Improving the BIM 5D implementation in an Organisation for Infrastructure Projects

By taking lessons from the Building Sector

Aishani Lotliker
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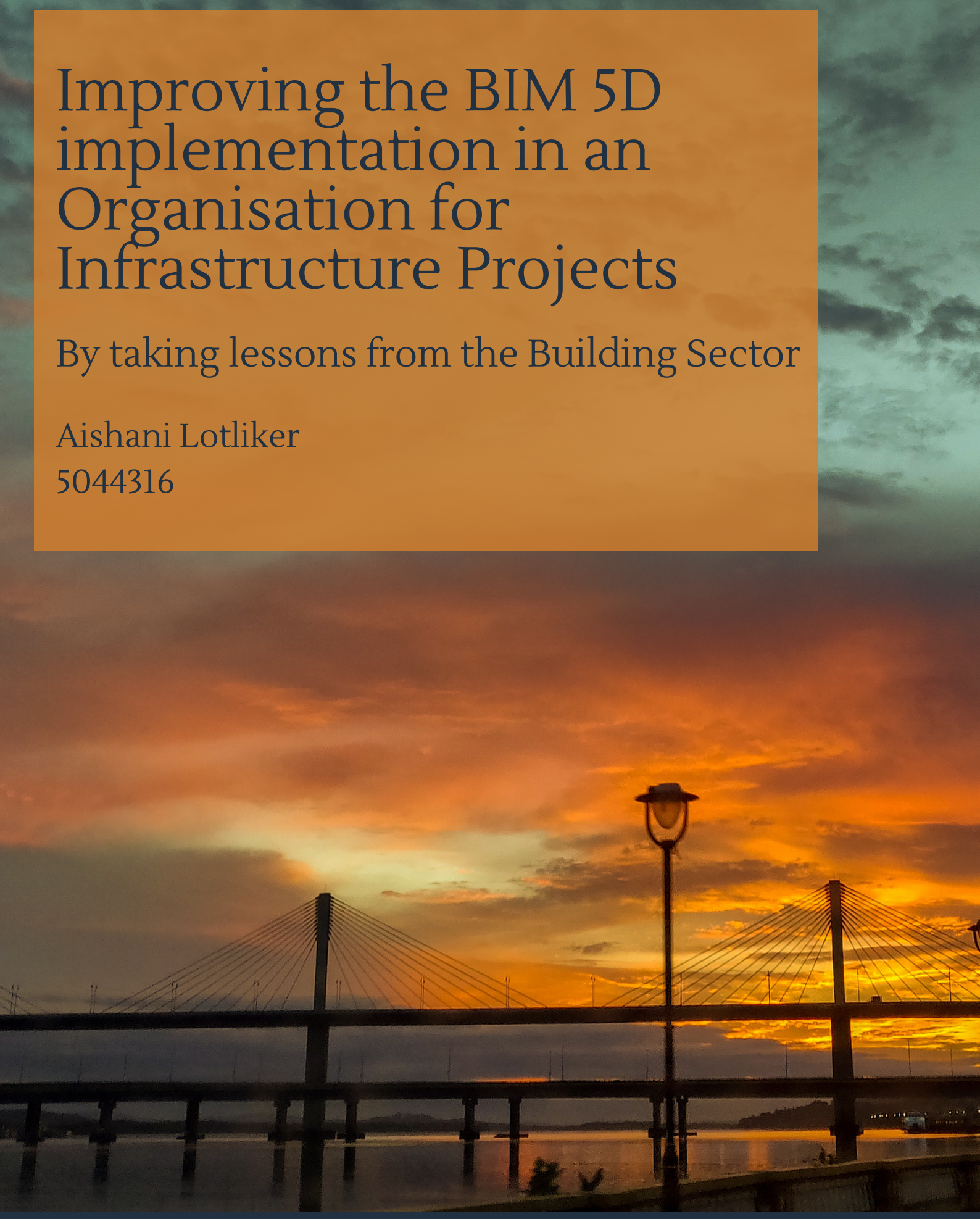

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IMPROVING THE BIM 5D IMPLEMENTATION IN AN ORGANISATION FOR INFRASTRUCTURE PROJECTS

BY TAKING LESSONS FROM THE BUILDING SECTOR

Masters Graduation Thesis Proposal

done for the fulfilment of the degree MSc in Construction Management and Engineering at Delft University of Technology

by

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PREFACE

Before you lies the Thesis "Enhancing BIM 5D implementation in Organisations for Infrastructure Projects", the basis of which is research conducted in Collaboration with Arcadis B.V. Amersfoort. I was engaged in researching and writing this thesis from February to August 2021. With this thesis, I conclude my Masters in Construction Management and Engineering at the Delft University of Technology.

This thesis wouldn't be complete without the support of my supervisor, Piet-Jan Schipper. I want to thank him for providing me with this opportunity to conduct my thesis in Arcadis and for all his efforts, like the constant inputs and motivation during the weekly meetings.

I want to thank my university supervisors for their excellent guidance and support during this process. First of all, I would like to thank my Chair, Prof. Dr. Paul W. Chan, for his musing insights, which pushed me to achieve better results. Secondly, my supervisor Ing. Ronald van Warmerdam, for his meticulous inputs, which helped me delve deeper into my thesis, and my second supervisor, Dr.Ir. Rob Stikkelman for his valuable comments during the progress meetings.

A special mention to the interviewees from Arcadis who took time out of their busy schedule to answer my questions and enlighten me with their knowledge and experience.

I would like to dedicate my thesis to my grandfather, Srikant Lotliker, who we lost due to COVID 19 in May. I wouldn't be here without his constant encouragement. And last but not least, I want to thank my parents, Vaikunth and Babita Lotliker, my sister Asmi Lotliker, my grandparents, Sarita Lotliker and Vandana Nagvekar, my aunt Dr Nandini Karekar and my uncle Rajiv Lotliker for their immense love and support, and my friends who stood by my side during the tough times and made being away from home a little less difficult.

I hope you enjoy reading my thesis!

Aishani Vaikunth Lotliker
Delft
August, 2021

ABSTRACT

Building Information Modelling (BIM) has significantly improved the efficiency of construction projects. Using BIM tools provides various opportunities for cost management professionals to improve their cost management services' quality, speed, accuracy, value, and sophistication. Despite these benefits, BIM implementation for infrastructure projects can be quite challenging as these projects are highly complex. Very few organizations (who deal with infrastructure) have implemented BIM higher than BIM 4D in their projects. Therefore, this study investigates the challenges organizations face while implementing BIM 5D for infrastructure projects and identifies ways to minimize these challenges and enhance the BIM 5D process. The research methodology for this research is based on a literature study and interviews conducted with experts from Arcadis. This thesis first explores the challenges faced by organizations while implementing BIM 5D for infrastructure projects. In addition, this thesis also looks into the steps the building sector took to enhance the BIM 5D implementation and how these steps can be fine-tuned to suit the infrastructure projects. Based on these two points, recommendations are created for organizations dealing with infrastructure projects to BIM 5D, depending on their role in the project. The results show that the project managers should be targeted first to promote the use of BIM 5D. The expertise of BIM front runners should be utilized in projects, and a standard BIM Execution Plan should be prepared and followed by involving both designers and cost managers. The BIM 5D processes also need to be tailored to suit the needs of specific (larger) clients.

Keywords: *BIM 5D, implementation, enhance, infrastructure, building, organisations, recommendations.*

EXECUTIVE SUMMARY

Introduction

In the last couple of years, digitisation has played an essential role in transforming and developing the construction industry [Chen and Luo, 2014]. Digitisation, namely Building Information Modeling (BIM), is considered one of the most promising developments in the construction industry [Bosch-Sijtsema et al., 2017]. BIM is changing the management approach to the work done in the Construction industry as a whole. The term BIM originated for buildings but is now slowly gaining popularity in the Infrastructure sector.

In this research, we focus on BIM 5D, i.e. adding the cost data to the 3D BIM model to calculate the project's total cost. Previous research has shown that the use of BIM 5D comes with significant added advantages like it helps fasten the decision-making process, increases the efficiency within the organisations, improves collaboration between the various parties and departments within an organisation [(Yan and Damian, 2008), (Mesároš and Mandičák, 2017)]. But despite the advantages, BIM 5D can be quite challenging due to numerous obstacles like the lack of standardisation, high time/cost investment and the fragmented nature of the construction industry. The challenges identified in previous literature are, however, limited to the building sector. Infrastructure projects are vast, unique and complex and thus face different challenges compared when to buildings. For organisations to successfully implement BIM 5D for infrastructure projects, they first need to understand the challenges thoroughly, check the impact of the challenges on the organisation's working, and what changes are required to minimise the effects of these challenges.

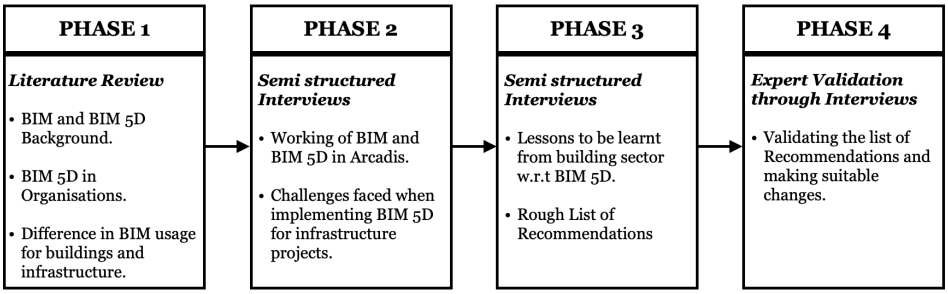
Hence, we arrive at the problem definition *BIM 5D in infrastructure projects slow-moving due to the presence of numerous challenges, while the building sector has managed to achieve the benefits of it. Additionally, the work processes in the organisations need to be suitably adjusted to account for BIM 5D.* From the problem definition, we arrive at the main question of this research. The main question is further divided into six sub-questions.

What are the obstacles faced by organisations while implementing BIM 5D for infrastructure projects?
What changes need to be introduced to improve the use of BIM 5D for infrastructure projects in the future?

Method

The research methodology adopted to answer this question is a Qualitative Research

Methodology, and the research was divided into 4 Phases. The research methods used were literature study and semi-structured interviews.



Phase 1 consists of a literature study. The research base is established in this phase by defining BIM, BIM 5D - benefits and drawbacks, the problems encountered while implementing BIM 5D specifically by organisations, the management strategies to enhance BIM 5D in organisations categorised according to the organisation's role. Further, the research also looked into the difference in BIM usage in Buildings and Infrastructure and why the Building sector has been more successful in BIM implementation than infrastructure. The four elements of BIM described by Bradley et al., 2016: Process, Representation, Collaboration and Life-Cycle are used to structure the challenges and the outcomes of the recommendations to make it easier for organisations to decide which aspect they would like to focus on. The next three phases, Phase 2, 3 and 4, consists of semi-structured interviews. Phase 2 interviews were conducted with three focus groups: BIM experts, Cost Managers with BIM experience and Cost Managers with no BIM experience, all from the infrastructure industry. The main aim of this phase is to understand the working of the different departments in Arcadis concerning Costing and BIM. The data gathered in this phase is related to the working in the organisation before and after the application of BIM 5D, the details of the BIM and BIM 5D softwares the company uses and the challenges they faced while transitioning from traditional costing practice to BIM 5D for the infrastructure department. Phase 3 interviews were conducted with BIM Experts and Cost Managers from the building department. The point of focus in this stage was to understand the steps taken by the building department to enhance BIM 5D and the favorability of the building department over the infrastructure w.r.t BIM 5D. From these points, the researcher created a list of lessons to suit the infrastructure department and improvement points for both the departments.

The list of recommendations for organisations dealing with infrastructure to enhance BIM 5D was created from the previous phases' data. These recommendations are divided according to the role of the organisation: Consultants, Clients and Contractors. In Phase 4, these recommendations are validated by experts from Arcadis. After validation of the results, suitable changes are made to arrive at the final result.

Findings
this research aimed to identify ways for Arcadis and organisations in general to increase their BIM Maturity. As mentioned earlier, the first step is to identify the challenges faced. In this thesis, seven additional challenges faced by infrastructure projects while implementing BIM 5D were identified. These arise due to insufficient information in the 3D model (ground conditions and distinct object separation) and the lack of object libraries. Another challenge detected in this thesis, which organisations face, is hesitance to give up old technology. For large organisations, it is impossible to shift to 5D based costing directly. The shift takes place in phases. Sometimes, one of the intermediate phases is assumed to be BIM 5D, restricting the progress.

The other findings which can help organisations enhance their BIM 5D implementation include:

- The BIM Execution Plan (BEP) needs to be prepared at the start of the project by combined efforts from designers and cost-managers to agree upon the BIM 5D process and type of information to be fed into the 3D model for accurate cost estimation.
- Sufficient BIM front runners need to be assigned in the organisation to help with knowledge transfer in projects.
- The benefits to BIM 5D should be popularised in the organisation to promote its use. This needs to start with the project managers as they are in charge of making the major decisions in a project.
- To make the clients more accepting of BIM 5D, the organisations need to fine-tune the BIM process to suit the client requirements. This method has been proven effective by the energy department in Arcadis. But this is only possible for large clients.
- The starting point when it comes to BIM 5D implementation is having good cost libraries in the BIM 5D software.
- For Arcadis, improving the collaboration between the regional Arcadis offices and the GEC will help improve the BIM 5D processes as the GEC has BIM expertise.

Limitations and Future Recommendations
Although significant efforts were made to ensure that the research is being conducted thoroughly, it has a few limitations. The first limitation is that there is scarce literature present on the implementation of BIM 5D in organisations. The management strategies used to make the recommendations is based on the findings of one paper. If more literature were available on this topic, then the management strategies according to the role of the organisation would have been explained more elaborately. Secondly, the data was gathered from one organisation, Arcadis, which is a consultants firm. The recommendations for the organisations are made on the assumption that they face similar challenges as those detected in this thesis. Moreover, the recommendations were validated only with experts from Arcadis. For better results, it is beneficial to investigate with a broader

set of organisations. Thirdly, in Arcadis, BIM 5D has been implemented on two types of infrastructures. Thus Bridges and the challenges identified in Phase 2 of the research are limited.

Recommendations for further research have been stated to overcome the limitations stated for this research. Researchers in the future can look to validate if other organisations face the same type of challenges identified in this research and thereby validate whether the recommendations stated are suitable or not. Since a significant portion of the cost for infrastructure projects is based on its schedule, it will be beneficial if more research is done to automate the BIM 4D and 5D processes together. Lastly, it is also seen that some departments still struggle with BIM 3D, as the projects are mainly geography-based. Such departments should focus on creating an up to par 3D model as the high quality of the 3D model is crucial for creating an accurate BIM 5D estimate.

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ABBREVIATIONS

- **BIM :** Building Information Modelling.
- **GDP :** Gross Domestic Product.
- **LOD :** Level of Detail.
- **BOQ :** Bill of Quantities.
- **CAD :** Computer-aided Design.
- **GIS :** Geographic Information System.
- **FTE :** Full-Time Equivalent.
- **BEP :** BIM Execution Plan.
- **GEC :** Global Excellence Centres.
- **COP :** Communities of Practice.

1

INTRODUCTION

This chapter, i.e. the first chapter of the report, shows an overview of the Research Introduction. It starts with the Research Context, the Research Focus, Problem Definition, followed by the Research Goal and the Research Gap from which we arrive at the Research Questions. Subsequently, the Qualitative Research Technique and the methods of Data Gathering followed for the thesis are explained. Finally, the Guide is described in the end, i.e. brief description of the contents of the future chapters. A preliminary literature review is conducted to identify and establish the problem and the gap before diving into the main part of the thesis.

1.1. RESEARCH CONTEXT

The Construction Industry, the building sector and the infrastructure sector is one of the major industries in the world and plays a critical role in determining the strength or weakness of the economy. The European construction sector output is 1.3 trillion Euros, and it makes up around 9 per cent of the European GDP [“Handbook for BIM European Public Sector ”, 2017]. Yet, it suffers from low productivity and low efficiency (time and cost) [Hasan and Rasheed, 2019]. Due to the increasing complexity and the tight budget and schedule requirements, the management of construction projects is getting more challenging [Gunduz and Yahya, 2018]. What exacerbates the situation is the lack of availability of real-time data, hampering the effective information exchange, in turn, the collaboration between the various parties [Xu, 2017]. This has led to the adaptation of digital systems, called BIM. BIM improves the efficiency of the projects (in terms of time and cost, without compromising the quality) and the coordination and communication between project team members and the stakeholders involved throughout the life-cycle of the project [M. Subhi and Dr. R. N. Uma, 2017].

In the last couple of years, digitisation has played an important role in transforming and developing the construction industry [Chen and Luo, 2014]. Digitisation, namely Building Information Modeling (BIM), is considered one of the most promising developments

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in the construction industry [Bosch-Sijtsema et al., 2017]. The US National Building Information Model Standard Project Committee defines "Building Information Modeling (BIM) as a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition" [“National BIM Standard - United States”, 2014]. The BIM model enables contractors and project managers to see the detailed components of the asset like their material, dimensions and other design parameters [Wang and Chien, 2014]. It helps in reducing errors and omissions,improves collaboration between the various parties and enables constructability, process integration and clash detection [(Smits et al., 2017), (Olugboyega et al., 2019)].

The construction sector in Europe is starting to adapt to the use of BIM in the management of projects. To promote the use of BIM in the EU, a BIM Task Group is established [“Handbook for BIM European Public Sector ”, 2017]. Governments of various countries like Denmark, France and Poland have introduced different policies to encourage the use of BIM [European Construction Sector Observatory, 2019].

