integrates the 3d models.
        - Checks: SBS, interfaces, quantities and visual control.
        - If clashes are detected, BIM modellers are informed about it and asked to work on it
        - No clashes. Integral 3D model is developed
    - Input
        - BIM protocol
        - Information delivery manual
        - Work Breakdown Structure (WBS)
        - System Breakdown Structure (SBS)
- Issues and delays
    - Issues
        - Extracting information from old drawings.
        - Working with point cloud was challenging
        - Working with external parties. Road design was given to external party and they could not be contacted after the road design was completed.
        - Inexperienced team. Some didn't have knowledge on infrastructure projects
        - Dealing with amount of clashes. There were too many clashes.
        - Time to understand the requirements. Information was not clear
        - Corona crisis. Not able to see people.
        - Responsibilities were not clear. Who is doing what was difficult to identify.
    - Delay:

        - External party – road design team. 2 months delay. They were looking for other opportunities
        - Level of detail was not established properly.
        - Inexperienced team
- Best practice
    - Working with point cloud.
    - If the data is provided correctly, execution won't be a problem.
    - BIM is still people's work and answers are needed with how to make it easier.

Appendix D3: Transcripts of interviewee A3:

Date: 16-Apr-21
Time: 14:00 – 15:00

Agenda

- Introduction
- 4D process
- Issues & delays
- Best practices

Minutes

- Introduction
    - Started my carrer at W+B in 2019.
    - Case – A is the first project.
    - BIM Role with case – A: 4D planner
    - Educational background: Masters in Construction Management and Engineering
- 4D model process
    - Two inputs required: 3D BIM model and planning
    - BIM Coordinator makes the integral model.
    - 4D planner gets the input from the BIM coordinator to make 4D planning
    - 4D models are developed in loops
    - Synchro Pro was the software used for making the 4D models
    - Object tree was developed alongwith BIM coordinators & modellers
    - BIM coordinators established the script for coding the 3D models
    - BIM modellers applied the script to 3D models
    - 4D planners applied the script to project planning
    - BIM coordinators checks if everything in place
    - 3D models are exported to BIM360.
    - Every Friday, a model is updated which is used for the 4D models
    - After the 4D model is made, it is exported to BIM360. Sent to the client on delivery date
    - The best way to communicate: Review meetings.
    - The source file was not delivered. Only in videos. The idea was to deliver all the source files.
    - Communicate the process in the beginning.
    - Actors involved in this phase: 4D planner, BIM coordinator, BIM modeller, planning team, structural engineers, Rijkswaterstaat (planning team).
    - For the planning, requirements are got from the client, planning sessions are conducted to discuss the planning, W+B makes the planning and discussed in the planning sessions. On approval, it is implemented in the primavera planning and to the 4D models
- Issues
    - Align the level of the detail with the model. It was not clear what level of detail was required to be achieved.
    - Getting input for the planning. Not much connection between planning and BIM planning.
    - Less knowledge and experience: Information required for the planning
    - Client experience. Educating the client with 4D cost some time
    - Project was big with different teams

    - Communication with the back office and the project teams was not good
    - Inexperienced people
- Delays:
    - Did not develop a good 4D model because of the information requirements. (Delays in the input)
    - Aligning level of detail
- Best practice:
    - Important to have good established roles. Sources of input needed and who is the person to reach.
    - Good defined of who delivers what and when
    - Good information flow and workflow
    - Good structure of the object tree
    - Good coded models

Appendix E: Case -A BIM design process

The BIM uses of this project include 3D modelling, clash detection, 4D planning, and cost estimation. The overall process of the project is visualised in figure H.

1. 3D modelling: The process was started by discussing the project requirements with the project leader and referred as input in addition to BIM protocol, BEP, WIKI page. The road design were developed in Open roads and exported to Civil 3D. The civil models were developed in Revit. The manuals on how to use Revit was available in WIKI page. If more information was required, BIM modellers contacted the project leader. The system breakdown structure (SBS) code was given by the project leader to assign the codes to the models and objects in each models. The discipline models are submitted to the head BIM modeller for internal check in .nwc file. On approval, the files are converted to .nwf file to perform the clash detection. The files are uploaded to the BIM360 environment. 2D plans are made after the completion of 3D models. The process is shown in figure E.

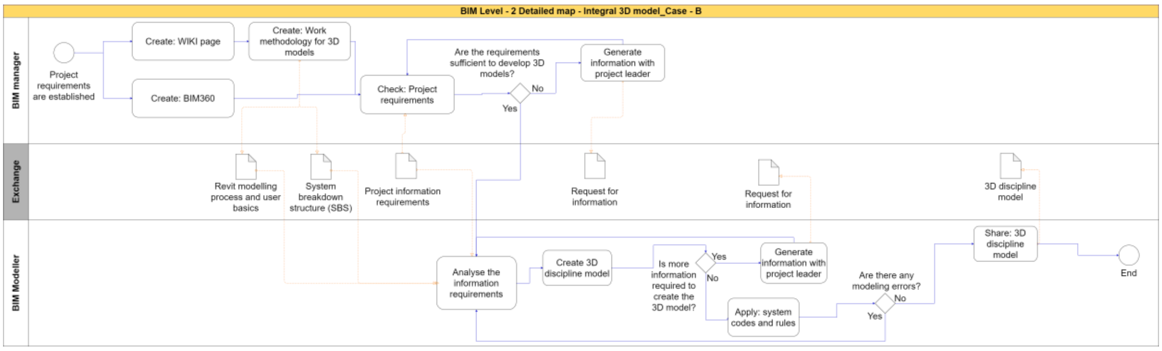


Figure. E Case – B 3D modeling process

2. Clash detection: First, a check on the coding was done to analyse if right models are chosen for clash detection. A matrix is created to analyse the potential clash tests needed for this project. This is developed by BIM coordinator in consultation with different discipline leaders. The clash detection is performed in Navisworks and connected with BIM360 environment. The clashes are automatically reported in BIM360 environment and concerned people are assigned to solve the clashes. This is a cyclic process until clashes are no longer observed and project leader approves the model. Then the integral model is exported to .nwd file. The process is shown in figure F.