Initially, BIM was mainly used as a tool in the pre-construction phase of the project. But now, BIM can be used throughout the life cycle of the project. Apart from 3D modelling, BIM is starting to gain popularity in the industry for Time Management (4D), Cost Estimation (5D), Sustainability Assessment (6D) and Facility Management (7D). The amount of popularity depends on the sector; it is way more advanced for buildings than infrastructure. In the figure below, figure 1.1 you can see the various tasks of BIM corresponding to the phases.

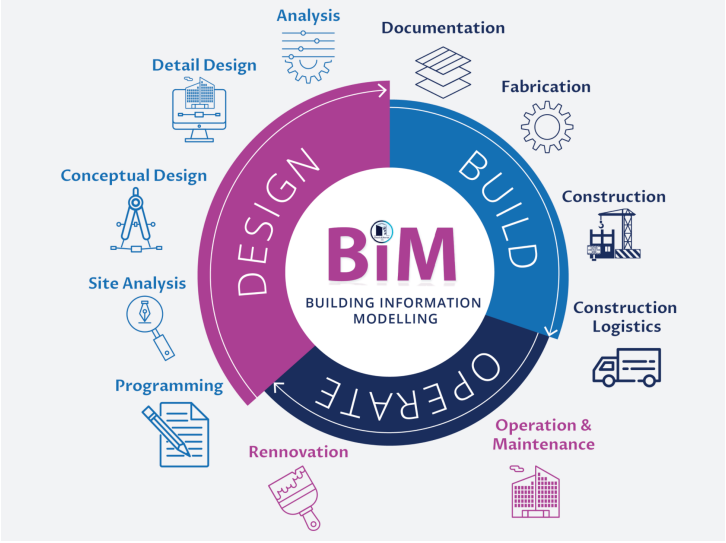

Figure 1.1: Various uses of BIM [Derrick Steven Design, 2020]

1.2. RESEARCH FOCUS

Traditional costing methods involve estimating material, labour and equipment quantities using a spreadsheet. The materials are derived from drawings, or more recently, using AutoCAD. The traditional costing methods are extensive and time-consuming as the costing begins only once the preliminary design is complete. Besides, this process is also susceptible to human error and, therefore, inaccuracies [Nigam et al., 2016]. In comparison to the traditional costing methods, BIM 5D offers various competitive advantages to accept the new age approach to cost management, as a result of which it is becoming increasingly popular [Wang and Chien, 2014].

Previous research has shown that the use of BIM 5D comes with great added advantages. One of the advantages offered by BIM 5D is that it enables faster decision-making, thus increasing efficiency within the organisation. It has been quite successful during coordinated project delivery for both building and infrastructure projects [Vass and Gustavsson, 2015]. BIM 5D improves collaboration between the various parties and departments within an organisation, which saves time and costs in turn boots productivity [(Yan and Damian, 2008), (Mesároš and Mandičák, 2017), (Alrashed and Kantamaneni, 2018)].

A key area where BIM has provided a tremendous advantage is the automated quantity take-off from the 3D model [(Wang and Chien, 2014), (Kehily et al., 2017)]. This automated quantity take-off is called BIM 5D - linking and extracting data from the 3D model and combining it with cost data in a database (which includes market conditions, time-cost factors, location risks etc.) to create an effective cost estimate [Mitchell, 2012]. Moses et al., 2020 has stated that to have a good cost estimate, the model must be of a certain maturity and level of detail. Thus, to have a good BIM 5D implementation, an organisation needs to have a strong BIM 3D or, in general, a good BIM base. To successfully implement BIM 5D, organisations need to have good costing software, object libraries (containing information like material, labour requirement, cost, sustainability etc., of an object) and extensive cost-related data. But apart from this, they also need to have a strong BIM network, an information loaded 3D model, good collaboration between the various departments, and standard procedures. This is the focus of this research.

1.3. PROBLEM DEFINITION

BIM 5D can be quite challenging due to the presence of numerous obstacles. The obstacles faced while implementing BIM 5D are mainly due to the following reasons. One reason is due to the lack of standardisation [Poljanšek, 2017]. The norms applicable to a project vary depending on the location and the type of the project [(Ademci and Gundes, 2018), (Georgiadou, 2019)]. The presence of multiple software and their incompatibility increase the complexity when multiple parties work together [(Georgiadou, 2019), (Hasan and Rasheed, 2019), (Stanley and Thurnell, 2014)]. Second, it is due to the time and cost required for the initial instalment of the software are quite high [Huang, 2018]. Since a larger amount of time is required to train the personnel, it creates a shortage of skilled personnel [(Stanley and Thurnell, 2014), (Yao et al., 2020), (Georgiadou, 2019)]. Next, the fragmented nature of the construction industry prevents a smooth workflow

preventing an effective BIM 5D implementation [(Ademci and Gundes, 2018), (Stanley and Thurnell, 2014)]. The collaboration between the different domains in the construction industry is low due to the current work. Using BIM will help eliminate this obstacle, as BIM promotes collaboration between the different departments.

The work practises and processes in an organisation need to be suitably adjusted to tackle the challenges and achieve the full benefits of BIM 5D. [(Sanchez et al., 2016), (Lindblad and Vass, 2015)]. As organisations keep learning about the challenges they face, it gets easier for them to eliminate them by making changes in the work processes. The challenges identified above are, however, limited to the building sector. Infrastructure projects, airports, bridges, distribution systems etc., being vast, unique and complex, face different challenges compared to buildings. So for organisations to successfully implement BIM 5D for infrastructure projects, they first need to thoroughly understand the challenges they face. And second, see how these challenges impact the working in the organisation and the changes required to minimise the impact of these challenges. Due to this, very few infrastructure projects have implemented BIM dimensions above 4D into their projects, despite the availability of numerous BIM 5D softwares [Forgues et al., 2012].

Hence, we arrive at the problem definition *BIM 5D in infrastructure projects slow-moving due to the presence of numerous challenges, while the building sector has managed to achieve the benefits of it. Additionally, the work processes in the organisations need to be suitably adjusted to account for BIM 5D.*

1.4. RESEARCH GAP

Previous research done on BIM applications in the construction industry is vast, but various gaps exist since the adoption of BIM into the infrastructure industry is relatively new. The preliminary literature review helped to point out the research gaps aimed to be filled with the help of this research.

Although there are various research papers published about the benefits and challenges of implementing BIM 5D they either deal with the Construction Industry in general (Hasan and Rasheed, 2019), (Sattineni and Macdonald, 2014), (Ghazaryan, 2019)] or from the perspective of the Quantity Surveyor/Cost Consultant [(Stanley and Thurnell, 2014), (Thurairajah and Goucher Bsc, 2013), (Mayouf et al., 2019)]. No research has been done to study the challenges faced by organisations while dealing with BIM 5D for Infrastructure.

Another major research gap aimed to be filled with the help of this research is the recommendations the building sector can provide to the Infrastructure for the BIM implementation as BIM implementation is more mature in that industry. Costin et al., 2018 states that BIM has managed to bring about a boost in the building industry, from life cycle management, project delivery, and technological advancements. This research aims to expand this knowledge of BIM into the infrastructure industry. The infrastructure industry can utilise all of the benefits while learning and improving the challenges and shortcomings of the building industry. Besides, the successes realised in the building

industry can encourage stakeholders in Infrastructure to invest in BIM in the future.

A couple of recommendations have been made by the previous years' masters thesis. Kharoubi, 2019 recommended investigating the cultural and managerial challenges which hamper BIM 5D in project teams and how they can be minimised. Exel, 2020 has recommended investigating the factors that are withholding the Dutch organisations from using BIM.

1.5. RESEARCH QUESTIONS

What are the obstacles faced by organisations while implementing BIM 5D for infrastructure projects?
What changes need to be introduced to improve the use of BIM 5D for infrastructure projects in the future?

Figure 1.2: Main Research Question

The problem definition and research gap serve as a basis for the main question. It is stated in these sections that even though BIM 5D has several benefits, it has not been fully implemented for infrastructure projects in organisations. This thesis first detects the challenges organisations face while implementing BIM 5D for Infrastructure and then worked towards finding ways to eliminate these challenges for a successful BIM 5D execution.
The main research question is divided into six sub-questions to help guide the research in a structured way. The literature review helps answer Sub-question 1. It helps identify the challenges organisations face while implementing BIM 5D and why BIM 5D is limited in the organisation. Sub-question 2 helps understand the working of BIM within the different departments in Arcadis. Sub-question 3 helps identify the problems faced by the organisation while using BIM 5D for their pilot projects. These challenges are compared to the organisational challenges found in the literature and see how similar or unique they are. Sub-question 4 and Sub-question 5 provide answers to how the building sector has successfully implemented BIM and the lessons the Infrastructure can learn from them. They also help in making the final recommendations. Furthermore, finally, Sub-question 6 states the recommendations for an improved BIM 5D implementation. These recommendations are prepared from the data gathered while answering the previous five sub-questions.

1.6. RESEARCH GOAL

This thesis research is carried out with the support of the Energy and Technology department in Arcadis. Arcadis BV is one of the leading design, engineering and management consulting companies based in the Netherlands. Arcadis has implemented BIM 5D only recently, and its benefits are quite evident in the few projects where it is applied. Nevertheless, even though it has several benefits to offer, BIM 5D implementation takes a long

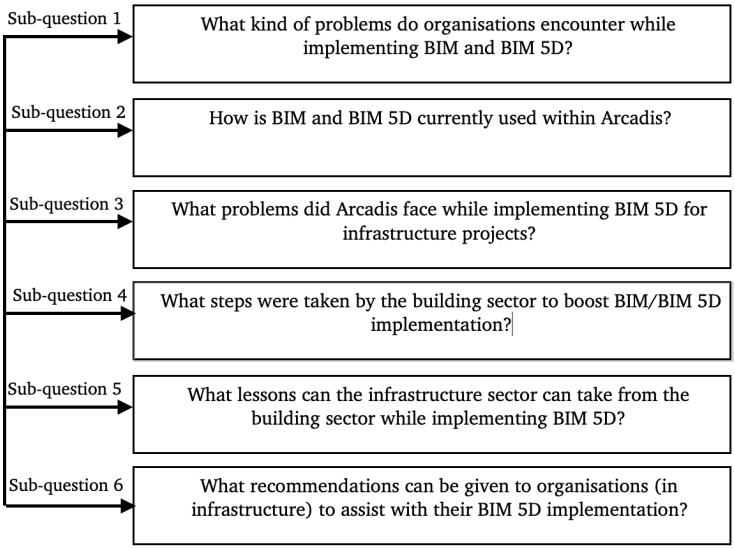

Figure 1.3: Sub-questions to the main question

time as there are various challenges. They have to be minimised or eliminated to achieve a successful BIM 5D implementation. For the research, the challenges faced were understood and analysed to create recommendations that help the organisation improve BIM 5D within the organisation. The recommendations are specific to Arcadis. After making suitable assumptions, they are made more general.

This research primarily focuses on how organisations can improve their implementation of BIM 5D, i.e. implementing BIM for calculating cost estimates and quantity takes offs [Matejka and Vitasek, 2018] for infrastructure projects. These recommendations created at the end of the research help organisations reap the maximum benefits the technology offers. First, the Literature study helps the working of BIM in an organisation, understand the challenges faced while implementing BIM 5D in organisations and get in-depth information on how the usage of BIM differs for the Building sector and Infrastructure. Second, the interviews conducted help understand the challenges faced by Arcadis and learn the steps taken by the building department, which helped them with the BIM 5D implementation. By taking these 2 points into consideration, the recommendations are created. Experts from Arcadis validated the recommendations at the end of the research.

1.7. QUALITATIVE RESEARCH TECHNIQUE

This research study is conducted to develop a set of recommendations and guidelines for Arcadis and other organisations, which help them implement BIM 5D in a better way so

that the benefits are realised. It is a qualitative analysis. Qualitative research comprises non-numerical collection and analysis of data. For example, a qualitative researcher gathers data by studying case studies, conducting interviews, studying literature, etc. The data collected is then analysed to gain in-depth insights into a problem or generate new ideas for research [Richards and Morse, 2013].

The qualitative research methods used for the thesis are literature study and conducting interviews through focus groups.

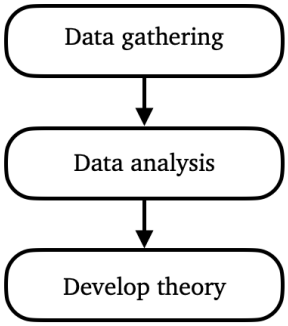

Figure 1.4: Research strategy

The Qualitative Method has several limitations:

- Since the research is open-ended, it is not possible to verify the results.
- The observations made are subjective to the experiences of the interviewee.
- The data cannot be represented statistically [Richards and Morse, 2013].

Measures that need to be taken to minimise or eliminate the above limitations are be stated in Chapter 8 once the complete analysis is explained. (Refer to Chapter 8.) Apart from the given limitations, it is the most suited approach for the given topic.

1.8. DATA GATHERING - 4 PHASES

The research is conducted in 4 phases and follows a combination of a literature study and an interview method. See figure 1.5.

Phase 1, is the starting point of this research. Phase 1 answers sub-question 1. An extensive literature study helps attain in-depth information about:

- BIM and its various dimensions.
- The benefits and problems encountered while implementing BIM 5D.

- General information regarding BIM 5D implementation in organisations and management strategies.
- The difference in the application of BIM usage in Building and Infrastructure.
- Reasons why the Building sector has been more successful in BIM implementation when compared to infrastructure.

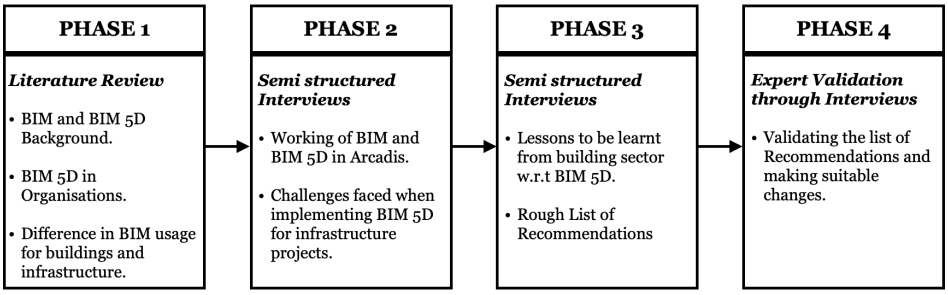

Figure 1.5: Research Methodology in Phases

After conducting the literature study and gathering relevant data, several interviews are scheduled with the BIM and BIM 5D experts from both the infrastructure and the building sector. The interviewees are divided into Focus Groups based on their expertise. This is Phase 2 and Phase 3 of the research. Phase 1, the literature survey, is used to create the questionnaire for the interviews for the next two phases. The questionnaire varies for every focus group.

Phase 2 consists of semi-structured interviews. Phase 2 has three focus groups: BIM experts, Cost Managers with BIM experience and Cost Managers with no BIM experience, all from the infrastructure industry. Phase 2 provides answers to sub-question 2 and sub-question 3. The main aim of this phase is to understand the working of the different departments in Arcadis concerning Costing and BIM. The main aim of conducting these interviews is to find out:

- The details of the BIM software the company uses.
- The working of BIM, before the application of BIM 5D.
- The working of current costing method with BIM 5D within Arcadis, in the infrastructure department.
- The challenges they faced while transitioning from traditional costing practice to BIM 5D for the infrastructure department.

Phase 3 also consists of semi-structured interviews. In Phase 3 BIM Experts and Cost Managers with BIM experience, from the building industry, were interviewed. Phase 3 provides answers to sub-question 4 and sub-question 5. The aim of this Phase is to understand:

- The measures which the Building department has taken to implement BIM successfully.
- How can the steps taken by the Building department be fine-tuned to suit the infrastructure department?

In **Phase 4**, the researcher validates the results obtained at the end of Phase 3 with experts from Arcadis. After validation the results, suitable changes are made to arrive at the final result, i.e. How Arcadis and the infrastructure industry, in general, can improve the BIM 5D implementation.

1.9. THESIS GUIDE

The following is the outline of this Thesis Report. It is going to consist of 9 main chapters:

1. **Introduction**
   Chapter 1 contains an overview of the thesis, including an introduction to the topic, problem statement, the research gap research relevance, the research questions and the research methodology followed.

2. **Research Methodology - Interviews**
   Chapter 2 contains the methodology used to conduct the interviews, which is the main source of data gathering for the thesis. It also consists of the interview selection, interview protocol, data analysis and expert validation. The focus groups for the 2 phases of the interviews, i.e. Phase 2 and Phase 3, are mentioned in this chapter.

3. **Theoretical Background**
   Chapter 3 introduces in detail the various topics covered in this research (BIM, BIM 5D). This chapter also contains the benefits and challenges of using BIM 5D, the things that needed to be considered to implement BIM 5D in organisations, the challenges faced while implementing BIM 5D in organisations, and the difference in BIM implementation between buildings and infrastructure. The chapter ends with a conclusion of the findings.

4. **Phase 2 - Research Outcomes**
   Chapter 4 contains the research outcomes, the data gathered from the interview, in Phase 2 . This chapter answers sub-questions 2 and 3. In this chapter the working of the infrastructure department in the organisation and the challenges they faced while implementing BIM 5D for their pilot projects are described. After this, an analysis of the challenges is performed to point out the prominent challenges in

each focus group and with this understand the reason behind the opinion of a particular interviewee.

5. **Phase 3 - Research Outcomes**
   Chapter 5 contains the research outcomes, the data gathered from the interview, in Phase 3 . This chapter answers sub-questions 4 and 5. This this chapter we look into the favourable conditions that has lead to a high BIM maturity in building industry, the steps the building industry took to enhance the BIM 5D implementation, its lessons to the infrastructure department and point of improvements for both the departments to enhance organisational BIM maturity.

6. **Results - Recommendations for Organisations**
   In Chapter 6 the results obtained from the literature study and by conducting the interviews are analysed. Based on this analysis, recommendations/instructions for future improvements are provided for the organisations, depending on their role: Consultant, Client and Contractor. The reasons for suggesting these recommendations and the challenges they eliminate are explained.

7. **Phase 4 - Validation of Recommendations**
   In Chapter 7 the results obtained are validated by conducting interviews with the research committee and several project managers.

8. **Discussion and Limitations**
   Chapter 8 contains the discussion of the practical and scientific findings and the shortcomings of this research. The shortcomings are highlighted and used to make recommendations for future research mentioned in the next chapter.

9. **Conclusion and Future Recommendations**
   Chapter 9 contains the conclusion of this research; the answers to the sub-questions and the main question of the research. Based on these answers, recommendations are made for future research.

2

RESEARCH METHODOLOGY

With the help of a preliminary literature review, the problem definition was stated, the research gaps were identified, and the research questions are formulated. With this, it is seen that the literature available for BIM 5D for infrastructure is a bit inadequate. The availability of research papers on the leanings for infrastructure from the building is also limited. Hence, it is essential to gather data from an organisation that has already implemented BIM 5D for infrastructure and whose building department has a high BIM maturity. Thus, apart from a literature methodology, an interview methodology is adopted for this research; the interviews are the primary data gathering and validation source.

A Qualitative Research Methodology is adopted for this research. The research methodology for Phases 2, 3 and 4, all of which consists of interviews (Refer to figure 1.8), is explained in this chapter. A research methodology is a plan mapped out by the researcher to either find the problem or the solution for a problem [Jamshed, 2014]. The research methodology for this thesis consists of the interview selection, interview protocol, data analysis and data validation. A semi-structured interview approach is adopted. Semi-structured interviews are built according to a guide, interview protocol, which contains a set of questions created by keeping in mind the end topic of research [Jamshed, 2014].

2.1. INTERVIEW SELECTION

As mentioned earlier, the interviewees are the main source of data, and the thesis mainly depends on their experience in BIM/BIM 5D, their outputs and suggestions. Hence, it was quite important to select the interviewees tactfully. The interviewees were selected based on their current role in the organisation and not their total years of experience as BIM 5D is relatively new in the organisation.

The first set of contacts were received from the Energy and Technology department in the organisation. The department was briefed on the research topic and was asked to

suggest interviewees who suit the profile. A post was circulated on Linked-In and Yammer(the Arcadis social networking website), from which the list of the interviewees extended. The interviewees were asked to suggest a few more interviewees based on their roles. The interviewees were mainly from Arcadis Netherlands and a few from the Arcadis United Kingdom and the Arcadis Global Excellence Centers, also known as the GEC, in Romania. Based on their background, the contacts received were placed in specific groups in either phase 2 or 3.

2.1.1. PHASE 2

In Phase 2, 13 people were interviewed, and there were three focus groups:- BIM experts, Cost Managers with BIM 5D experience and Cost Managers without BIM 5D experience. They were all from the infrastructure background as the main aim of Phase 2 is to understand the challenges faced in implementing BIM 5D for infrastructure projects. The names and background are given below:

	INTERVIEWEE NAME	ROLE IN ORGANISATION
1.1	Julian Spierings	BIM Ambassador - Infrastructure
1.2	Bull Garth	BIM Ambassador - Water Infrastructure
1.3	Piet-Jan Schipper	BIM Consultant - Energy Infrastructure
1.4	Gertjan van Drunen	BIM Consultant - Energy Infrastructure
1.5	Jurgen Haitsma	Leader for Digital transformation in Arcadis Netherlands
1.6	Machiel Groenevelt	BIM Ambassador - Tram and Heavy Rail

Figure 2.1: Phase 2 Interviewees - Focus Group 1

	INTERVIEWEE NAME	ROLE IN ORGANISATION
2.1	Cronje Pieter	Cost Estimator, Quantity Surveyors (Cost X model)
2.2	Edwin van der Knoop	Cost Manager (Cost X model)
2.3	Ruan Pronk	Cost Manager (Cost + model)
2.4	Mark van Zeist	Cost Manager (Cost X model)

Figure 2.2: Phase 2 Interviewees - Focus Group 2

	INTERVIEWEE NAME	ROLE IN ORGANISATION
3.1	Paul van Wee	Cost Engineer Infrastructure
3.2	Marteen Jansen	Cost Manager for Infrastructure Projects

Figure 2.3: Phase 2 Interviewees - Focus Group 3

Apart from these three focus groups, an additional interview was conducted with the

Business Line Leader for GEC in Romania (2.A) to understand better how the GEC works and functions and how they collaborate with the regional offices and the challenges they face. This helped the researcher gain a better understanding of the working of the organisation.

2.1.2. PHASE 3

In Phase 3, 6 people were interviewed from the building department. The main aim of Phase 3 is to understand what steps the building department took to implement BIM 5D to a higher maturity and what lessons can the infrastructure department learn from the building department. The names and background are given below:

	INTERVIEWEE NAME	ROLE IN ORGANISATION
4.1	Sander van Gemert	Cost Management Ambassador for buildings
4.2	Hans van Voornhoven	Cost Management Ambassador for buildings
4.3	Bram Tegels	Senior BIM Consultant
4.4	Tom Borst	Senior Design Engineer
4.5	Hannah Marie Bermudez	Architect at GEC Manila
4.6	Jan Zandbergen	Junior Consultant for 6D BIM

Figure 2.4: Phase 3 Interviewees

2.1.3. PHASE 4

For Phase 4, validation interviews, the interviewees were a mix from the building sector and infrastructure background as it is best to have inputs from people working in both sectors. They are the same people from the previous 2 phases. The names and background are given below:

	INTERVIEWEE NAME	ROLE IN ORGANISATION
V.1	Machiel Groenevelt	BIM Ambassador - Tram and Heavy Rail
V.2	Jurgen Haitsma	Leader for Digital transformation in Arcadis Netherlands
V.3	Mark van Zeist	Cost Manager (Cost X model)

Figure 2.5: Validation Interviewees

2.2. INTERVIEW PROTOCOL

An interview protocol consists of the script the interviewer says before the interview, a list of interview questions asked during the interview and the script to say at the end while concluding the interview. It helps the qualitative researcher, interviewer by acting

as a guide to help direct the interview process [Jacob and Furgerson, 2012].

The interviews were scheduled on Microsoft teams, as the current conditions do not allow us to meet in person. The duration of the interviews was approximately one hour. All the interviews were conducted in English. To be fully focused on the conversation, the interviewees were asked for permission to record the interviews. The recorded interviews help for future reference. The interview questions were sent to the interviewees a week in advance while scheduling the interviews to help them prepare for interviews.

The interview started by asking the interviewee about their general work experience, work experience in the company, and job description. After this, the interviewer describes the research goal to the interviewee. The questions which were asked for research are divided into the Phase in which they are asked. The questions can be found in Appendix B. The interview questions were focused on the four main aspects of BIM, shown in figure 3.1.

At the end of these interviews, the interviewee is again reminded of the research goal and asked to give any additional points they feel have been missed during the interview or points they feel will help with the research. The interview can also involve questions that are not stated in the interview protocol. This interview protocol is prepared after reading and understanding relevant literature and is updated when required. Additional questions were asked to clarify or justify the points made by the previous interviewees.

2.3. DATA ANALYSIS

The data collected from the literature research, Phase 1, and interviews, Phase 2 and Phase 3, is analysed. The summaries of the interview are given in Appendix C. For Phase 2, the barriers identified by all the interviewees are noted and compared with the barriers found in the literature to find whether the struggles faced are similar or are there any struggles specific to the organisation or type of structure. After this, the challenges are ranked according to most faced till least faced by the organisation. For Phase 3 (Refer to figure 1.8), the interviews are aimed at finding ways to eliminate the challenges faced. After the Phase 3 interviews, a list of recommendations is prepared. The list also shows which challenges are critical to eliminating to achieve a successful BIM implementation.

2.4. VALIDATION

A list of recommendations is prepared to help the organisation with its BIM implementation. This result obtained is validated by conducting validation interviews with the experts in Arcadis. The interviewees for validation are selected based on their role and the information they provided in the previous interviews. After this, a final list of recommendations is prepared, which is the final result. The validation interviews are the last Phase of the thesis, Phase 4 (Refer to figure 1.8).

3

PHASE 1 - THEORETICAL BACKGROUND

This chapter consists of the theoretical background, which helps lay the foundation of the research. The contents of this chapter are the findings from the literature. This chapter deals with the first phase of the research, as shown in Chapter 1 - figure 1.5. The first section of this chapter consists of a general BIM overview: the BIM background and BIM use. In the second section, we dive into the fifth dimension of BIM, i.e. BIM 5D: its usage and the benefits of implementing BIM 5D. The third section deals with BIM 5D in organisations, i.e. the challenges faced while implementing BIM 5D in organisations and what management strategies need to be applied for a successful BIM 5D implementation. In the fourth section, we see how BIM varies between the building sector and the infrastructure sector. And finally, the last section is a conclusion of all the findings of the literature review. This chapter provides the answer to sub-question 1: *What kind of problems do organisations encounter while implementing BIM and BIM 5D?*.

3.1. BIM - DEFINITION

A Building Information Model portrays the actual built- facility in a digital format [Ford et al., 1995]. It consists of a three-dimensional geometry of the building components, with information attached to it, as the physical properties and functionality [Migilinskas et al., 2013]. The BIM model depicts the relationship between the various components of the built facility [Borrmann et al., 2018]. BIM also contains functional information of the elements like labour hours, cost, Co2 emission etc. Combining the information from different domains into an object library requires a collaborative approach that allows integration of various areas of construction [Lu et al., 2013]. The digital representation of the physical and functional elements of the built facility aids in decision making throughout the life-cycle of the project [Nowak et al., 2016]. The common aspect about the BIM explanations given above is that the BIM concept consists of four key elements: Process, Representation, Collaboration and Life-cycle [Bradley et al., 2016].

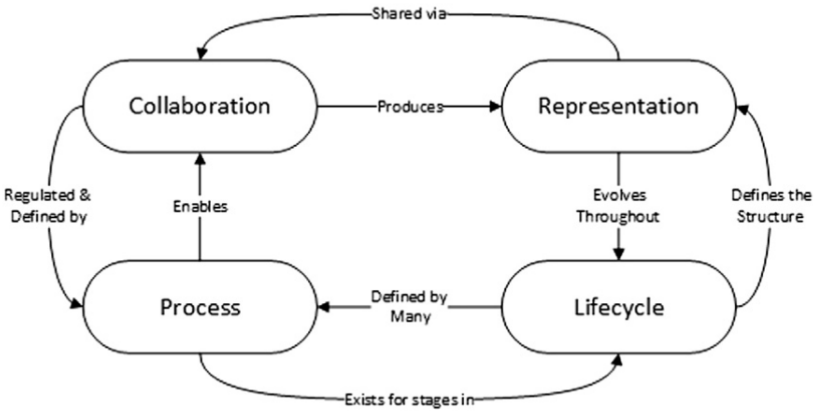

Figure 3.1: Key elements of BIM [Bradley et al., 2016].

Process deals with designing a BIM procedure, understanding the working of BIM, following a standard process, having the right software and knowing the dependencies between the tasks and which parties are involved at which phase [Kurul et al., 2013]. **Representation** deals with the depiction of a structure in the different models (3D, 4D, 5D etc.), the use of the objects in the model to depict the real-life, the relation between objects, the amount and type of information present in these object libraries [Alexander Koutamanis, 2019]. Apart from the physical representation, the model also needs to contain the functional elements to enhance the decision-making [Bradley et al., 2016]. **Collaboration** deals with information sharing with the different parties involved, not only outside the department but within the department, the tools and that strategies need to be implemented to promote communication between the teams and the development of a common data-sharing platform [Homayouni et al., 2010]. **Life-cycle** deals with the use of BIM in the different phases of the project life-cycle and the type of information required in each phase [Eadie et al., 2013]. Quality interaction between these four elements is essential to design an efficient BIM project environment [Bradley et al., 2016].

BIM DIMENSIONS, MATURITY AND LEVEL OF DETAIL

In this sub-section, the term BIM will be explained using - The BIM dimensions, BIM Maturity and BIM Level of Detail, to get a better understanding of BIM.

Previously, BIM was only used in the industry as an instrument to help with visualisation, BIM 3D model. Nowadays, the usage of BIM has evolved into a process to improve the entire life cycle of a building [Mesároš et al., 2019]. Apart from the 3D model, the data of the built environment is represented using the dimensions of BIM. There are currently seven dimensions of BIM.

- **BIM 3D:** A visual representation of the graphical and non-graphical components of the building.

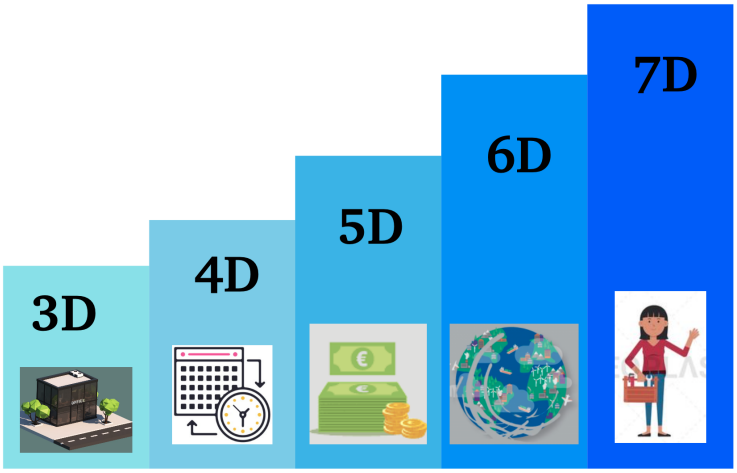

Figure 3.2: BIM Dimensions

- **BIM 4D:** BIM 3D + Project Time Schedule.
  It acts as a planning and scheduling tool. The time data is added for each of the components. The main benefit of BIM 4D is that it helps project planners/contractors to identify inaccuracies and optimise the project schedule [Pandit et al., 2008].

- **BIM 5D:** BIM 3D + Project Time Schedule + Cost.
  It is a costing tool. BIM 5D eases the task of material/labour estimates and quantity take-off. It helps in prompt decision making. In the traditional process, the design must be completed to a certain stage; only then is it possible to draw out the estimate. By using BIM 5D, the designing and costing are done simultaneously to keep the project within budget [Mitchell, 2012].

- **BIM 6D:** BIM 3D + Project Time Schedule + Cost + Sustainability.
  BIM 6D helps with the energy analysis. The BIM 6D model, also known as the energy model, helps reduce the energy emissions and minimize carbon emissions [(Montiel-Santiago et al., 2020), (Wu et al., 2019)].

- **BIM 7D:** BIM 3D + Project Time Schedule + Cost + Sustainability + Facility Management.
  It acts as a tool for the maintenance of the building or infrastructure (preventative and corrective) and helps with asset management [McArthur, 2015].

The BIM Models contain varying details about the geometry, planning, cost etc. The amount of information added to the model determines the Level of Detail of the BIM model. There are five levels of details which are LOD 100, LOD 200, LOD 300, LOD 400 and LOD 500 [Latiffi et al., 2015]. The extent of the ability of BIM technology to perform a

given task and exchange the information involved is known as The BIM Maturity [Succar, 2010]. The four BIM Maturity levels progress from Level 0 to Level 3 [Jayasena, 2013]. The terms Level of Detail and BIM Maturity are briefly explained as they are used in the report. For detailed information regarding BIM Level of Detail and BIM Maturity refer to Appendix A.

3.2. BIM 5D - DESCRIPTION

This section aims to provide details of BIM 5D, the reasons why BIM 5D is beneficial and the drawbacks of using BIM 5D. The final thesis deliverable is to provide recommendations to enhance BIM 5D implementation in organisations. But what is BIM 5D? How is it different from the traditional methods, what benefits does it provide over the traditional methods and what are its drawbacks? This section will provide answers to these questions.

Cost management is one of the main drivers in project management [Nicholas and Steyn, 2017]. Traditionally, in the construction sector, the cost was usually estimated at the end of the design phase, individually by all the stakeholders involved in the project [Forgues et al., 2012]. The fragmented nature of the industry and the large amount of data involved make it difficult to manage the cost. The data available to the stakeholders also varied to a large degree which leads to ineffective estimates, especially for large projects [Forgues et al., 2012]. Specific literature shows that the variation between the initial budget and final budget is around 40% [Flyvbjerg et al., 2014].

In the cost estimation of the construction project, the project schedule, too, plays a significant role. Project schedule and project cost are dependent on each other as a change in the project schedule brings a difference in the project cost. By using BIM 5D, the cost estimation becomes efficient as it becomes easier to incorporate specific regulations about information management processes while providing a collaborative environment for all the stakeholders [Agostinelli et al., 2019]. Initially, the cost estimates of a project start with a rough estimate of the project cost and high percentage of uncertainty but, as the project progresses, the accuracy of the cost of the project increases and this percentage decreases as by the end, the risk assessment is completed and costs are properly accounted for [Elghaish et al., 2020].