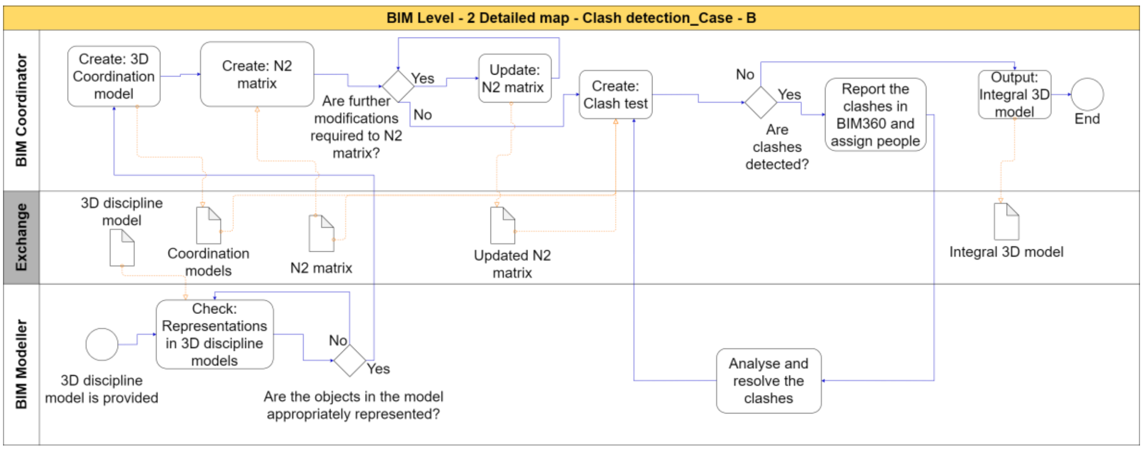


Figure. F Case – B – Clash detection process

3. 4D modelling: A planning is made with Primavera. Input for the planning is given by Project Leader. Having the integral 3D models and primavera planning as input, 4D models were developed. Rules were assigned to every object on the nature of their existence in the construction project. For

instance, construct, demolish, temporary, etc. If the error is observed with clashes, BIM modeller is notified. If the error is observed with planning, project leader is notified. The output of the 4D process is a video animation showing the evolution of project over time. This is shown in figure G.