5D BIM helps tackle problems that arise due to the fragmented nature of the industry. 5D BIM is a five-dimensional representation of a project depicting its physical functional aspects [Lee et al., 2016]. BIM 5D helps in the automatic generation of the Bill of Quantities (BOQ) of the project. The BOQ includes all the physical objects [Mesároš et al., 2019]. This helps the quantity surveyor/cost estimator to gather accurate data much quicker than the traditional methods and explore new ways of providing efficient designs, performance and costs [Mayouf et al., 2019]. 5D adds the cost element to the already existing time management, makes it easier to calculate labour cost and cost required to hire machinery, thus achieving an integrated project delivery approach [Smith, 2014].

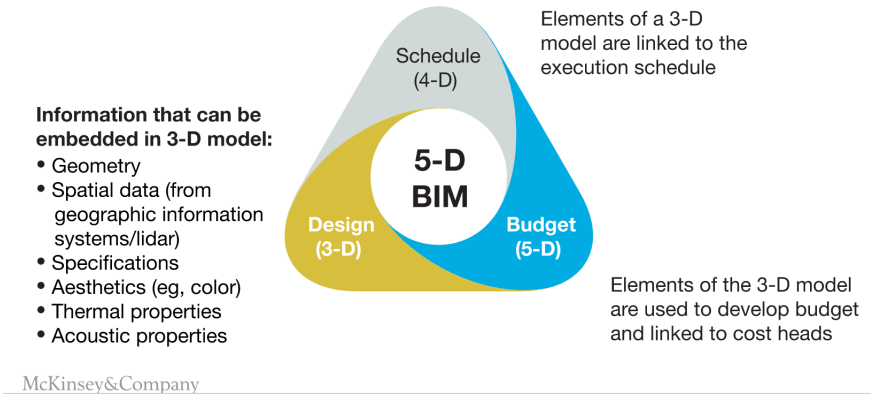

Figure 3.3: 5D BIM ["5D BIM: How it will help the construction industry", 2019]

3.2.1. BENEFITS

The advantage BIM 5D has over the traditional costing methods is that BIM 5D allows stakeholders and project teams to be more involved in the decision making by providing a common working platform. BIM 5D thereby helps to increase project productivity. It allows construction teams and consultants to save time and money while allowing projects to proceed smoothly. Another advantage offered by BIM 5D is that it provides a visual (3D model) of the development of the project at the pre-construction stage, which eliminates major project management problems and inefficiencies in the construction procedure [(D. W. Chan et al., 2019), (Migilinskas et al., 2013), (Hasan and Rasheed, 2019)].

The benefits observed during the pre-construction and construction after implementing BIM 5D are:

- **Simplifies cost-estimation and forecasting:** BIM 5D helps with the creation of efficient cost estimates of the project. BIM software's can easily automate the time-consuming difficulties linked with traditional cost estimation and assessment. This allows estimators to focus on the important and difficult aspect of cost estimation, which is risks assessment [(Al-Ashmori et al., 2020), (D. W. Chan et al., 2019)].
- **Exhaustive quantity take-off:** BIM 5D helps with the automatic generation of the Bill of Quantities (BOQ). Traditional methods of creation of the BOQ are time-consuming and are susceptible to manual error. Generating the BOQ by using BIM 5D helps save time and eliminate mistakes, allowing the cost estimators to focus the assessment of financial risks and generation of pricing models [Hasan and Rasheed, 2019].
- **Enhances information exchange:** A great deal of the project success depends on the effective exchange of information. BIM acts as an ideal communication platform that enables easy and successful communication among stakeholders like

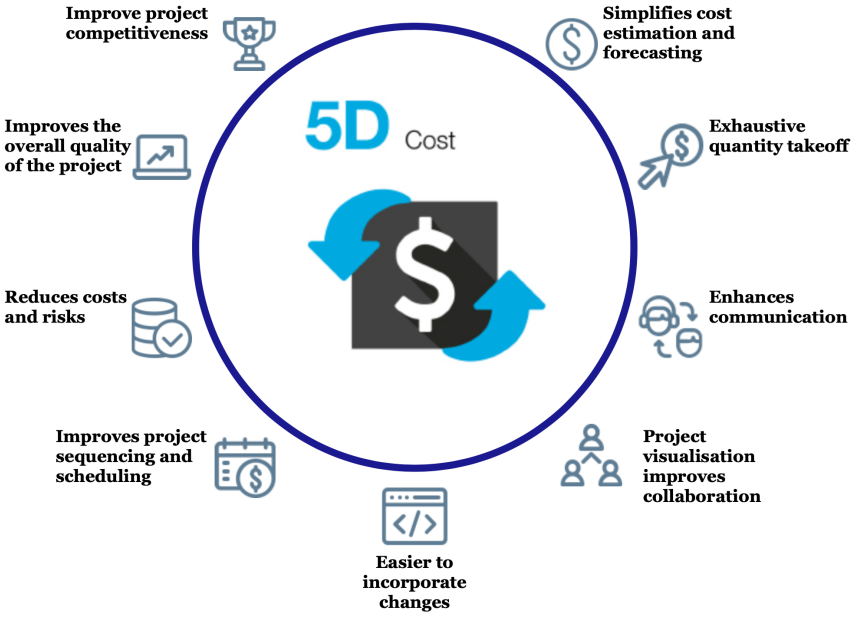

Figure 3.4: Benefits of BIM 5D

investors, designers, construction managers, and other industries. BIM 5D helps create detailed cost estimates. It helps identify the quantities in the 3D model quite easily and presents the stakeholders with an accurate cost estimate throughout its life cycle. Accurate cost estimates lead to lesser risks and losses due to miscommunication and mismanagement. [(Al-Ashmori et al., 2020), (D. W. Chan et al., 2019)].

- **Project visualisation improves collaboration:** Creation of a 3D model with the help of BIM provides the stakeholders with a good project visualisation. It helps the stakeholders to visualise the project and in turn it helps them to better understand the project [(Migilinskas et al., 2013), (Eadie et al., 2013), (D. W. Chan et al., 2019)]. BIM helps with the early detection of mistakes by providing the clash detection feature. With the use of clash detection, BIM modellers can automatically detect clashes within the 3D structural model and the various other systems used in a building or infrastructure at a very early stage [(Al-Ashmori et al., 2020)]. The elimination of clashes helps create accurate estimates as the additional elements of the model are deleted.

- **Easier to incorporate changes:** It is logical to assume that almost every project will undergo several changes throughout the pre-construction and construction phase. With the help of BIM 5D, the cost-estimator can better monitor these changes as the cost is linked to the components. The cost-estimator need not go through

with the entire design process from the start. It helps monitor costs from the initial phase of the project and keep the project cost in check by making appropriate changes if the initial cost is more than the allotted cost. It helps save a lot of time when compared with 2D design drawings. [(Migilinskas et al., 2013), (Al-Ashmori et al., 2020)].

- **Improves project sequencing and scheduling:** BIM 4D shows the scheduled tasks for the stakeholders, both individual and group tasks, and it easy to schedule or communicate the changes if they occurred, to the respective stakeholders. [(Al-Ashmori et al., 2020), (D. W. Chan et al., 2019)]. As the cost estimates are linked with the schedule, the resource is easily quantified, reducing the site issues due to finances. BIM 5D helps make the material procurement easier, as the cost is linked with the schedule. The updated material list accessible to the stakeholders helps with the timely procurement of material which helps prevent any delays.

- **Reduces costs and risks:** BIM 5D can help reduce the cost of construction in multiple ways. Enhancing communication, collaboration, and minimising mistakes, adjustments, and exclusions helps reduce the time required to construct a project, thus reducing the project's costs. There is a decrease in labour expenses as the task of documentation is reduced. The project schedule allows efficient use of materials, equipment and labour. An enhanced coordination with the stakeholders helps in reducing the risks involved [(Al-Ashmori et al., 2020), (D. W. Chan et al., 2019), (Yan and Damian, 2008)].

- **Improves the overall quality of the project:** BIM software encourages the use of pre-construction technologies and makes it easier to build effective diagrams, production processes, construction schedules and cost estimates. This increases productivity, eliminates waste, and lowers labor and resource costs [(Al-Ashmori et al., 2020), (Eadie et al., 2013), (D. W. Chan et al., 2019), (Yan and Damian, 2008)].

- **Improves project competitiveness:** BIM 5D improves the competitiveness of companies. It can help organisations win the contract and increase their revenue as additional points may be awarded to organisations for knowledge and experience in new technologies [(Eadie et al., 2013), (D. W. Chan et al., 2019)]. Lately, since BIM is becoming increasingly popular, clients have specifically started asking for BIM.

3.2.2. DRAWBACKS

Despite the benefits of BIM 5D mentioned above; there are several drawbacks of implementing the technology, which prevent it from reaching its full potential. First, they are related to the high installation cost of the and second, the training required to use the software [Dobelis, 2013]. BIM 5D software requires a considerable amount of investment. Apart from the software, the hardware also needs to be updated to suit the BIM 5D software [(Vass and Gustavsson, 2017), (Bosch-Sijtsema et al., 2017)]. This makes BIM not worth it for small organisations. Training of the employees and hiring additional personnel to carry out the BIM 5D training takes up a lot of time [Stanley and Thurnell, 2014]. Project teams can rather spend this time on the project. But BIM implementation

not as much about the software as it is about organisational change [(Dobelis, 2013), (Won et al., 2013)]. There are two factors because of which BIM 5D in organisations is slow: the change factor and people factor [Dobelis, 2013]. Change factor deals with organisational change, shifts in responsibilities and the working [McHugh, 1997]; and the People factor is the opinion and perception of people towards BIM 5D [Bhuyan, 2007]. The challenges which arise due to these two factors are explained in detail in the next section.

3.3. BIM 5D IN ORGANISATIONS

In the previous section, Section 3.2, we saw what BIM 5D is, and in sub-section 3.2.1 we saw the benefits offered by BIM 5D. Based on these benefits, it is pretty evident that implementing BIM 5D will help organisations improve their construction management process. However, despite the given benefits, it is quite a difficult task to incorporate new technology (BIM 5D) in an organisation, and often organisations find it hard to achieve the benefits offered by it [Maioli, 2020]. To overcome these challenges, we first need to understand the challenges that organisations face. In this section, we will see the challenges faced while implementing BIM 5D to know why despite the presence of BIM 5D software, the BIM 5D implementation is not very efficient.

BIM 5D has brought about a change in the working of organisations by providing a common working environment for a project [Berente et al., 2010, (Won et al., 2013) (Villena-Manzanares et al., 2020)]. Apart from a BIM 5D software, the organisation needs good BIM modelling software, planning software and common data sharing. If all the BIM softwares/procedures are not up to the mark in an organisation, it will hinder the BIM 5D implementation. But the mere presence of BIM softwares in an organisation can not guarantee an efficient BIM implementation in an organisation; the change factor and the people factor also need to be considered [Dobelis, 2013].

3.3.1. CHALLENGES FACED

The slow rate of implementation of BIM 5D has led to several types of research being done to look into the various obstacles present [Hasan and Rasheed, 2019]. The obstacles are related to the implementation of BIM in general as well, as a weak BIM will result in a weak BIM 5D implementation in an organisation. The obstacles are generally differentiated as Technical and Non-Technical [Alreshidi et al., 2017]. The barriers are not just intra-organisational but also inter-organisational. Intra-organizational challenges are challenges that occur internally within the organisation, while inter-organisational challenges are challenges faced while collaborating with parties outside the organisation [Vass and Gustavsson, 2017].

The challenges faced while implementing BIM 5D for organisations are :

1. **High installation cost and time:** Installation of the BIM 5D hardware and software requires huge investment. This includes the cost of software, hardware and training the personnel [Huang, 2018]. Due to highly advanced hardware and software

requirements, a full implementation takes up a lot of time. Moreover, just a one-time installation of the software is not enough; it has to be timely updated to match the technological progress in the market. This can sometimes end up being expensive.[(Vass and Gustavsson, 2017), (Bosch-Sijtsema et al., 2017)]. BIM 5D requires all the stakeholders to contribute to the project. A high collaborating environment requires contributions from all the stakeholders involved, which initially takes up a lot of time as everyone has to be brought on the same page. The longer it takes for a project to initialise, the higher the cost. When project management sees an increase in time and cost, they are opposed to the idea of 5D BIM adoption as the economic benefits are not straightforward in the initial stages [(Yao et al., 2020), (Georgiadou, 2019]. Also sometimes, the company needs to provide incentives to promote the use of BIM 5D, which increases the cost of installation [(Alreshidi et al., 2017), (Hong et al., 2017), Langar, 2017)].

2. **Software support:** The software selected by organisations is the one that will best suit their needs. The softwares available in the market are not expansive enough to suit all the organisational requirements [(Georgiadou, 2019), (Hasan and Rasheed, 2019), (Stanley and Thurnell, 2014)]. Tulenheimo, 2015 shows that around 36% of Finnish construction consulting companies customised the components themselves, and 56% had to get the components customised by a specialist outside the company. Developing ones own software can ease the task and enhance the business advantage and cause several problems with implementation, maintenance and support of the product. Things can also get difficult when different departments in an organisation use different software as not all of the BIM 5D softwares present in the market are compatible with each other [(Bosch-Sijtsema et al., 2017), (Alreshidi et al., 2017)].

3. **Numerous data-sets:** The challenge arises due to the dependencies between the data sets, like families and libraries. If the data sets are independent, it becomes tough to combine them. Then, the cost engineer needs to export data from one data set and import it into the other. This makes the task quite tedious and prone to human error [Matejka and Vitasek, 2018].

4. **Change in working of the organisation :** BIM 5D implementation calls for a change in the way the project teams in organisations function. Changing the work practices of major organisations is challenging due to their large size and due interactions between the different departments. It leads to the creation of new roles like the BIM coordinator or BIM specialists. Either the organisation hires additional specialised managers, or the current project managers get overburdened with BIM-related work. This change in working also increases costs [(Vass and Gustavsson, 2017), (Bosch-Sijtsema et al., 2017), (Alreshidi et al., 2017), (Hong et al., 2017)].

5. **Non-Standard BIM definition and procedure:** Numerous norms, guidelines and codes regulate the construction industry. These norms warrant the safety of the built projects [Poljanšek, 2017]. These norms however vary to a large degree depending on the country and the type of construction [(Ademci and Gundes, 2018),

(Georgiadou, 2019)]. This gives rise to one of the main factors for the slow implementation of BIM, i.e. the lack of standardisation and protocol. The absence of standard BIM definition and procedure complicates the BIM implementation process. The lack of standard guidelines also inhibits the use of BIM. This creates misunderstandings and thus increases communication issues and decreases collaboration. Hence, they need to be categorised into sector standards and organisation standards to eliminate complexity. [(Vass and Gustavsson, 2017), (Bosch-Sijtsema et al., 2017), (Alreshidi et al., 2017), (Hong et al., 2017), (Langar, 2017), (Gu and London, 2010)].

6. **Training the employees:** The training of the personnel is also a very time-consuming process [Stanley and Thurnell, 2014], which gives rise to another challenge, i.e. the lack of experienced personnel. Several types of research show that there are very few people who have complete BIM 5D knowledge in an organisation. Employees new to the technology need to undergo a training process that requires a considerable amount of time and money. Sometimes the organisation may need to hire external consultations to help with the training process. problems arise while collaborating with external parties, when they too lack the required knowledge [(Vass and Gustavsson, 2017), (Bosch-Sijtsema et al., 2017), (Alreshidi et al., 2017), (Hong et al., 2017), (Langar, 2017)].

7. **Resistance by employees:** Usually, when an organisation decides to adopt new technology, it is met with cultural resistance from the employees within that organisation [Hasan and Rasheed, 2019]. The transformation is hindered mainly because the older employees are quite unenthusiastic to try out new technology compared to the younger generation who are quite accepting of it [Stanley and Thurnell, 2014]. A lack of trust and feeling of trepidation towards the new technology poses a major challenge for organisations to implement BIM [(Bosch-Sijtsema et al., 2017), (Alreshidi et al., 2017), (Hong et al., 2017), Langar, 2017)]. The amount of support provided to the use of new technology varies according to the organisation and its values.

8. **Risks and Liability:** The implementation of BIM 5D within the organisation has its fair share of risks. Not every organisation wants to share its data among all its suppliers, contractors and sub-contractors. It also leads to problems regarding the ownership of the BIM Model [Mat Ya'Acob et al., 2018]. Furthermore, the liability conditions regarding the shared data and in case of a faulty cost-estimate are still ambiguous, and this needs additional clauses in the contract [Liao and Ai Lin Teo, 2018].

9. **Unwillingness to take risk:** The use of BIM 5D increases the risk for all the stakeholders involved. Various other issues arise like the who (which stakeholder) will have the ownership of the BIM model, who will have the right to access information in the models, who are in control of the information and who will be held accountable in case of error is detected [Georgiadou, 2019]. This increase in the risks to be borne by the stakeholder regarding these errors discourages companies from using 5D BIM.

10. **Intangible benefits:** The benefits offered by 5D BIM, improving quality, productivity and efficiency, are intangible and hence it is difficult to quantify them. Often the benefits are not clear in economic terms and it also takes time for the benefits to be evident [(Vass and Gustavsson, 2017), (Bosch-Sijtsema et al., 2017), (Alreshidi et al., 2017), (Hong et al., 2017), (Langar, 2017), (Elmualim and Gilder, 2013)].

3.3.2. MANAGEMENT STRATEGIES

As mentioned in the research focus, Section 1.2, to have a good BIM 5D implementation, the organisation needs to have a strong BIM foundation. [Won et al., 2013] states in their paper that there are two approaches towards BIM. Some studies claim that BIM provides an opportunity for the organisation to restructure the working. In contrast, others claim that organisations should only adopt those technologies that suit their current working method. Large shifts in teams and working occur as organisations try to incorporate BIM, taking into account a shift in teams, legal risks, and high investment costs of software, hardware, and personnel training. Several researches show that it is more important to overcome non-technical organisational barriers than technical barriers [(Won et al., 2013), (Mom et al., 2014), (Liao and Teo, 2017), (Alreshidi et al., 2017), (Lindblad and Vass, 2015), (Merschbrock and Munkvold, 2015)].

The management strategies to be implemented in an organisation to enhance the BIM 5D adaptation depend on the organisation's role. The book Management Strategies for 5D-BIM Adoption in Hong Kong [I. Y. Chan et al., 2018] has divided the strategies into three perspectives.

1. Client developers perspective: Client developers should focus on promoting and adopting an integrated procurement delivery method, as it provides them with competitive advantages. Boost the BIM 5D knowledge of the employees by providing training and focusing on developing a standard use BIM 5D.

2. Contractors perspective: Contractors need to focus on making the employees more accepting of BIM and provide constant feedback to the employees to enhance future performance and encourage diversified perspectives.

3. Consultants perspective: Consultants need to focus more on developing the standard way of working with BIM, for example, with the help of guidelines or a framework. Consultants should use their first-hand experience and professional knowledge while developing the standard working method.

3.4. COMPARISON OF BIM IN BUILDINGS V/S INFRASTRUCTURE

Building projects and infrastructure projects vary by a large degree. Sub-question 5 of this research, figure 1.3, deals with the lessons the infrastructure sector can take from the building sector while implementing BIM 5D. Before we apply the lessons from the building sector to the infrastructure sector, we first need to understand how the application of BIM varies between the two. After we understand this, we can only judge what

steps can be applied to the infrastructure and which cannot. In this section, we will compare the application of BIM between buildings and infrastructure.

The term infrastructure is defined as " A diverse collection of constructed facilities and their associated services [Albert A. Grant and Andrew C. Lemer, 1993]. There is no general way of classifying the types of civil infrastructure projects, but according to previous research, there are five domains of classification [Cheng et al., 2016]:

1. Transportation Infrastructure:- roads and tunnels, railways, bridges, airports, ports and harbours.
2. Energy Infrastructure:- power generation plants (energy grids, nuclear plants, windmills etc.), oil gas industries and mining.
3. Utility Infrastructure:- Water, electricity, sewage networks.
4. Recreational Infrastructure:- Stadiums, amusement parks etc.
5. Water management Infrastructure:- Dams, dikes and canals.

Civil infrastructure projects are large scale projects which involve significant projects capital investment, are massive in size, are susceptible to a large number of operational and technical complexities and ample collaboration between the various stakeholders involved. They require sufficient integration of information and process to achieve a higher quality of design, construction, operation and maintenance, hence the use of BIM [Cheng et al., 2016]. BIM displayed a perception that it should only be used for building projects and seems irrelevant to infrastructure projects. The complex nature of the industry too slowed down the use of BIM as organisations were reluctant to take risks by introducing new technologies [Yabuki, 2010]. However, the implementation of BIM in the infrastructure sector has shown that it provides similar advantages, compared to the building projects [Alsina Saltarén et al., 2019], refer to section 3.2.1.
The principles of BIM for infrastructure projects have been derived from the developments in the building sector. Hence there exist **similarities** between the two. The aspects of BIM like a standard plan, information sharing and the collaboration and coordination between the stakeholders are similar for both the building and infrastructure industries [Bradley et al., 2016]. Both sectors require thorough pre-construction planning to design and construct the facility. This involves the development of engineering analysis, project scheduling (BIM 4D) and material management to ensure a timely material supply [Chong et al., 2016]. Following the pre-construction phase, in the construction phase, both sectors need to check, control and examine the cost encountered by using the BIM 4D and 5D model and provide a good visualisation platform for the stakeholders [Chong et al., 2016].

Despite the similarities, the implementation of BIM in infrastructure is quite different when compared to buildings [Shou et al., 2015]. Due to the large number and variety of activities, higher complexity and enormous size, infrastructure projects are much more expansive compared to buildings [Bradley et al., 2016]. Several research point out the **differences** which need to be considered before we implement BIM to infrastructure.

Firstly, the building sector makes use of the Cartesian coordinate system for reference, while infrastructure uses multiple stations and alignment curves for references. This difference has been one of the crucial factors which have prevented the direct implementation of BIM to infrastructure, mainly transportation, as traditional CAD tools primarily used the Cartesian system [Costin et al., 2018]. Second is the difference between the structural components of a building and infrastructure [Cheng et al., 2016]. This means that the data involves in both is different, and the data from buildings cannot be directly used for infrastructure. Thirdly, apart from the foundation, the surrounding environment has less impact on the building construction. Still, for the construction of infrastructure projects, every small variation in the environment needs to be taken into account [Cheng et al., 2016]. For this reason, buildings are called "Vertical Projects", and infrastructures are called "Horizontal Projects". BIM, for infrastructure projects, usually connected with geographical information systems (GIS) as they sometimes extended for tens of kilometers [(Alsina Saltarén et al., 2019), (Costin et al., 2018)]. The final difference is modelling of the structures. The modelling for buildings is done vertically, floor-wise, but for infrastructure, the modelling is done horizontally with respect to the reference line. Also, concerning the modelling, in the design stage, for buildings, it is component-based and provides an advantage in clash detection and an informative visual aid. Whereas for infrastructure, clash detection and visualisation does not add a lot of value [(Bradley et al., 2016), (Alsina Saltarén et al., 2019)].

3.5. CONCLUSION

With this chapter, we complete Phase 1 of the thesis project, refer to figure 1.5. This chapter aims to lay a base for the research, provide a theoretical background for the readers and answer sub-question 1, figure 1.3. Section 3.1 provided a BIM overview. BIM is made of 4 key elements:- Process, Representation, Collaboration, and Life-cycle. These four elements will be used to structure the interviews and also the final recommendations. In section 3.2, the focus of the literature review is narrowed down to 5D BIM. This section highlighted the benefits offered by BIM 5D, like it simplifies costing estimations, creates accurate cost estimates by providing extensive takeoff and incorporating risks, enhances communication and collaboration and improves overall project quality. Finally, in Section 3.3 we arrive at the main focal point of the thesis, i.e. BIM 5D in organisations. This section highlights the challenges organisations face while implementing BIM 5D. These are related to either the high cost and time required for training or the people factor and change factor. With this, we arrive at the answer for sub-question 1:- What kind of problems do organisations encounter while implementing BIM 5D? The challenges can be categorised into technical and non-technical challenges. While initially, organisations focused more on eliminating the technical issues, it is now clear from the literature that it is more critical for organisations to overcome non-technical problems than technical. In Section 3.4 the management strategies to be applied to enhance BIM 5D in organisations are also stated depending on the organisation's role. The last section of this chapter focuses on the comparison of BIM in infrastructure and buildings. The similarities identified are the standard processes, information sharing, collaboration, and basic requirements. The differences are that buildings use the Cartesian coordinate system and are modelled vertically and whereas infrastructure is modelled using a reference line hori-

zontally. Apart from this, the components used for both vary.

With this chapter, we have not only answered the sub-question 1, but we have also done research that has helped lay the foundation that will help to answer the other five sub-questions. The challenges found in sub-question 1 and sub-question 3 are compared to detect the additional challenges faced by infrastructure projects while implementing BIM 5D. The points of differences pointed out between building and infrastructure in Section 3.4 will help identify the lessons from the building sector directly applicable to infrastructure and the ones which require fine-tuning. And finally, the management strategies found in Section 3.3.2 are used to structure the recommendations for organisations depending on their role.

4

PHASE 2 - RESEARCH OUTCOME

This chapter consist of the outcomes from Phase 2 of the research. In the first section we look into why this thesis promotes the use of BIM 5D in organisations. Following that the chapter is divided into the working of BIM and BIM 5D working in the infrastructure department in Arcadis, the challenges faced while implementing BIM 5d for pilot projects after which the challenges mentioned are analysed. The chapter ends with a summary of the findings in Phase 2. This section answers the sub-question 2 and 3: *" How is BIM and BIM 5D currently used within Arcadis? "* and *" What problems did Arcadis face while implementing BIM 5D for infrastructure projects? "*.

4.1. WHY BIM 5D FOR ARCADIS?

Arcadis, being one of the leading design and engineering consultants in the world , have great expertise in cost and commercial management. With the help of BIM 5D, Arcadis aims to bring Cost and Commercial Management into the BIM environment. BIM 5D is one of the key factor of Arcadis' Digital Cost Management strategy allowing designers and cost managers opportunities to utilise BIM 5D. BIM 5D allows the digitisation of the process of measurement and costing of construction works, helps provide better financial outcomes for clients in a more efficient way and creates the foundation for advanced use of data and visualisation.

By implementing BIM 5D on projects, Arcadis has seen the benefits it has to offer. In the first project it helped achieve Full-Time Equivalent (FTE) saving of 1.05 per month for the pre-tender estimates and 1.5 per month for cost estimates. In the second project they achieved 20-30% of time-savings compared to traditional methods, visual benefits which helped in client engagement and an accurate quantity take-off.

BIM 5D has helped bring about a change in the organisation. It allows a better understanding of design and visualization with 3D. Clash detection is useful when various disciplines come together as it helps avoid on-site surprises. It helps achieve cost-certainty

in the early stages of the project (Interviewee 1.5, 1.6). It is also advantageous as the digital way is neater, organised, transparent and it is easier to communicate to the clients and other estimators. This makes it easier to accommodate changes (Interviewee 1.4). It allows for more time to be spent on important things like reviewing the rates which have not been fully automated yet (Interviewee 2.1). It allows data to be shared and enhances collaboration as it provides a common working platform. It also limits the contractors risks and allows for improved site management (Interviewee 2.1, 2.2, 2.4)

Every transformation is a trade-off between doing productive work on a project of today vs investing time in future projects (Interviewee 2.1). Changing procedures and a change in the way of working requires high investment costs and time which can be very difficult initially and gets easier over time. But if you want to realise the benefits it offers then you need to take a risk and go ahead and implement it while being patient.

4.2. DATA GATHERED

Since the aim of this phase was to answer the sub-questions 2 and 3; the interview questions were focused on the topics stated below:

- The working of BIM before BIM 5D was implemented for the infrastructure department.
- The shift to BIM and BIM 5D.
- The reaction and acceptance of the colleagues to the shift.
- The software used for BIM and whether it allows for good collaboration between the various parties involved.
- The details of the model prepared.
- The object libraries used and how extensive they are.
- The training process.
- The overall experience of using BIM in infrastructure projects.

4.3. WORKING OF BIM AND BIM 5D IN ARCADIS

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4.4. BIM 5D CHALLENGES IN ARCADIS FOR INFRASTRUCTURE

BIM 5D in Arcadis is still in the initial phases for infrastructure. Even though there are various policies in place that promote BIM use, these are limited to BIM 3D. This sub-section will explain the reasons for this will be presented in this sub-section. This sub-section will aim to answer sub-question 3. The challenges faced will be divided into four sections, the four elements essential for BIM implementation: Process, Representation, Collaboration and Life-cycle (Refer to figure 1.1. The challenges will also be divided based on whether found in previous literature or not. The challenges not found in literature is marked with an *.

PROCESS

1. **Misconceptions and Unawareness regarding the working of BIM**
   People within an organisation sometimes have misconceptions about BIM. Wire-frame and 2D AutoCAD models are assumed to be BIM models but are not as they don't contain any intelligence. Sometimes people believe they work with BIM because they use BIM 360 (Interviewee 1.1, 1.2, 1.3, 1.4, 1.6). Whereas some people are unaware of the working of BIM as the employees have only worked with contractors who have BIM 4D and 5D, but they haven't worked with it themselves (Interviewee 2.2). This gives rise to more challenges, i.e. Project Managers hesitant to use BIM, lack of experienced staff.

2. **Project Managers hesitant to use BIM 5D**
   There has been immense support by the Top Management to use BIM 5D, but that does not ensure that all project managers are supportive of it (Interviewee 1.1, 1.3, 1.6). This is mainly due to the lack of awareness regarding the working of BIM, less experience and no to less training in BIM. According to Interviewee 1.6, if a project manager is not supportive of BIM 5D in a project, it can have all the BIM experts in a project, but BIM 5D will not be implemented. Hence, it is crucial for the project manager to fully support BIM for it to be implemented in a project. Sometimes this hesitance can also be due to the conservative mindset of the managers (Interviewee 1.3).

3. **Project teams do not spend time creating the BEP**
   Numerous challenges arise as projects do not spend enough time making the BEP,

and hence it is not standardised as each time it has been prepared differently (Interviewee 1.3 - 1.6 and 2.1 - 2.4). When each team solves matters in their way, they keep reinventing the wheel; the problems keep arising without developing a solution. The BEP is generally made without considering the planning experts and cost experts (Interviewee 2.1 - 2.4). Project managers would rather spend time on the project rather than the BEP as they believe it takes up a lot of time and fail to understand that the BEP helps bring clarity to the project outcomes, simplifies the project progress and makes it easier to incorporate changes in the future (Interviewee 1.3 - 1.6).

4. **Several departments do not have access to BIM 5D softwares**
   Since Cost X is newly introduced in the infrastructure department, many departments do not have access to the software. The costing department has worked with it only for a bridge project (Interviewee 2.1 - 2.4). According to Interviewee 3.2, although the costing department has access to the software, not everyone in the department is involved. Various things need to be lined up before the software is used extensively. An example of that is the object libraries. Getting the BIM 5D software license is expensive, so the departments need to be sure that once they acquire the software, it will be put to good use (Interviewee 3.2).

5. **Hardware provided is not suitable to work with files of large size**
   Interviewees 1.1, 1.5 and 1.6, have pointed out that the organisation's hardware is not always up to the required standard. To process models of considerable size, one needs a perfect computer with good RAM. For Cost X, a high power laptop is necessary to open the model, extract the information and navigate it accurately. Working on old and slow laptops can hamper work and cause delays, which costs extra money (Interviewee 2.1).

6. **Non-standard File Type**
   Maintaining a standard file type is important, so the different files interact well with each other (Interviewee 1.1). It also helps maintain uniformity. Exchanging files in file types other than the .ifc or .dwfx can lead to a loss of information from the modellers to the cost-estimators as only these two file types are compatible with the Cost X model (Interviewee 2.1).

7. **Interaction between Softwares**
   In Arcadis, the most popular software for BIM modelling in Revit. The Civil 3D software is also widely used in the infrastructure department, but it is not BIM software. The problem which arises with this is that different software uses different file types which can be incompatible with the software used. (Interviewee 1.1).

8. **Hesitant to give up Outdated Technology.***
   Some departments within the organisation have in recent years developed a system using Excel to help with the cost estimation process (Interviewee 1.3, 1.5, 1.6). The quantities are extracted from the BIM 3D model and are transferred to Excel, where the cost estimation is done. Because infrastructure projects have a long

lead time, these departments feel that the new systems haven't been put to good use and are hesitant to invest in a new technology when the current developments haven't been utilised. Programming in Excel has a lot of room for error (Interviewee 2.1, 2.4) and can be risky as the complexity of the cost estimation keeps increasing.

9. **Unwillingness of clients to use BIM/BIM 5D**
The unwillingness of the client/asset owners to move into the BIM ways is due to lack of experience and non-availability of software. This hampers the growth of the organisation as they are mainly client-driven (Interviewee 1.2 - 1.6). Even though The Netherlands is pushing the BIM implementation in projects, the clients are not ready to accept it or even if they are, it is limited to BIM 3D (Interviewee 2.1, 2.2 and 2.4). According to interviewee 2.1, most clients are not aware of the advantages BIM 5D has to offer. And as mentioned earlier, unless project managers are convinced of BIM 5D and its benefits, they cannot sell it to their clients (Interviewee 1.5).

10. **BIM is not cost-efficient for small projects**
According to interviewee 2.2, implementing BIM 5D for all scales of projects is not always cost-efficient. For projects of a smaller-scale traditional method is a better fit at the moment. The benefits offered by BIM are not seen immediately, and it takes time to set in the working of the organisation; until then, it is not cost-efficient.

REPRESENTATION

11. **Modelling Software not suited for infrastructure**
A big disadvantage of Revit in infrastructure is that the Dutch Revit Standards in-built in Revit are only limited to buildings (Interviewee 1.4). Revit, although it works well for buildings for infrastructure, it can be difficult. For a certain type of infrastructure, like stations, it can be comparatively easier to use, but it can be tricky (Interviewee 1.1, 2.1). This makes the modelling of most infrastructure in Revit quite difficult and tedious. For example, in energy infrastructure - a full bay can be reused for future projects only if the voltages and the primary objects match, which does not happen often.

12. **Lack of availability of object libraries including BIM 5D information***
The object libraries for costing in the Cost X software are limited to specific projects and departments, making it challenging to incorporate BIM 5D for now (Interviewee 1.2 - 1.6). The data set is available, but the information is cluttered on excel sheets and not in the form of BIM object libraries. Even though the libraries need not be created from scratch, it will still take a significant amount of effort to add all the costing information to the existing libraries (Interviewee 3.1). According to Interviewee 2.1, 2,2 and 2.4, creating a sound library (database) is always a starting point for using BIM in a project. It will help automate the costings process but is also a tedious process and needs to be done as and when new components are encountered for projects. This is the only way the object-based library can grow.