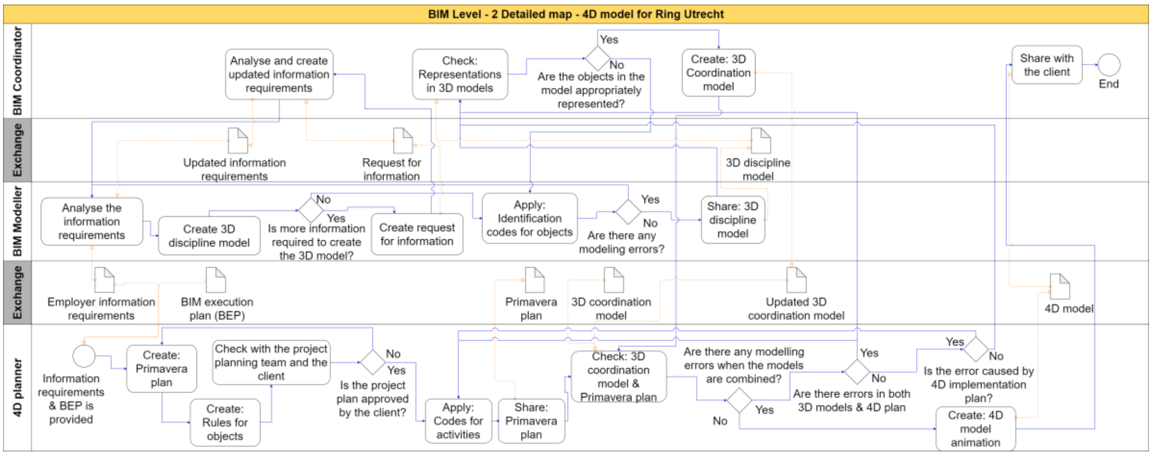


Figure. G . Case – B – 4D model

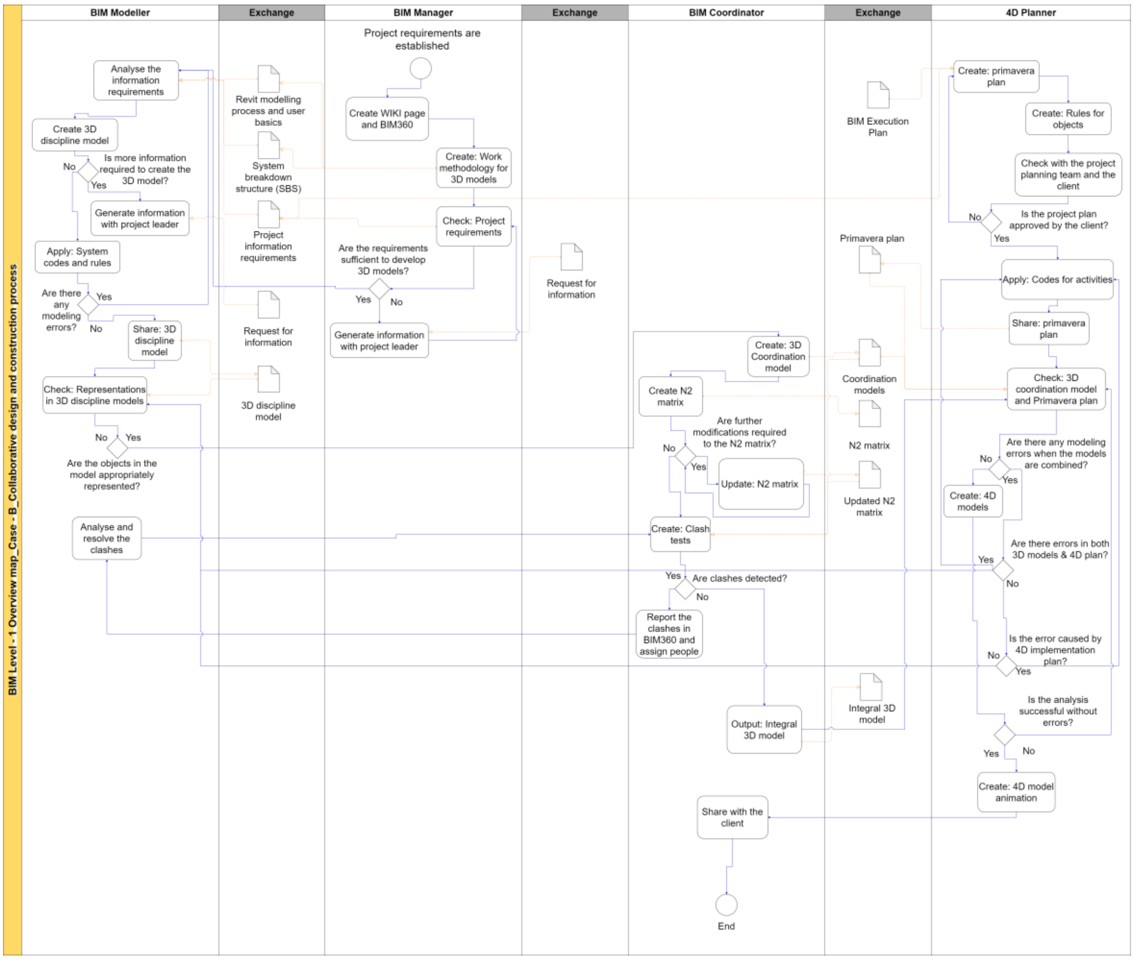


Figure. H Case – B: Overall BIM design process

Appendix F1: Transcripts of interviewee B1

Date: 30-Apr-21
Time: 14:30 – 15:30

Agenda

- Introduction
- 3D Design process
- Issues & delays
- Best practices

Minutes

- Introduction
    - Worked in W+B for 3 years.
    - Education: Civil Engineering
    - Started as designer for case-B. Now, BIM modeller (head of the structural designer group)
    - Responsibilities: Check the structural models developed by the BIM modellers
- 3D design process:
        - Discussion with the project leader on working with the capabilities for project requirements.
        - This information is given to the modellers.
        - If more information is required, modellers contact the project leader directly.
        - Once the model is developed, converted to nwc. internal check is given to me. Then the files are converted nwf to perform the clash detection
        - Project leader is responsible for the SBS. It is developed by discussing with BIM manager, BIM coordinator and BIM modeller
        - When the 3D model is ready, 2D plans are made
- Issues and delays
    - Issues
        - Some people were not used to this kind of working methodology. There were also people who saw the benefit of BIM
        - If everything is not defined properly at the start, then there will be issues later. Missing object, physical codes, not good described demands, boundaries were present in this project.
        - What the BIM model should contain should be defined. More information can be added but minimum requirements should be given.
        - Changes on working methodology of CDE was a problem.
        - Though everything is structured, you need someone to keep the system running and updated. If not updated, this can lead to big errors.
    - Delays
        - Working with not practical deadlines.
        - Project leaders think developing BIM models can be done in a short time.
        - Time is underestimated
        - Assessing the model at the end. Fixing the things that is noticed is difficult.
- Best practice
    - Create a knowledge platform (wiki page)
    - To make more choices at the start and not change. More can be added but not removed/modified.

Appendix F2: Transcripts of Interviewee B2

Date: 28-Apr-21
Time: 10:30 – 11:30

Agenda

- Introduction
- 3D Design & clash detection process
- Issues & delays
- Best practices

Minutes:

- Introduction
    - BIM Coordinator: Clash detection in BIM360, Document management system., information management system, issue management system, working with Navisworks.
    - Education: Masters in Project Management of civil structures and infrastructures. (BIM). Studied UK Level 2 BIM.
    - Experience with BIM: 15 years.
    - The project is to redesign the existing infrastructure by expanding the roads and construct a underground tunnel.
- Clash detection process
    - First check the views of the models. All the models must have the right name. Check if the right models are chosen.
    - Create matrix for clash detection. BIM coordinator is supposed to create an overview on which models must be clashed against each other and checked with BIM manager. This has to be done in consultation with different discipline leaders.
    - Work with Navisworks. Import the files(.nwf) and perform the clash detection.
    - The clashes are automatically reported in BIM360 environment and people are assigned to solve the clashes.
    - The integral model is exported to .nwd file.
    - The clash detection continues till the project leader approves that the design is correct.
    - Assign the rules: Construct, demolish, etc. (BIM Modeller). Check is done by BIM coordinator.
- Issues and delays
    - Issues
        - BIM360 process was changed as the project involved 200 models and information management was complex. The theory does not always work in practice.
        - Awareness on BIM knowledge. Most of the time people are not aware of the information flow. They think BIM is just 3D models. They don't know how to use BIM.
        - Lack of training.
        - Technical issue: BIM360 activation license. It is not official CDE environment of the company. This has to be discussed with the company. If it was recognised as company CDE, it would have been easier.
        - Modellers are not aware/understand why specific quality is required.
        - Sharing the information with project leaders will be a problem in the future.

- Delay:
    - Workflows had to be changed and tested.

- Best practice
  - Create standards
  - Communication on how processes works.

Appendix F3: Transcripts of interviewee B3

Date: 07-May-21

Time: 11:00 – 12:00

Agenda

- Introduction
- Role as BIM manager
- Project setup process
- Issues & delays
- Best practices

Minutes:

- Introduction
  - 8 years working at Witteveen+Bos. Started as designer with North South Lane (NSL).
  - Education: Bachelors in Civil Engineering
  - Role with case-B: Started as designer. Now BIM manager. Also provide Revit usage instructions. To provide the right structure information.
  - Provide education to other schools on using Revit
  - Experience with BIM: 6 years
- Project setup process – WIKI & BIM360
  - BIM manager created the Wiki page for the project. It includes the organisation structure, communication structure, information building and exchange, ISO19650 working, education, published documents, recycle bin.
  - BIM operational structure: Project team is divided into delivery teams and task teams. <u>Delivery team</u>: Managing information model and coordinate information model with other delivery teams and the integral design manager. <u>Task team:</u> Designs, engineers and produces the information within a delivery team. Every delivery team has a task team.
  - Communication structure: In (available information from previous phase) - WIP – Shared – Published – Archived. Separate folders are created for delivery teams.
  - Relatics for Systems engineering. System Breakdown structure (SBS) and Object Breakdown Structure (SBS)
  - Every design change is registered in design change log.
  - Created road designs in open roads. Exported to Civil 3D. Civil models are made in Revit. Navisworks is used for clash detection and quantity take off. Everything is managed through BIM360. BIM360 is the CDE used in the project. It was quite new for everyone.
- Issues & delays:
  - Issues
    - Informing everyone. BIM users are aware of the way to work. The benefits are seen. Integrating Project leader and design leader with the BIM process is challenging.
    - Interest with BIM. People are not interested to work with BIM as 2D is considered as deliverables and other goals are there for the project. Sometimes, BIM is an additional task to do.
    - Contacting concerned person. There is no organogram.