When the libraries are being built, the initial years can be pretty challenging as there are many components for various types of infrastructure like bridges, dikes, sluices, aqua ducts, and these objects vary by a significant degree (Interviewee 1.2 - 1.6).

13. **Object separation for cost-estimation in the 3D model***
According to interviewees 2.1, 2.2 and 2.4, the issue the cost-estimators face is that the design is not up to the standard they require. Object separation in the 3D model can be difficult for cost-engineers if the model is not up to the mark. This can make it difficult to calculate the cost as the dimensions of the various objects is unclear. This creates a problem irrespective if BIM 5D is used or not (Interviewee 3.1).

14. **Difficult to assess the ground conditions***
If the ground conditions are not mentioned in the 3D model, it can be challenging to calculate the cost as they vary dramatically depending on the ground conditions. The designers and modellers also need to consider the terrain line, topography and geography to help generate an accurate cost estimate. The Water infrastructure department doesn't use BIM at all because it is related more to geography and is less object-based (Interviewee 1.2). Automating these things is very tedious and requires a lot of time (Interviewee 2.1).

15. **3D Design made is not up to the standard for cost managers to calculate cost***
Getting the 3D BIM model right is quite essential to get for a good BIM 5D. The designer needs to have a clear idea of the cost estimators information before they model, so the cost engineers have the required information to calculate the cost (Interviewee 2.2). It is challenging for cost engineers to work with BIM 5D as the details required for costing are missing. For example, the type of steel beam is mentioned, but weight is not mentioned - that has to be added manually, for concrete - volume is provided. Still, the dimensions to calculate the amount of form-work is not added (Interviewee 2.1). Temporary works are not added to the model; the cost estimators need to add this data accordingly (Interviewee 3.1). Geo-technical information needs to be added accurately to the 3D BIM model to get a more extensive cost model. Cost estimators also need to know the time of equipment hire (Interviewee 2.4). Since infrastructure work proceeds phase by phase, a different model is created for each phase as the work is separate. These models are not built in a standardised manner, and hence it is challenging to integrate all information in one model (Interviewee 2.2).

16. **Cost Managers need to check design (double work)***
When it comes to BIM 5D, the cost managers have additional work, i.e., checking the design details. The cost managers need to verify the model to see if the design and the codes assigned are correct, and only then the cost can be calculated (Interviewee 2.2). It is easier to conduct the checks in the preliminary phases as the number of components is less, but as the detail level increases, it becomes pretty tedious to work (Interviewee 2.4).

17. **Lack of experienced BIM staff**
People are sometimes hesitant to shift to a new technology due to misconceptions and unawareness regarding BIM (Interviewee 1.2, 1.4, 2.2). An inexperienced team takes a longer time to complete the project as most people are still trying to figure out a new way of working (Interviewee 1.1). The engineering department lacks basic Revit skills as people who work on BIM innovation are moved to billable projects. Naturally, billable projects are the highest priority (Interviewee 1.1, 1.6). This hampers the BIM growth in an organisation.

18. **Few BIM ambassadors compared to the size of the organisation**
According to Interviewee 1.6, the infrastructure department in the organisation have very few BIM ambassadors compared to the department's size. The organisation needs more BIM analysers who help manage and promote the work related to BIM as the BIM ambassadors are overburdened as it is challenging to focus on all BIM-related projects.

COLLABORATION

19. **Knowledge gap and lack of collaboration between regional offices and GEC***
A lot of engineering work and creation of knowledge regarding the modelling is done in Global Excellence Centers (GEC) and not the regional offices of Arcadis. There is a vast knowledge gap between the GEC and the regional offices as sometimes countries are unaware of the capabilities of the GEC (Interviewee 1.3, 1.4). This gap is because of the resistance to working with the GEC due to the lack of trust. Regional offices need to be clear that GEC is built to assist them throughout and not only for specific projects. They should also understand that GEC is not a separate organisation but a part of Arcadis that enhances the projects (Additional Interviewee).

20. **Knowledge sharing within and between the departments**
Most of the knowledge sharing is only done if the new project team includes teammates from previous projects who faced similar challenges. If it is an entirely new team, then they don't know the lessons learnt from the previous projects which they can implement in their current projects (Interviewee 1.1). This is a significant challenge as the teams spend a lot of time figuring out new things instead of getting past inputs which can help them speed up the process. Although most of the information is added to BIM 360, it mainly consists of the final documents, and only the team members have access to this (Interviewee 1.6). Apart from this, the departments are not aware of the other department's new technologies. For example, the energy department is developing a Cost Plus model, and most of the different departments have no idea about this (Interviewee 1.2, 1.3, 1.4, 2.4, 3.1, 3.2).

21. **Not everyone has access to BIM 360**
BIM 360 is used to file and save all the data from previous projects. A limited number of people are given access to BIM 360, and this depends on the project

leader. BIM 360 also has limitations in sharing data with clients due to data security reasons (Interviewee 1.3, 1.4). Few BIM ambassadors believe that shifting to BIM 360 is a step backwards from previous data management to now. The earlier system promoted knowledge transfer, and the current system hampers the knowledge transfer within the project and colleagues (Interviewee 1.6).

22. **Clients do not have access to BIM 5D softwares**
The Cost X model is only accessible only if you have the software. The clients are unwilling to invest in additional software and buy the license if they are not thoroughly convinced of its benefits (Interviewee 2.2). According to interviewee 3.1, primarily for clients, the method of cost estimation does not matter. The only thing necessary is that all quantities need to be traceable in other documents, as a result of which the clients are indifferent whether they have access to the Cost X model or not.

LIFE-CYCLE

23. **Lack of Competition in Infrastructure**
In the building sector, the clients have higher demands and higher competition (Interviewee 1.6). Concerning BIM 5D, the building sector is more aware that you need to connect objects to quantities. It is also effortless to do it in buildings as suppliers have all the respective libraries coded that the clients can use (Interviewee 1.3). In the building sector, everyone collectively comes together to enhance the BIM (Interviewee 1.6). This motivation to use BIM is not present in the clients of infrastructure projects, which hinders the industry's BIM growth.

4.5. ANALYSING CHALLENGES

As mentioned earlier, the interviews in Phase 2 were conducted by dividing the interviewees into three focus groups. The challenges they said were analysed to see the most prevailing challenges in each focus group and overall. The reasons why certain focus groups or individuals mentioned or didn't mention the challenges is explored. The score for each focus group and the score overall are given in Appendix D. This helps with formulating the recommendations at the end.

CHALLENGES - FOCUS GROUP 1

The individuals from Focus Group 1 are BIM Ambassadors and BIM consultants. They deal more with Project teams and the managers to promote the use of BIM and better understand the overall organisational aspects that hinder the growth of BIM. Hence, they have a higher knowledge regarding the Process aspect of BIM. The challenges are ranked according to the number of mentions, figureD.1. The most prevailing challenges for Focus Group 1 were:

- Challenge 1 - Misconceptions and Unawareness regarding the working of BIM, Challenge 17 - Lack of experienced BIM staff and Challenge 20 - Knowledge sharing within departments. These challenges were mentioned by all except Interviewee 1.5 since he works with the senior BIM employees, who have a clear idea about

the working of BIM, given their position and is not usually involved in the inter-departmental working.

- Challenge 2 - Project managers hesitant to use BIM 5D and Challenge 3 - Project teams do not stick to standard procedures. These challenges were mentioned by all except Interviewee 1.2 since he is the BIM ambassador for water infrastructure, and the use of BIM in that particular department is limited.
- Challenge 4 - Several departments do not have access to BIM 5D software. This challenge was mentioned by all except interviewees 1.3 and 1.4 since they work in the energy department of BIM who already has their own BIM 5D program in place (Cost + model).
- Challenge 9 - Unwillingness of clients to use BIM/BIM 5D.
- Challenge 12 - Lack of availability of object libraries in the BIM 5D software. This challenge was mentioned by all except interviewees 1.1 and 1.2. They have less experience with BIM 5D, given the department in which they work.

The knowledge of Focus group 1 is centred at BIM in general and not is specific to BIM 5D. This is why the challenges related to BIM 5D were not mentioned by them. The lowest-ranked challenges for this focus group are:

- Challenge 13 - Object separation for cost-estimation in the 3D model.
- Challenge 14 - Difficult to assess the ground conditions.
- Challenge 15 - 3D design made is not up to the standard for cost managers to calculate the cost.
- Challenge 16 - Cost Managers need to check design (double work).

  Challenges 14 - 17 These challenges are more specific to BIM 5D and cost managers encounter them when calculating costs. However, Challenge 14 was mentioned by Interviewee 1.2, since that is the main reason why the water department is unable to implement BIM/BIM 5D in the projects, as they deal more with geography and are less object-based.

- Challenge 18 - Few BIM Ambassadors compared to the size of the organisation.

  Interviewee 1.6 stated Challenge 18 as one of the challenges he thought the infrastructure department faced. But this point was opposed by interviewee 1.5 by saying that if the department has enough BIM ambassadors and are often not approached as much by project teams. The BIM ambassadors, apart from this role, also have to focus on their projects.

- Challenge 22 - Clients do not have access to BIM 5D softwares. This is mentioned because Focus Group 1 doesn't know the status of BIM 5D w.r.t the clients as they have never worked with it.

CHALLENGES - FOCUS GROUP 2

The people from Focus Group 2 are Cost Managers working with BIM 5D; they are more aware of the challenges that occur after the model is passed on from the Design department and the BIM 5D software currently lacks. The main reason behind most of the challenges they face is that the 3D model does not contain the right information required for costing and issues related to software. Hence, they have a higher knowledge regarding the Representation aspect of BIM. The challenges are ranked according to the number of mentions, figureD.2. The most prevailing challenges for Focus Group 2 were:

- Challenge 3 - Project teams do not stick to standard procedures.
- Challenge 4 - Several departments do not have access to BIM 5D software.
- Challenge 9 - Unwillingness of clients to use BIM/BIM 5D.
- Challenge 12 - Lack of availability of object libraries, including BIM 5D information.
- Challenge 13 - Object separation for cost-estimation in the 3D model.
- Challenge 14 - Difficult to assess ground conditions.
- Challenge 15 - 3D design made is not up to the standard for cost managers to calculate the cost.
- Challenge 16 - Cost Managers need to check design (double work).

The standout from Focus Group 2 is Interviewee 2.3. He is responsible for creating the Cost + program. He is only involved in the costing of Energy infrastructure projects within the infrastructure department, which cater to one client organisation. The Cost + program is an Excel program, which contains all the objects used in the construction of energy infrastructure and their rates. The rates are standardised according to the client requirements. Another noteworthy point is the design of 6 energy infrastructures, to which the Cost + model was applied was almost similar. The main difference was that the scale and the voltage of the project varied.

Interviewee 2.1 introduced the Cost X model in the department, is most experienced with the Cost X and has a thorough understanding of the model's working. Interviewees 2.1, 2.2 and 2.4 are from the same department and faced similar challenges while implementing BIM 5D. Since their expertise is costing and BIM 5D and their work is limited to the costing department, they have limited experience in the general BIM processes in the organisation. Interviewees 2.1, 2.2 and 2.4 are the BIM 5D experts and have worked on maximum Cost X projects in the organisation. Hence they never encountered the challenge 1, challenge 2, challenge 5, challenge 7, challenge 18, challenge 19, challenge 20 and challenge 21.

CHALLENGES - FOCUS GROUP 3

The people from Focus Group 3 are Cost Managers who haven't yet worked with BIM 5D; they are more aware of the challenges that usually prevent the shift from traditional to BIM 5D. They stated the reasons due to which they still work with traditional methods as challenges. The interviewees vary tremendously in age, experience in costing and encounter with BIM 5D and hence they both have different reasons which stop them from moving to BIM. The challenges are ranked according to the number of mentions, figure D.3. Interviewee 3.1, having a higher encounter with BIM 5D, was more specific with the challenges he mentioned, and these were similar to the one mentioned by Focus Group 2. These were challenge 12, challenge 13, challenge 14 challenge 15, challenge 16. Interviewee 3.2, having less encounter with BIM 5D, only mentioned the general challenges like misconceptions and unavailability of software, 1 and challenge 4. The challenge 20 - Knowledge sharing within and between the departments was the only one mentioned by both of them. The reason for this is that the people working with traditional methods are not informed of all the latest developments with BIM 5D, and hence they feel they are not up-to-date with the progress of BIM 5D.

Challenges 12, 13, 14, 15, 16 are specific to the BIM 5D processes for infrastructure. These challenges were not found in any previous literature. They can be beneficial for BIM 5D experts, and working towards eliminating these challenges can help them improve the BIM 5D processes. Challenges 19 is also discovered in this research. Most large organisations have their own operating companies, GEC being the operating company of Arcadis, and improving the collaboration between organisations and their operating companies can help improve BIM 5D. Challenge 8 was also not found in previous literature as the past papers only talk about the direct shift from traditional to BIM 5D. But incorporating BIM 5D is not easy and can not be done at once, especially in large organisations. To help organisations slowly transition into BIM 5D, they usually create an intermediate software, usually using excel, which contains some features of an ideal BIM 5D software but not all. This is usually done so that the work processes are not suddenly changed but are slowly transitioned to fit BIM 5D. But this poses a challenge when people assume that the intermediate software is the BIM 5D software and do not agree to move ahead.

4.6. FINDINGS SUMMARY

An overview of the findings in Phase 2 is mentioned in this chapter:

- The development of a standard BIM definition is vital to ensure everyone in the team is in concordance.
- The use of BIM 5D is restricted to a few departments. The knowledge sharing between departments is also insufficient as the departments are unaware of the innovations going on in the other.
- If a project manager is not supportive of BIM 5D in a project, it can have all the BIM experts in a project, but BIM 5D will not be implemented.

- Unawareness of the benefits of BIM and BIM 5D in the organisations is one of the leading causes of its slow progress.
- Not investing time in preparing the BEP leads to non-standardised way of working in a project hampering collaboration, automation, knowledge transfer and blurring the project outcomes. BEP can help with costing details in the model.
- The effective communication between the architects and the cost-engineers is essential. The cost-estimator needs to be aware of the object boundary to calculate the accurate cost. The cost-estimator and designer should be clear about what information they will be adding to the 3D model, to reduce rework. This can be a achieved by investing time in the BEP.
- The model needs to be in .ifc or .dwfx file format for it to be compatible with the Cost X model. Even if the Cost + model is used, the file type should be standard as it has to be compatible with Autodesk Revit, which is the popular choice in Arcadis. Thus, to maintain uniformity, it is very important to stick to a standard file type.
- Despite the challenges, Revit remains a popular choice in the organisation as it improves collaboration with the various departments. On a positive note, Revit is constantly evolving and is adding new features to help model infrastructure projects, and these BIM experts are getting well versed with it.
- BIM 5D improvement in an organisation will only occur as more and more projects are done with BIM 5D. Implementing BIM 5D on projects will help the object libraries grow, increase the experience BIM staff and popularise its benefits. This can be difficult if the clients do not demand BIM 5D as Arcadis is a client driven organisation.
- Creating a sound library (database) is always a starting point for using BIM in a project. It will help automate the costings process. It needs to be done as and when new components are encountered for projects. This is the only way the object-based library can grow.
- Improving the collaboration between the regional Arcadis offices and the GEC will help improve the BIM processes as the GEC has high BIM knowledge and expertise and also offer competitive labour costs.
- The analysis of the challenges indicated that the issues majorly identified by Focus Group 1 were related to the general working of BIM in the organisation as most of them are BIM Ambassadors or BIM front runners. Whereas for Focus Group 2 and 3, since they only work within their department, the issues identified were specific to BIM 5D and costing.

5

PHASE 3 - RESEARCH OUTCOME

This chapter consist of the outcomes from Phase 3 of the research. In this chapter, we first clarify the most significant assumption made at the start of the thesis: "The building industry is mature with its BIM implementation than infrastructure". After confirming that the assumption made is valid, we look at the steps the building industry took to achieve a high BIM 5D maturity, the advantages the building sector has over the infrastructure (in terms of BIM). Then, the infrastructure department can learn from the building department are highlighted and then the finally points of improvement for both the departments to reduce the risk of re-inventing the wheel. This section answers the sub-question 4 and 5: *" What steps were taken by the building sector to boost BIM/BIM 5D implementation? "* and *" What lessons can the infrastructure sector take from the building sector while implementing BIM 5D? ".*

5.1. DATA GATHERED

Since the aim of this phase was to answer the sub-questions 4 and sub-question 5; the interview questions were focused on the topics stated below:

- The working of BIM and BIM 5D for the building department.
- The ways they have managed to achieve a high BIM maturity.
- The reasons why BIM is more mature in the building sector and department.
- The recommendations they can give the infrastructure sector for implementing BIM.
- The lessons they can learn from infrastructure regarding BIM 5D.

5.2. IS BUILDING DEPARTMENT MORE MATURE IN BIM 5D?

In section 2.4 of the literature review, the BIM application in Infrastructure and Buildings were compared. It is seen that BIM application for both is similar in some aspects, but

with others, it varies by a large degree. There are 2 aspects in which the BIM application varies, first is due to the geometry and the size [(Costin et al., 2018), (Cheng et al., 2016)] and second is the manner in which the different parties collaborate [(Bradley et al., 2016)]. Just these two differences give rise to many challenges for the implementation of BIM in infrastructure projects.
An assumption was made at the beginning of the thesis that the building industry is more mature in BIM and BIM 5D than the infrastructure industry. This was validated with the help of literature, [(Costin et al., 2018), (Kim et al., 2016), (Bae et al., 2016), (Chong et al., 2016)] and with the help of interviews. The points from the interviews which helped validate this are:

- The building department has a 5D BIM App, similar to the Cost + model, which was developed ten years ago. It is an extensive and complex Excel program connected to the calculation model (Interviewee 4.1, 4.2).
- The energy department has just adopted this same program for their pilot projects (Interviewee 4.2), ten years after the building department. They are working towards creating a similar work process and program that will specifically suit their needs.
- In the infrastructure department, they still work with the outdated CAD software compared to the buildings department which is fully working with BIM (Interviewee 4.1, 4.2).
- The building department has also started linking shadow costs to the BIM 5D app for sustainability assessment (BIM 6D) (Interviewee 4.1, 4.6).
- But there is one point where both the departments are at an equal level in progress. The experience of using the BIM 5D software, Cost X. Both the departments are in the initial stages of using this software since it has been newly introduced in the organisation.

5.3. STEPS TAKEN BY BUILDING DEPARTMENT

As seen in the above sub-section, the building department is way ahead in the infrastructure for BIM and BIM 5D. The building department has also been using BIM for over ten years, so they have had the time to figure out which ways of working are favourable and which are not. The steps taken by the building department which helped the department advance in BIM are given below:

- The designers are asked to create the models in a certain way, including all the necessary information needed by the cost estimators (Interviewee 4.1). This is done by involving the cost estimators and cost managers in planning the BEP (Interviewee 4.3). This makes the job easier for the cost estimators as they have a clear idea of what information is included in the model and what additional information must be added.
- The department has already had their basic BIM training, so everyone is already familiar with BIM and BIM 5D (Interviewee 4.5) and is aware of how beneficial it

is when the teams follow the BEP. Apart from receiving the training, it is essential to learn BIM by applying it to projects; this is where the actual learning occurs (Interviewee 4.2).

- Since the department has been working on it for a long time; the people have had the opportunity to work with BIM on several projects and figure things out. Working on projects with BIM and BIM 5D has helped prove to the project managers that using BIM and BIM 5D can help achieve the stated benefits (Interviewee 4.4).
- The rate libraries are kept up to date by connecting material, labour and equipment cost to each element according to the market development. Apart from this, regular checks are conducted to review the rates to ensure they are updated with the market (Interviewee 4.3).
- The building department has sufficient BIM ambassadors, such that even when some BIM ambassadors have to work on their projects, there are adequate BIM ambassadors in the building department to help in other ongoing BIM projects (Interviewee 4.2). Moreover, apart from relying on BIM ambassadors and front runners, the building department has also involved many people in the working of BIM.
- The building department has worked with the GEC to help create the models and libraries. The GEC has played an essential role in the development of BIM 5D (Interviewee 4.2). main knowledge transfer that can happen from past to future projects is communication and collaboration skills with different parties involved (Interviewee 4.2). Since the building department has worked with BIM 5D longer and has more experience collaborating with various parties.
- Despite the BIM maturity being high, the building department knows that it is an on-going research and will continue looking for insights to implement BIM more efficiently.

5.4. FAVOURABILITY FOR BUILDING DEPARTMENT

As seen in the above sub-section, the building department has taken many initiatives to enhance the BIM and BIM 5D maturity. But there are several advantages the building industry has over the infrastructure industry, which has helped paved the way for high maturity levels of BIM. This will help us understand which infrastructure department can use steps from the building industry as lessons by tweaking them to suit the needs of the infrastructure department and which steps will not be applicable for the building industry. The findings from the interviews are given below:

- The building department has a customised method statement which explains the details of the costing process: the various types of measurements you can take out like gross volume, gross area, built-up surface area, all standardised ways of measuring surface areas, built-up areas and volumes. It also talks about measuring in a standardised manner (Interviewee 4.3) by calculating the roof area, built-up area, and the gross volume compared with other measurements. You can see if the

quantities have the proper measurements compared to the other measurements made. Because the process is standardised, there are approximate measurements available. Like the number of doors per area depends on the type of the building. This is not available for infrastructure.

- The building department also has the advantage that the Dutch standards are available and built-in Revit. It is a BIM library that contains the object naming, the set parameters etc. (Interviewee 4.2, 4.3, 4.4 and Interviewee 1.4).

- The main part of costing for buildings is material, but infrastructure projects are related to planning (Interviewee 4.3). This is because the completion of infrastructure projects take a much longer time than buildings. A minor delay in designing or procurement can increase the cost of infrastructure projects by a considerable margin. Combining the BIM 4D and 5D at the moment in one software is very difficult, at the moment, given the level of automation.

- Clients in the building department require BIM implementation in the project (Interviewee 4.1). Even though they only ask for a 3D model for visualisation, it can complement the BIM 5D process as BOQ is extracted from the BIM model for cost estimation. And having a good BIM 3D model is necessary for a good BIM 5D. For infrastructure, very few clients ask for BIM (Interviewee 1.3).

- Change Management is the biggest challenge which implementing new software. People need a lot of convincing to help them improve the working process (Interviewee 4.3). Since the clients demand BIM in their projects, it has helped the organisation accept it better as they have no other option but to work with BIM since it is a client-driven company.

5.5. LESSONS FOR INFRASTRUCTURE

In the previous two sub-sections, we saw what steps the building department has taken to implement BIM and BIM 5D and the advantages the building industry has over the infrastructure department. After analysing the data from the interviews, a list of applicable lessons for the infrastructure department is created. This will help in the creation of the final list of recommendations.

- The cost program, which is currently being used for buildings, can be used for infrastructure but not in its current state. The energy department has adopted this currently; it is being tailored only to suit the needs of their clients. The other departments within the infrastructure can start developing this if they are hesitant to directly move to the Cost X software. The problem with this is that if departments within infrastructure start developing this technology with excel sheets now, it will take them an even longer time to shift to the Cost X model. But still, it is a step towards BIM 5D and is worth investing in.

- Designers should be asked to make their models in a precise way. For BIM 5D, it is essential that the cost-engineer knows what is modelled and what is not to

interpret the model accordingly. This is a challenge faced in the infrastructure department. Only designers are included in BEP, and the cost-estimators are directly handed over the model at the end of the design phase. An extensive information model can be achieved by involving the cost-engineers while the project teams prepare the BEP. The designers and engineers should follow the BEP, so the cost manager has all the required information in the model. This will make it easier to detect object demarcation and access the actual ground conditions, and hence the 3D model will be up to the standard required by the cost-estimator.

- The cost data is very extensive sometimes is very complicated. In the initial phases, it gets tricky as not a lot of information is required. So the infrastructure department can try to reduce the complexity by sorting out and organising the data based on the phase of the projects and according to the type of infrastructure will make it easier to access it.
- Start implementing BIM and BIM 5D in projects. This will offer various benefits and help eliminate some challenges faced by the infrastructure department. Firstly, the libraries will get updated during a project as new objects are encountered. Having a good object library results in an improved BIM model and Quantity takeoff. Secondly, it will help build up the BIM and BIM 5D experience of employees and find ways to suit their department better. Lastly, it will also help project managers see the benefits BIM and BIM 5D has to offer, and they will be more encouraged to implement them for their projects.
- Since the infrastructure is just starting with BIM 5D, it is recommended that they directly adopt to the Cost X or Cost +, which is much more advanced than using simple Excel sheets. They can work with the GEC to build the initial set of object libraries, and the new ones can be added as a new object is encountered. The GEC can also help with the initial figuring out of the Cost X model, as the GEC has more knowledge about it, thus bridging the knowledge gap between the GEC and the regional offices. A standardised method should be followed to create the object libraries, so the information is stored in the same manner. A team should be dedicated to updating and checking object libraries; this can be partly from the regional offices and partly from the GEC.
- The main part of infrastructure cost is mainly related to planning; the infrastructure department should focus more on the cost of time and people, which can be difficult at the moment. Once the current costing process is automated, they can automate both BIM 4D and 5D together.
- Slowly, with time, try getting all the employees in BIM and BIM 5D so the maturity of the entire department can grow, instead of just relying on BIM Ambassadors and front runners.

5.6. POINTS OF IMPROVEMENT

Although the building department has implemented BIM for ten years and is quite mature compared to the infrastructure sector, that does not mean that it is perfect. There

are several areas of improvement for both sectors. The benefit of adding this section, points of progress for both while the infrastructure is learning from the building sector, is that it will help eliminate the risk of reinventing the wheel and help both advances in the right way.

- For both the building and the energy infrastructure department, the entire costing program is on Excel. This extensive model has just one person working on it, so only he understands entirely how it works, making it difficult for other people in the organisation to think along, understand and contribute to using or improving the model. To eliminate this, it is best if more people are involved in this costing model so that the BIM experienced professionals in the organisation are more.
- If training is held regularly; then people tend to work in a standardised manner, as they work in the way they are taught and don't struggle to find ways which best suit them. This will pave the way for a standard way of working. Training for designers and engineers are pretty popular but not so much for cost managers. The Cost X training can be given so that everyone starts working in a standard way from the initial stages. Both the departments need to take this initiative.
- For a highly collaborative project environment, all the respective parties should understand the standard guidelines when they start with a project. Invest more time in planning and understanding the challenges rather than just focusing on their job.
- Since both the building and the infrastructure departments are just in the initial phase of shifting to the Cost X model, they should understand that it will take a lot of time and effort for the benefits to be noticed. They need to continue with the BIM 5D implementation and not give up.
- For BIM 6D, since it done at the end, adjustments can not be made as the design is already finalised. If environmental cost and carbon emission are available at the earlier stage the sustainability experts can advise the designer regarding the effect of the selected elements before the design is finalised. This step is for the future and currently out of scope of this research.

6

Result - Recommendations for Organisations

After analysing the data in the first and second round of interviews, the challenges faced by infrastructure projects were recognised and the reasons why the building sector is ahead with BIM 5D were understood. The interviewees were the highly experienced BIM and BIM 5D professionals of the organisation. From the challenges and lessons from the building sector, the changes which need to be brought about in the working were identified.

The recommendations are based on the data collected and thus this section answers the sub-question 6: *"What recommendations can be given to organisations (in infrastructure) to assist with their BIM 5D implementation?"*. The recommendations are based on the findings from the book, Management Strategies for 5D-BIM Adoption in Hong Kong [I. Y. Chan et al., 2018] and hence were sorted according to the type of organisation: Consultant, Client and Contractors, as the implementation strategy depends on the role of the organisation the strategy changes. Although the recommendations are divided into 3 categories, they have come common goal; i.e. improving the maturity in the organisation w.r.t BIM 5D. In each section first the recommendations are presented and followed by the expected outcomes of the recommendations divided according to the four elements of BIM stated by Bradley et al., 2016.

Before we have a look at the recommendations, here's a list of assumptions on which these recommendations are made:

- The organisations follow the same working structure as Arcadis: they have assigned BIM front runners and they have operating companies.
- The organisations make use of a standard BIM document before starting a project with BIM.

- The organisations have adapted an intermediate software between the traditional costing methods and BIM 5D instead of directly shifting from one to the other.
- And finally, the organisations faced the same challenges as Arcadis while implementing BIM 5D irrespective of their roles.

6.1. RECOMMENDATIONS FOR CONSULTANCY ORGANISATIONS

The information was gathered from a consulting organisation, so for this reason the recommendations for the consultants will be divided into recommendations for individuals and teams. According to the book, Management Strategies for 5D-BIM Adoption in Hong Kong [I. Y. Chan et al., 2018], the plan of improvement of BIM 5D, for consultancy organisations, should be focused more on the development of the standard way of working with BIM by taking the help of guidelines or a framework.

1. **Publicize the benefits of BIM and BIM 5D to Project Managers.**

   Recommendation 1: Promote the use and publicise the benefits of BIM and BIM 5D to Project Managers to ensure a project has enough support and resources to incorporate BIM 5D. The infrastructure department should first evaluate the BIM maturity of the various sub-departments to determine the efforts required.

   Project Managers and Lead Engineers take the major decisions to set the course of action for a particular project. Hence, the promotion of BIM should start from them. This will ensure that the project has sufficient additional time allocated for BIM (initially, until the organisation gets a hang of BIM 5D), additional BIM experts and resources. This will also make it easier for the BIM experts to advice the right course of action, as the project management decisions will be based around BIM.

   Before publicizing the benefits, the misconception and unawareness regarding BIM 5D also needs to be cleared out. This can be done by the top management by promoting a standard BIM definition throughout the organisation. A common BIM definition will allow the organisation on the same page regarding BIM. The top management and top BIM experts in the organisation first need to estimate the BIM maturity of the organisation and also for the various departments, for example: by conducting a survey. This will help determine the effort required.

   According to Interviewee 1.6, promoting BIM 5D is very important as only once you start using new technology and you will realise the benefits it has to offer. This is proven to be effective by the building department as it got their project managers on board and started implementing BIM 5D to projects. Indirectly, this will also lead to an increase of object libraries, which is another recommendation 5.

   The benefits of using BIM can be publicised by the examples from previous projects, holding seminars, making use of the BIM front runners to help with initial figuring out of BIM and also by collaborating with the GEC. The project managers can also help to make BIM 5D popular among their clients by revealing the progress from previous projects. All in all, this will help resolve challenges 1, 2, 9, 12 and 19. Although, the project teams will consume more time and effort initially, as they are still figuring out BIM 5D, it will be beneficial in the long term.

2. **Utilize the expertise of BIM Front Runners.**

   Recommendation 2: Utilize the expertise of the BIM Front Runners as they are already well-versed with the BIM to promote prompt decision making and effective knowledge transfer by including at least one BIM Front runner in a project team.

   BIM front runners are assigned in the organisation to keep track of the constantly advancing technology. They have the required BIM knowledge and know which aspects will be beneficial to their department. This is why project managers should utilize the expertise of the BIM front runners by actively involving them in the project decision making related to BIM and BIM 5D. It will help project teams to get the right start to the BIM implementation in a project and also promote the development of the standard way of working (either using the BEP or a standard software and file type) instead of project managers trying to solve issues in their own way.

   To implement this recommendation, the department needs to have sufficient number of BIM front runners and should also take into account the personal work allocated to the front runners to make sure they are not overburdened. Thus, it is important to work on increasing the BIM maturity of the organisation. The organisation may create a requirement sheet, which states the BIM experience and requirement required to become a BIM front runner. The revision of organisational roles will cost the organisation its resources.

   It should also be noted that for BIM front runners to assist the project teams, they should be provided with the right hardware. Thus, this recommendation will play a part in resolving the challenges 3, 5, 6 and 7. It will also help with recommendation 3. The same outcomes can be achieved my involving members of the GEC in the project teams.

3. **Spend time preparing the BIM Execution Plan.**

   Recommendation 3: All the department should get together before the start of the project to prepare the BIM Execution Plan and take collective efforts to continue to follow it.

   The most important point of focus, especially for consultancy organisations, is to create a standard way of working. The BIM Execution Plan, which is currently used in the organisation, can help with this and needs to be started as early as the tender phase (Interviewee 1.6). The BEP is a plan explaining how the various aspects of BIM modelling will be carried out. Involving the project planners and cost managers will put forth the requirements and questions of all the disciplines and reduce the discrepancies during the planning, costing and in the future sustainability. The BEP will particularly help cost estimators to detect object separation and access the information regarding the ground conditions, during the BIM 5D process (challenge 13 and 14). This is one of the lessons the infrastructure department needs to take from the building department.

   Following a standard BEP will offer many benefits to the project teams: it helps obtain a 3D model which contains all the right information needed for cost calculation, it helps keep track of changes and when they were introduced, it improves

collaboration between the different departments (internal and external) within a project team. But most importantly a standard BEP will aid in knowledge transfer (BIM guidelines) and create reusable information which will help fasten future BIM processes. Thus this action is highly recommended and needs to be initiated together by the Project manager and BIM front runners.

Therefore this recommendation helps resolve the challenges 3, 6, 13, 15, 16 and 20. This will increase the time spent on planning but will reduce discrepancies and confusion in turn saving time in the greater part of the project.

4. **Encourage departments to invest in the BIM 5D software.**

   Recommendation 4: Departments need to invest in the BIM 5D software and shift to BIM based costing to enhance the organisational BIM maturity.

   The BIM 5D, is slowly starting to gain popularity in the organisation. While a few departments are taking efforts to shift to BIM 5D by investing in the Cost X model or the Cost + Model, most departments mainly still use a simple excel sheet or simple programs for costing, which is not a BIM 5D software (challenge 4 and 8). The more time project teams take to shift to the BIM 5D technology the more difficult it will be for them to be up to date with it and hence the organisation will always be lagging. The departments should choose the software which most caters to the needs of the clients. An initial investment is required to attain the software license.

   Publishing the added value of BIM 5D in past project and its applicability in the future project can help motivate the shift to BIM 5D. The GEC and the BIM Communities Of Practice can also help with the shift. Once the departments and project-mangers shift to implementing BIM 5D in projects it will lead to an increase in object libraries and experienced BIM staff in an organisation, thus eliminating challenges 12 and 17 and increasing knowledge and thus BIM maturity. It will also allow the process to suit the client requirements, making them more accepting to BIM.

5. **Work on the expansion of the cost data base for BIM 5D.**

   Recommendation 5: Work on the expansion of the cost database, this can be general cost information or object libraries for the BIM 5D software.