    - Flowcharts for checking/moving to shared is not there. Who is approving is still challenge? Lots of parties are involved and who should approve is not clear.
    - Connection to objects.
    - Information system was not well-defined
  - Delay:
    - Design change. Extra bicycle lane was required which changed the complete design.
    - Mostly because of interests of stakeholders. They get changed. This changes the requirements which changes the design.
  - Best practice
    - Developing the wiki page
    - Defining the process at the earlier stages.

Appendix F4: Transcripts of interviewee B4:

Date: 07-May-21
Time: 15:00 – 16:00

Agenda

- Introduction
- 4D model process
- Issues & delays
- Best practices

Minutes:

- Introduction
  - Started as designer (drawings AUTOCAD in hand) with W+B in 1981. Working for 40 years.
  - Previous experience include BIM Coordinator for North South Lane
  - Experience with BIM: 20 years
  - Course on Primavera planning.
  - 4D BIM modeller & BIM coordinator for case-B. Involved with coordination, 4D and 5D.
  - Education: Master's in Civil Engineering
- 4D model process
  - Make preliminary design with 2d drawings
  - Make the 3D models with that.
  - Make a planning with primavera. The input for the planning was given by Project Leader. Before the planning, Systems engineering is checked by Project Manager. This is given for planning.
  - If error is observed with clashes, BIM modeller is notified. If error is observed with planning, project leader is notified.
  - CDE: BIM Xtra. Later it was changed to BIM360. Because it was too much risk with BIM extra as it was made by a small company.
  - The process map with the Case - A is the same. The differences are as follows:
    - The difference is 4D planner made the rules (Start & End of temporary elements)
    - Check: If 3D model is sufficient enough to perform a 4D analysis.
- Issues and delays
  - Issues
    - Change of CDE
    - Inexperienced team. Some people were new to the career and they struggled.
    - Time and efforts
  - Delay:
    - Design change
- Best practice
  - Though BIM is not a requirement, having 4D is beneficial to to show the client when the project will be completed.
  - Quantities for cost estimation.
  - Clear BIM Protocol, BEP. Create a WIKI page
  - Following ISO19650 norm
  - Make courses/education

Appendix G: Case – C BIM design process

The BIM process in the design phase included 3D modeling, and clash detection. These are explained below and an overview of the entire process is visualised in figure K.

1. <u>3D modelling</u>: Basic information that is required in the models were defined prior to the start in the form of template files. The coordinates were set which helped the modellers with the starting points and boundaries. The BIM modeller is requested to submit 3D models every 2 weeks and submit it for clash detection. The model is uploaded to BIM 360. The process is shown in figure I.

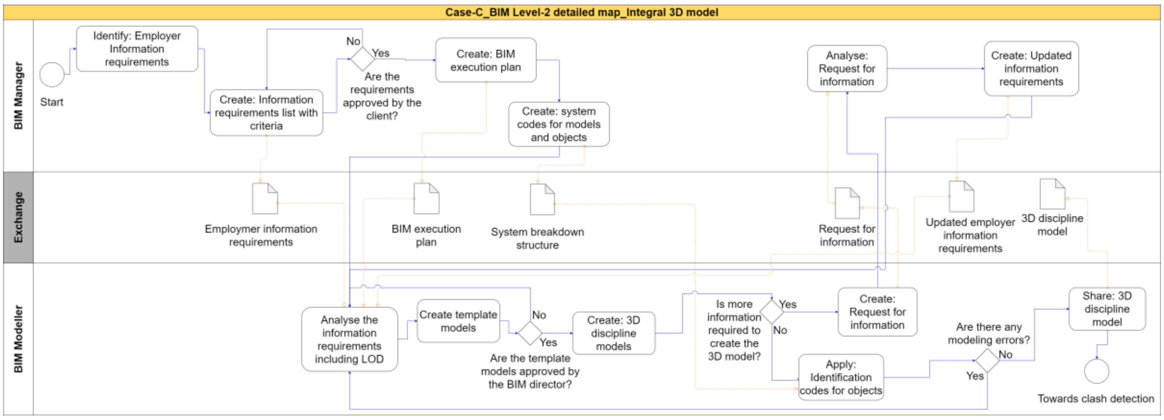


Figure. I Case – C: 3D modeling process

2. <u>Clash detection</u>: The process started with checking the objects in the models. BIM coordinator checks the correctness of the models if they have the right objects and codes for the objects. N2 matrix is developed by BIM coordinator along with systems engineering department to establish a relationship between certain objects. This helps to determine what needs to be clashed and it is the responsibility of the BIM coordinator to develop this N2 matrix and perform the clash detection. On receiving the 3D models from the BIM modeller, coordination model is developed in Navisworks. The BIM360 is connected to Navisworks and when clash detection is performed, clashes are automatically stored in BIM360 environment. If clashes are detected, request for information (RFI) is issued and sent to BIM modellers. The output of this process is one integral 3D model which is uploaded to BIM360. The process is shown in figure J.

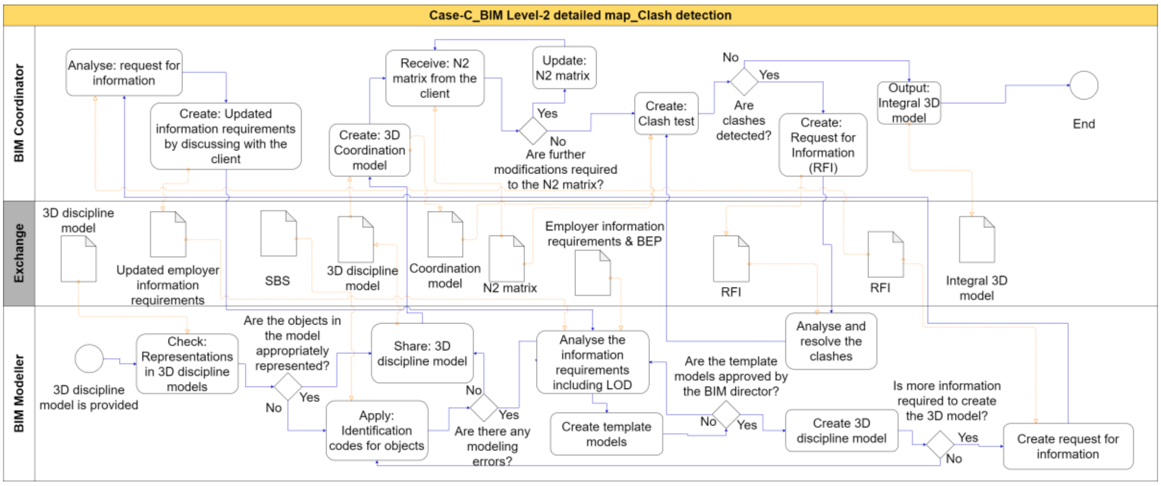


Figure. J Case – C: Clash detection process

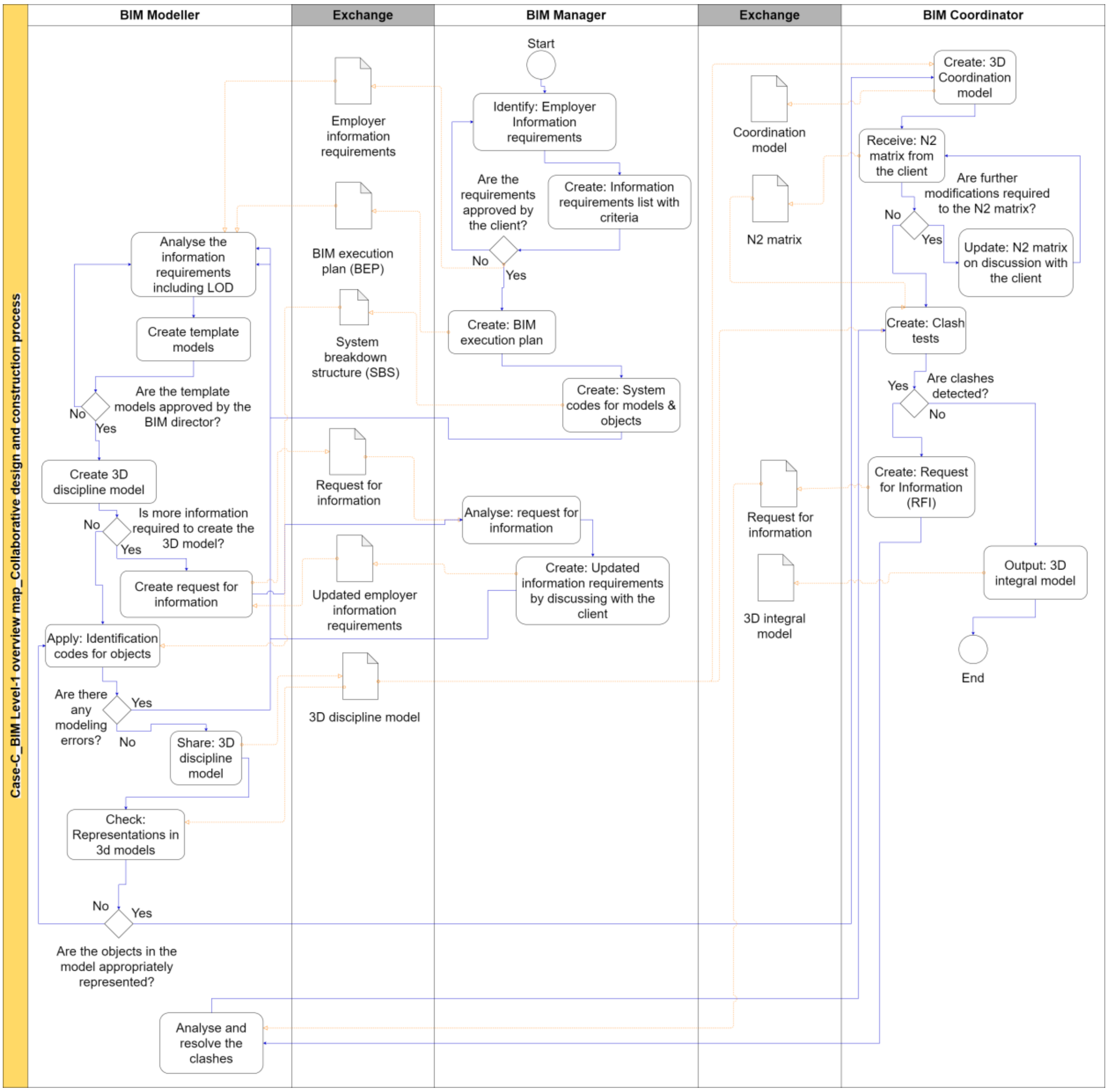


Figure. K Case – C: Overall BIM process

Appendix H1: Transcripts of interviewee C1:

Date: 29-Apr-21
Time: 09:00 – 10:00

Agenda

- Introduction
- View on BIM within W+B
- 3D model process
- Issues & delays
- Best practices

Minutes:

- Introduction
  - Working at W+B for 10 years.
  - BIM experience: 8 years
  - Other projects: Working with 2 large infrastructure projects.
  - BIM Modeler (Chief designer) in case-C
  - Education: Civil Engineering (Specialisation in Structural)
- View on BIM in W+B
  - Saw the emergence of 3D modelling. Already doing that in the company at limited capacity
- Design process
  - Template were set in which coordinates (borders of the project) and basic information was described. It is like example project. This was developed by referring to BIM execution plan.
  - BIM director identifies the requirements and makes the BIM execution plan.
  - Templates were checked with BIM director
  - Contractor wanted the design to be done in Revit.
  - The template were stored in BIM360
  - The model is started making in that template itself
  - Every 2 weeks, model is made and exported to Navisworks for clash detection.
  - Exports:
    - .dwg , .nwc, .ifc
    - .ifc (Autodesk does not like ifc)
    - .fdx for infraworks
    - .dwfx for SYNCHRO pro
  - Clashes were piled in BIM Collab. The issues are then transferred to the concerned modeller.
  - Mostly, we observed geometric clashes. Examples: Incorrect positioning.
  - 4D for this project was not done by Witteveen+Bos
  - The process is almost the same as case-A because of the same BIM director. The differences are: Checking for LOD in the requirements and creating template models
- Issues and delays
  - Issues
    - Connecting different models before it is sent to clash detection. Example: road design and technical installations. They are developed by different teams and can't be checked before clash detection. Sharing information with other disciplines

        - Less experience with BIM teams
        - Different workflows resulting changes to BIM360 environment. (BIM director was changed and the BIM360 structure (folder and model naming) was changed).
        - Really well documented but actual practice was different. This is because of time pressure and less priority.
    - Delay:
        - BIM was considered an additional thing to do. Capacity was not sufficient to deal with the time.
        - Coding the models was delayed.
- Best practice
    - Creating templates. It lead to less faulty process
    - Well-defined information requirements

Appendix H2: Transcripts for interviewee C2:

Date: 06-Apr-21
Time: 10:30 – 11:30

Agenda

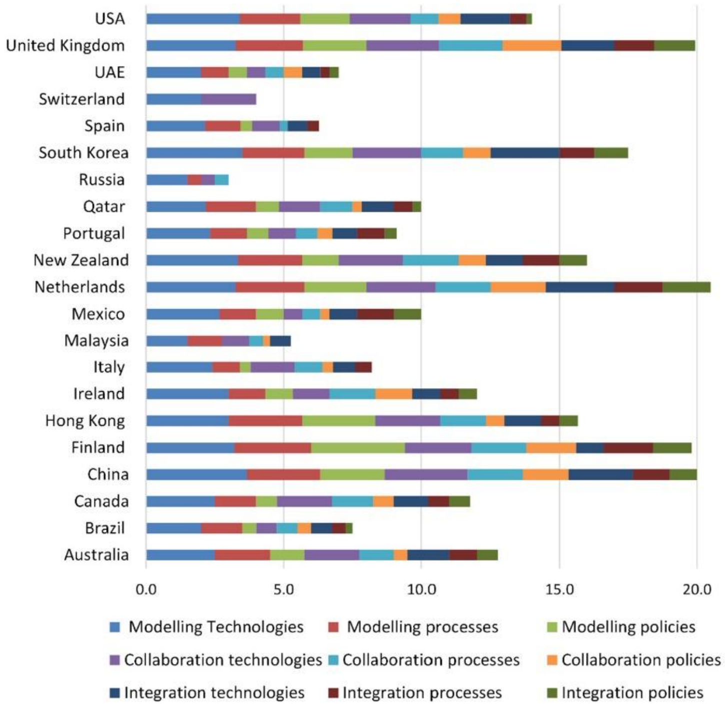
- Introduction
- Project setup process
- Clash detection process
- Issues & delays
- Best practices

Minutes:

- Introduction
    - Information manager in the starting phase of the project. Responsibilities: Guidelines on how they use BIM in the design phase.
    - 14 years with Witteveen+Bos.
    - Experience with BIM: 3D, 4D and 5D for 5+ years
    - Education: Civil Engineering (HBO)
- Project setup process:
    - Wrote down which application were about to be used. Right coordinates and agreements.
    - Made a discussion about system breakdown structure which was available from the client.
    - Made some modifications to it suitable to the project as decomposition is not always perfectly workable. So modifications are made to make it more clear.
    - There was no requirement for BIM. It was something additional which W+B offered.
    - Split up the disciplines: structural engineers, road design, technical installation, sewer, water
- Clash detection process:
    - Check: Which objects were there in the project
    - Create: N2 matrix (System engineering). See if certain objects has a relation and determined what needs to be clashed (BIM coordinator)
    - Perform a pre-analysis to reduce the number of clash tests (BIM Coordinator & system engineering)
    - Receive the 3D models from the BIM modeller. They update it in shared folder of BIM360 from work in progress. Make an integral model with the available discipline models in Navisworks
    - With BIM360, automation clash detection is done. In Navisworks, add additional clash detection. It was automatic and manual.
    - 2 ways to perform clash detection: With & without time
    - If clashes are detected, create RFI within BIM360 environment and send it back to modellers for corrections and do the clash detection again.
    - The output in this process is one integral 3D model which is uploaded to BIM360.
    - Coding the object is mostly done at the end of the project
- Issues and delays
    - Issues
        - Client didn't have information delivered. Sometimes information were missing.

        - BIM process is not integrated with the project plan
        - Nobody is feeling responsible working according to the system
        - There is knowledge gap on systems. They see that BIM is an additional thing to do
        - What was to be delivered at what time was a problem. (Structuring was a problem)
        - Getting everybody involved. It is not clear for everybody
        - Every project, there is a new process
    - Delay:
        - Sometimes new information were received from the client during the project.
- Best practice
    - Integration of GIS with BIM.

Appendix I: Theoretical barriers not observed in practice



12 theoretical barriers were not observed in practice and is something to note. These barriers are listed below and reasoning is given on why it was not observed in the case studies. A common reason why the barriers were not observed in practice is because of the Dutch context. As shown in this figure, the Dutch AEC industry has a good BIM adoption rate when compared to other countries (Kassem & Succar, 2017). BIM adoption is moderately balanced with three diffusion areas (modelling, collaboration, and integration). The technological readiness of the Dutch AEC industry is a reason for the other theoretical barriers to be not observed in practice. From the case study findings, no new barriers were found other than the ones listed in the theory.

15. Lack of common data environment to support collaboration: The analysed case studies had a CDE environment (BIM 360) to support collaboration in the project.

16. Data ownership and data privacy concerns: The organisation did not have concern regarding privacy and security of BIM models to be shared on cloud platforms and CDE.

17. Interoperability challenges across building project life-cycle: BIM managers were aware of the incompatibility of IFC, BIM Collaboration Format (BCF), and this barrier was not observed in practice. They used different file formats in addition to the source file to integrate the BIM models with other software.

18. Failure in technological support to collaboration: Using BIM 360 as CDE for projects was promising and issues were not observed with the technological support of the software

19. Disparities in approaches to collaboration among participants: The collaborative way of working was centralised with the BIM manager and head BIM modeler's directions. Instructions were given by these leaders to unify the work methodology and avoid disparities in collaboration approaches among members in BIM teams.

20. Overlooking national cultural variation in multi-cultural teams: Most of the members in BIM teams were from the same cultural context (The Netherlands). Though there were some members from other countries like Italy and Brazil, differences in national culture was not observed in the case studies and cultural context didn't influence the collaborative way of working.

21. Fragmented stakeholders as a norm: COVID-19 situation made the working entirely digital and didn't matter to the BIM teams if the stakeholders were dispersed across various offices and locations.

22. Lack of team working mentality: Working in silos was not an issue in the observed case studies. The organisational culture influenced the team working mentality. Weekly progress meetings were conducted and suggestions were provided by other members in BIM teams to improve the quality of work.

23. Different organisational structures in multi-disciplinary teams: Though members from different organisations were involved in executing BIM tasks, the organisational structures and hierarchies were not an issue because of the cultural context (The Netherlands). The collaborating organisations were Dutch companies and the structures and hierarchies were not a barrier in the observed case studies.

24. Dynamics and fragmented nature of the construction industry: COVID-19 situation made the working entirely digital and didn't matter if the companies and supply chain components were dispersed in different locations, cities, and countries.

25. Isolated working mentality of project teams: This is closely connected with lack of team working mentality. The organisational culture influenced the team working mentality.

26. Resistance towards sharing data and information: BIM teams were comfortable in sharing the models with other teams as the members were not allowed to share the data because of the organisational policy. Every member had to sign a non-disclosure agreement (NDA) with the company to protect the intellectual property and ownership concerns.

Theoretical barriers not observed in practice		
15	Lack of CDE to support collaboration	The analysed case studies had a CDE environment (BIM 360) to support collaboration in the project.
16	Data ownership and data privacy concerns	The organisation did not have concern regarding privacy and security of BIM models to be shared on cloud platforms and CDE.
17	Interoperability challenges across building project life-cycle	BIM managers were aware of the incompatibility of IFC and BCF formats and this barrier was not observed in practice.
18	Failure in technological support to collaboration	Using BIM 360 as CDE for projects was promising and issues were not observed with the technological support of the software
19	Disparities in approaches to collaboration among participants	The collaborative way of working was centralised with BIM manager and head BIM modeller's directions
20	Overlooking national cultural variation in multi-cultural teams	Most of the members in BIM teams were from the same cultural context (The Netherlands) and did not influence the collaborative way of working
21	Fragmented stakeholder as a norm	The working was entirely digital and didn't matter to the BIM teams if the stakeholders were dispersed across various offices and locations.
22	Lack of team working mentality	The organisational culture influenced the team working mentality
23	Different organisational structures in multi-disciplinary teams	The organisational structures and hierarchies was not an issue because of the cultural context (The Netherlands).
24	Dynamics and fragmented nature of the construction industry	The digital working did not matter if the companies and supply chain components were dispersed in different locations, cities and countries
25	Isolated working mentality of project teams	The organisational culture influenced the team working mentality. This is closely connected with lack of team working mentality
26	Resistance towards sharing data and information	BIM teams were comfortable in sharing the models with other teams as the members were not allowed to share the data because of the organisational policy

Appendix J: BPMN elements overview

Figure L shows the overview of BPMN elements. Flow objects determine the process behaviour by representing every action that can happen inside. They include: Events, Activities and Gateways. Events are the points which represents notable occurrences; Activities represents the logical sequence of the process; Gateways represent decision points. The objects are connected through connecting objects in three ways: Sequence Flow, Message Flow and Association. Swimlanes are useful to group the elements and they are grouped through pools and lanes. A pool is a container which has all the elements in different lanes. Artifacts provide additional information to the diagram and it does not affect the process flow. The most used elements in BPMN are Normal flows, Task, End Event, Start Event/Event/ Pool, Data-Based XOR Gateway and it is called as "common core of BPMN" (Chinosi, 2012). On the other hand, elements such as compensation association, multiple end event, cancel intermediate event, intermediate exception, multiple start event, compensation end event are not considered at all.

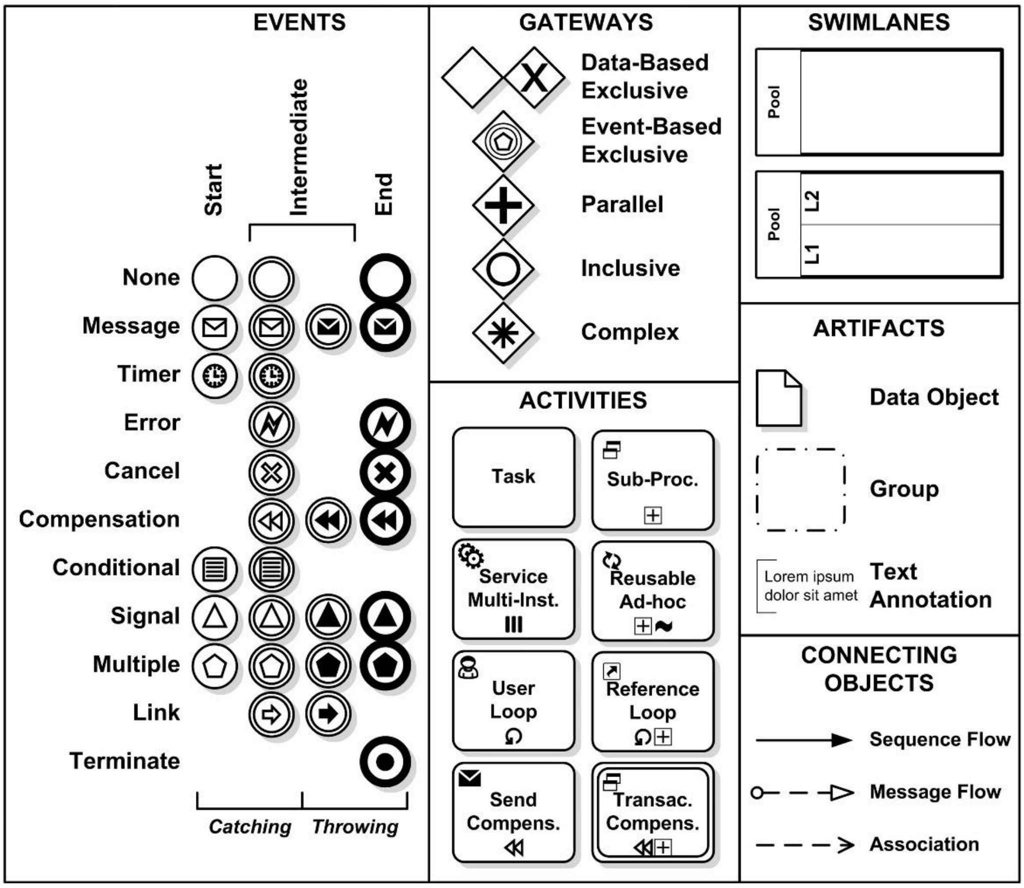


Figure. L BPMN elements overview (Chinosi, 2012).

Appendix K: Transcripts of focus group discussion

Date: 18-June-21
Time: 15:00 – 16:30
Location: Witteveen+Bos, Deventer

Agenda

- Introduction
- Most critical barrier
- Possible strategies

Minutes

- Introduction:
  - Interviewee – 1: I have a bachelors in Civil Engineering. Working with Witteveen+Bos for 11 years. Started my career as a draftsman, developed to a 3D model export. For the last 2 years, focusing on enhancing workflows and working with BIM. On a daily basis, leading a small group of BIM engineers.
  - Interviewee-2: I have a bachelors in Mechanical Engineering. Working with Witteveen+Bos for 7 years. Started as a BIM modeller.
- Most critical barrier
  - Interviewee-1: It is obvious for me. I see that a lot in the organisation. For collaboration in BIM teams, it can be the most critical barrier.
  - Interviewee-2: Yes. This is observed more for collaboration with the client. Information is not clear for them from the provided documents.
- Possible strategies
  - Interviewee-1: Standardising the process can be a good solution to solve lack of guidelines and standards if the work process aligns to our regular way of working. Integrating best practices to standardise our way of working can be effective to improve collaboration in BIM teams. Creating the process according to ISO 19650 actually gives us a direction of working for future projects.
    - Creating master BIM model can help to better collaborate with different BIM teams in a project. Practically, it might be difficult to create a single reference model for the entire project as different disciplines are involved. Many master BIM models are required in this case. For example, a master BIM model for each discipline.
    - Creating a knowledge sharing platform can improve collaboration in BIM teams but cannot solve lack of guidelines and standards unless you have all the BIM manuals uploaded in this platform. It is important to create well-defined manuals in addition to setting up the infrastructure for a knowledge sharing platform.
    - A software community is a must solution to improve collaboration in BIM.
    - Lessons learned documentation is done during evaluation of some projects. Currently, this is not analysed and applied at organisational level but the people who know the mistakes tries to avoid them in the future projects. Capturing lessons learned at different stages of the project can be a good solution.
    - Optimised BIM meetings helps to educate client and create awareness among them with the BIM standards.
    - The process maps is clear. Level-2 is required to understand the process better. It summarises the requirements of ISO 19650 and this process maps

can be included in the post-BIM execution plan that we have for our projects. This can be helpful for the BIM managers to understand the process. But for the other roles in BIM teams, they will be a little bit confused.

- Interviewee-2: Yes, it could be a solution if the process is aligned with the company culture. A Standardised process can help people act early to think better and avoid errors in later stages.
  - A master BIM model can be practically hard to achieve as information is communicated outside the BIM models. It can be part of the design but cannot be linked to everything.
  - Creating knowledge sharing platform can be the next step after creating guidelines and standards. This can be setup at the project level and organisational level.
  - A software community can be helpful for the practitioners to solve another barrier from this research which is insufficient knowledge, skills and abilities. It can educate them with BIM.
  - Lessons learned documentation is not widely done because of different reasons: People change in the project, we always have the time pressure with deadlines, we are not used to document lessons learned and analyse it. Same teams who work on new projects know the problems and avoid the mistakes.
  - Involving client as soon as possible with BIM meetings can help improve collaboration in BIM teams.
  - First impression of the process map was not good. It is complex. It looks crowded. But after explanation, it was easy to understand the process. The process map makes the workflow clear and it would be nice to use it in the future projects. The process is already in the head of people but when it is presented in a visual diagram, it can help to unify the working methodology. This process map can be a starting point to educate BIM teams.

Appendix L: Transcripts of qualitative validation with Interviewee-3

Date: 23-June-21
Time: 09:30 – 10:30

Agenda

- Introduction
- Most critical barrier
- Possible strategies

Minutes

- Introduction:
  - Education: Master's in Structural Engineering
  - Experience with W+B: 14 years.
  - Experience with BIM: Design leader for 2 large infrastructure projects and group leader for BIM model development and coordination.
- Most critical barrier
  - Yes. This is observed especially at the start of the project. Everybody starts working at the start of the project and you need to get awarded. When that's done, guidelines are created for the project. It takes some time to create the guidelines and work processes.
- Possible strategies
  - Standardising the process by integrating best practices can be a good solution to avoid lack of guidelines and standards. This is a good start to provide a standardised way of working. This is beneficial for organisational working but not for all the projects as we collaborate with different companies and they have own way of working.
  - Creating the process according to ISO19650 with little best practices can be the highest level to standardise the process. I hope.
  - Software community is already established and there are already members in the group. There are very few people in these communities. But it is a good idea to encourage people during the project to join the groups.
  - Most of the times client is less experienced and having meetings with them cannot be beneficial in getting the required information. But discussing expectations and conveying the information can be a good thing to do in projects. And this has to be repeated once in a while is required.
  - The automation process can help to know what steps to take. Like a guideline.