   Having a good object library is one of the most crucial points when it comes to implementing BIM 5D for a project. This is one of the top challenges faced by all focus groups challenge 12. There are two ways to go about with this. First build the object libraries as new components are encountered i.e. by implementing BIM 5D to more and more projects. Second can be by dedicating a team to build the database. Simultaneously implementing both the methods, will fasten the process and create a standard way of storing data in the libraries (so that they can be re-used). This team needs to be a diverse team, consisting of people from all backgrounds.

   Initially, it is a lot of work as there are very few object libraries present at the moment. But as and when BIM 5D is used on more projects, the process will get easier.

For this recommendation to be put in place, recommendation 1 and 4 need to be ahead.

The outcomes of recommendations for Consultants mentioned above are listed in the figure below.

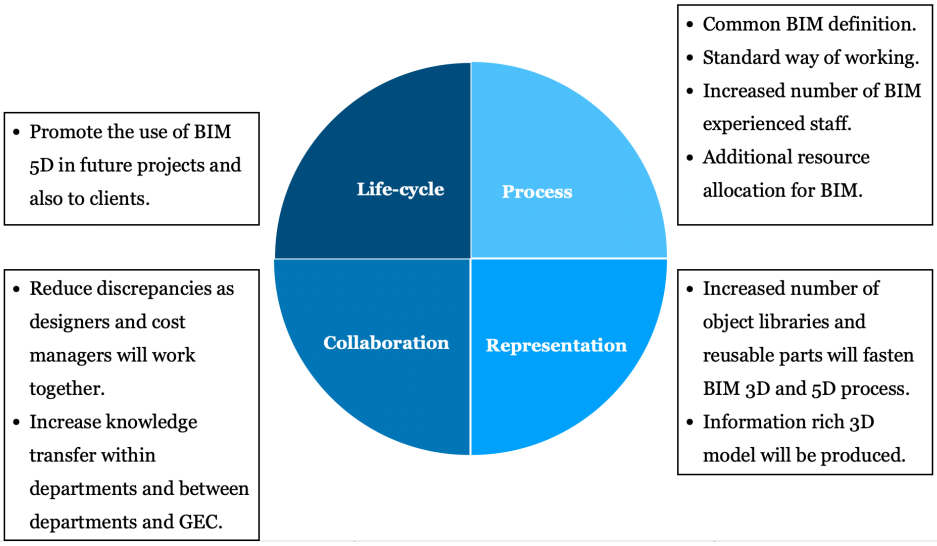

Figure 6.1: Outcomes of Recommendations for Consultancy Organisations

Apart from the general recommendations, there are a few more specific to individuals and teams. These are explained in the sections below:

6.1.1. RECOMMENDATIONS FOR INDIVIDUALS

This set of recommendations will be specific to individuals in a consultancy organisation.

1. Designers and modellers need to pay close attention and start coupling the reusable parts. This can be highly beneficial as it will make the BIM process faster and easier thus, making more accepting. For example, in energy infrastructure, a full bay can be reused for future projects, provided the voltage is the same. Doing the same and finding reusable parts for different infrastructures will help fasten the process than starting from scratch.

2. As mentioned earlier, the GEC has a lot of experience in BIM as they are used to working with several regional offices. Working on BIM and BIM 5D together with GEC can present the departments and project teams with several advantages. The GEC representative allocated in each department needs to promote the latest developments and success stories to the regional offices to encourage project teams to collaborate more with the GEC, as an effort to build trust between individual employees and the GEC.

3. When it comes to new technology, the contractors are usually more advanced and have a better idea of how to progress with new technologies because they have a higher first hand experience. Interviewee 2.2, has worked closely with contractors to improve his experience with BIM 5D. Similar efforts need to be made by every individual to learn about the new technologies from the contractors. Even if everyone contributes in a small way, collectively it can lead to sizeable knowledge contribution.

6.1.2. RECOMMENDATIONS FOR TEAMS

This set of recommendations will be specific to teams in a consultancy organisation.

1. As mentioned earlier, the levels of the BIM maturity of the departments vary. That means some departments have higher knowledge and grasp of the working of BIM 5D. Knowledge sharing between departments will be beneficial as it will prevent repetition of previous mistakes. Departments which have more knowledge, can help the others, but at the moment the knowledge transfer is restricted (challenge 20). The sharing of knowledge can be done by preparing a short report or presentation and share it with the help of COP, by using the BIM network and also by involving the GEC, as they interact with various project teams. This will help save ample time and can prevent re-inventing the wheel.

2. Project teams should take initiatives to include employees from the GEC as they can sometimes have more experience than the regional offices and the GEC offer skilled labour at competitive rates, which helps save time and costs. The GEC too needs to be fully transparent be vocal about the advantages as well as the challenges faced while dealing with projects so that there is no miscommunication. Infrastructure department should put efforts to increase collaboration with the GEC and build trust between the two parties.

6.2. RECOMMENDATIONS FOR CLIENT ORGANISATIONS

According to the book, Management Strategies for 5D-BIM Adoption in Hong Kong [I. Y. Chan et al., 2018], the plan of improvement of BIM 5d, for client organisations, should be focused more on boosting the BIM 5D knowledge of the employees by providing training and focus on the development of standard use of modelling using BIM 5D. Apart from the assumptions mentioned at the start of the Chapter, the assumption made in this section is that Contractors are more mature in BIM 5D than Client Organisations.

1. **Boost the benefits of BIM 5D to Project Managers.**
   Recommendation 1: Boosting the benefits of BIM and BIM 5D to Project Managers will ensure that project has enough support and resources to incorporate BIM 5D.

   This recommendation is the same as Recommendation 1 mentioned above.

2. **Boost the BIM 5D knowledge with the help of BIM Front Runners.**
   Recommendation 2: Utilize the expertise of the BIM Front Runners to boost the BIM 5D knowledge, promote prompt decision making and effective knowledge transfer in the organisation.

This recommendation is the same as Recommendation 2 mentioned above.

3. **BIM 5D training will boost BIM 5D knowledge.**

   Recommendation 3: Providing BIM 5D training to employees will help boost BIM 5D knowledge and establish a standard way of working.

   Offering standard training to the members will help cultivate a standard way of working as everyone will follow the steps taught in the training program thus eliminate challenge 3. The training programs will help boost the 5D knowledge and make the organisation more accepting to BIM 5D. This training can be provided in the manner which best suits the organisation. Whether the training should be given by an external party or by the current employees in the organisation, should be their choice depending on what suits it best.

   Depending on the maturity level of the of the organisation or a department within an organisation, the training program offered varies. Accordingly, the cost and time to be invested will vary. But merely providing BIM training doesn't increase the BIM maturity of the organisation. The knowledge gained in the training should be applied to real project to gain BIM 5D experience on a variety of projects.

4. **Learn new skills from Contractors.**
   Recommendation 4: Client organisations should take take initiative to learn new skills from contractors and expand their knowledge of BIM 5D.

   For costing related to scheduling, the contractors are more advanced as they know how to fasten the process and what to build first. They have a better idea of how to progress with new technologies. This step does not require a special provision but just a conscious effort to learn new skills. Learning about the new technologies the contractor uses can help in the future when they start adapting new technologies. This was proven to be effective by Interviewee 2.2, working closely with contractors on BIM 5D help him expand his BIM 5D knowledge.

The outcomes of recommendations for Clients mentioned above are listed in the figure below.

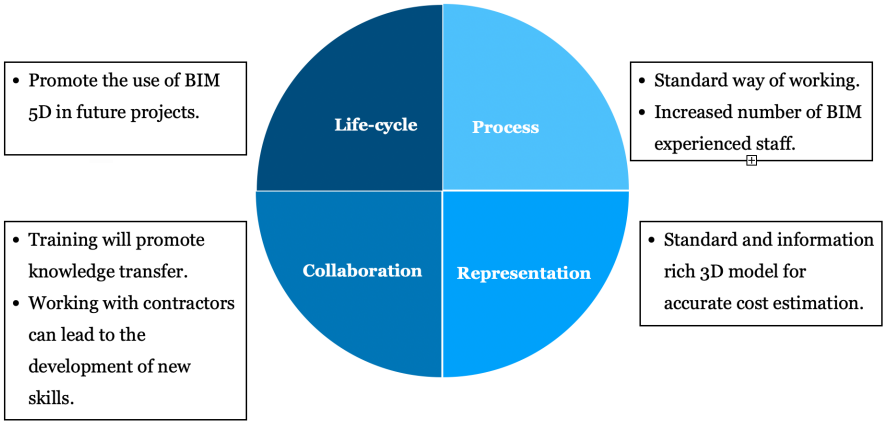

Figure 6.2: Outcomes of Recommendations for Client Organisations

6.3. RECOMMENDATIONS FOR CONTRACTOR ORGANISATIONS

According to the book, Management Strategies for 5D-BIM Adoption in Hong Kong [I. Y. Chan et al., 2018], the plan of improvement of BIM 5D is by providing constant feedback to the employees to enhance BIM 5D. The additional assumption made in this section is that Contractors most mature in BIM 5D than Client and Consultancy Organisations. After incorporating the recommendations for the consultants, some additional recommendations the contractors can focus on are:

1. **Work towards the constant improvement of the BIM 5D Process.**

   Recommendation 1: Work towards the constant improvement of the BIM 5D process in order to achieve maximum efficiency and maximum benefits of BIM 5D.

   The BIM maturity of an organisation can be improved by implementing it to more and more projects. This helps the people understand the process which works best for them. At the end of each major project, every team can prepare a small presentation for the BIM front runners or create a file that highlights the lessons learnt while implementing BIM in a project.

   The other thing is to improve is the alignment of the BIM processes with the organisations processes. This will then prevent future projects from repeating the mistakes, promote knowledge transfer and will lead to the growth of BIM 5D in the organisation.

2. **Promote the use of BIM 5D to Clients.**
   Recommendation 2: Promote the use of BIM 5D to Clients by displaying the added value of implementing BIM 5D.

   The contractor has the power to popularise the advantages of BIM 5D as they have a higher first-hand experience, as contractors are more diverse and do not stick to only buildings or infrastructure. Encouraging clients to invest in BIM 5D and

will result in the parties working with the same platform. This will be beneficial to contractors as it will lead to a strong collaboration between the parties and thus will lead to achieving a higher BIM maturity. This is also beneficial to clients as they can use the models in the Operation and Maintenance phase.

In a client driven organisation, it is very important to get the client on board with a technology to utilise it to the utmost potential and improve BIM maturity. This recommendation is also valid for Arcadis, as it is client-driven.

3. **A strong BIM 5D can fasten the BIM 6D Process.**
Recommendation 3: A strong BIM 5D can fasten the BIM 6D process and in turn increase the BIM maturity of the organisation.

   Having a highly matured BIM 5D can help fasten the BIM 6D process. According to Interviewee 4.1, BIM 6D calculation can be done in almost the same manner as 5D. The quantities extracted for the BIM 5D process can be used to calculate the amount of CO2 emissions for BIM 6D. The quantities can also be multiplied with shadow costs, instead of material or labour costs, for project managers to better understand the cost-benefits, in terms of economy, social and sustainability, linked to a project [Munda, 2014]. This will help organisations enhance the quality management processes.

4. **BIM 5D combined with GIS offers added advantages.**
Recommendation 4: BIM 5D combined with GIS offers added advantages for BIM 4D and 5D by providing timely information.

   By integrating GIS with BIM, not only do you see the design but also the real-time specifications of the project like the contracts and their status. Tender documents can be fed in with the help of GIS, to access documents specific to a part of a phase of the project. The 5D model created can be linked to the schedule of the project and the cost attached to the GIS [Andhyal* et al., 2021]. This can be done for one project as a whole or by dividing it into phases. Both GIS and BIM can be used to enhance each other as GIS can be used to both extract information from and feed information into BIM . Lately, there are various add-on's available and these help with automation. Similar benefits offered when BIM and GIS are combined are mentioned in Al-Saggaf and Jrade, 2015 and Mijic et al., 2017. Thus, it can help with the schedule based costing for infrastructure.

   Currently, infrastructure is mainly focused on BIM 3D, 4D and 5D but when they move to BIM 7D, maintenance and operation, GIS and digital twin will be of much help. For an organisation to achieve high level BIM maturity, it is important to up to date with all BIM and BIM related technologies. GIS can help ease this process for a BIM mature organisation.

All the recommendations mentioned above will require considerable time and cost investment but when compared with the benefits of BIM 5D once the process is perfected, it will be a valuable investment.

The outcomes of recommendations for Contractors mentioned above are listed in the figure below.

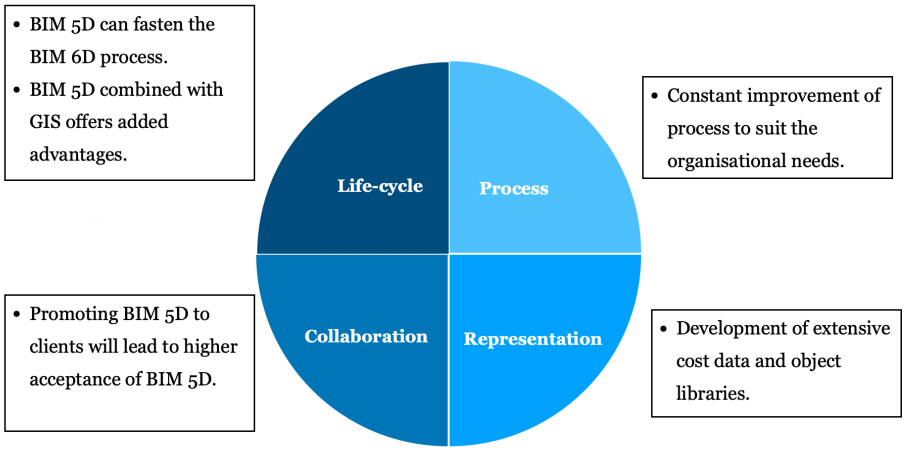

Figure 6.3: Outcomes of Recommendations for Contractor Organisations

7

Phase 4 - Validation of Recommendations

In the previous chapter, the result of this thesis - recommendations for organisations to enhance the BIM 5D implementation were stated. The experts in Arcadis have validated the recommendations for consultancy organisations. The comments and the suggestions provided by experts are stated in this chapter. This consists of the last phase of the research, Phase 4.

Interviews were conducted with three experts in the organisation. Their names are mentioned in Section 7. Interviewee V.1 is the BIM Ambassador for Tram and Heavy Rail. BIM Ambassadors in the organisation are front runners assigned to departments to help with the BIM implementation. They are up to date with BIM implementation in the organisation. Interviewee V.2 is the Leader for Digital Transformation in Arcadis Netherlands. Interviewee V.3 is a Cost Manager working with the Cost X model. He is one of the few employees who have worked on almost every project with Cost X, and it is costly trying to find ways to ease in BIM 5D in the organisation. All three experts are from different domains.

This was done in 2 steps. First, an Excel sheet was sent with the recommendations, which they were asked to mark. After the Excel sheet was filled in, a meeting was held to ask additional questions and discuss the results. A snapshot of the Excel sheet is shown in Appendix E and the questions are mentioned in Appendix B.3.

For the consultancy organisation, Recommendation 1 - Publicise the benefits of BIM and BIM 5D to Project Managers and recommendation 2 - Utilise the expertise of BIM Front Runners, are approved to be the most important. As the acceptance of project managers is most important for BIM 5D utilisation in a project, and BIM front runners have the expertise to guide the project teams with BIM in the right direction.
Recommendation 3 - Spend time preparing the BIM Execution Plan are ranked lower

by Interviewee V.1, and V.2 as according to them involving the BIM front runners will help with the BEP. So these two recommendations are not as important as the previous two. The main issue with the BEP at the moment is that it does not contain inputs cost managers. According to Interviewee V.3, BEP is necessary to establish how the different departments can contribute to improving the BIM process.
Recommendation 4 - Encourage department to invest in the BIM 5D (Cost X) software, said to be very important for organisations (Interviewee V.2, V.3). Yet, it has been ranked lower by Interviewee V.1 as this action should happen over time and not immediately. Departments should be given time to decide when they are ready to shift to the BIM 5D software based on the feasibility and client requirements.
Recommendation 5 - Work on the expansion of the cost data for BIM 5D, is ranked lower by V.1 and V.2. The reason being, the building of databases, should be done by everybody and not just one team as then everyone can experience the benefits BIM 5D has to offer. Also, establishing the database can be done simultaneously when a project implements BIM 5D instead of having a separate team. But this has been ranked higher by Interviewee V.3 as an already existing cost library can make the job of cost-managers a lot easier and fasten the BIM 5D process.

Two additional points are mentioned by Interviewee V.2 that need to be considered apart from these recommendations. First, the organisation needs to understand the BIM workflow in their department so they know what to prioritise. The second point is getting the clients on board with BIM and BIM 5D. For Arcadis, being a client-driven organisation, it is important that clients incorporate BIM in their projects. Unless the client demand BIM, the project teams will never really be serious about implementing BIM and BIM 5D in their projects. Consultancy organisations primarily focus on how they can improve the BIM 5D experience of clients. The BIM process, although standards, should be flexible enough to sort the client's requirements. An example of this is the Cost + model developed by the energy department. It was adapted from the building department, but it was fine-tuned to suit their client's requirements.

According to Interviewee V.3, a point to be considered is the segregation of data. This should be included in the BEP. The designers and cost estimate need to work together on a project to determine what information is already present and what information is not and who can make this information available easily. If the responsibility of adding all the information is given to the designers, they will get overburdened and hence show resistance. Therefore, BIM 5D is more a team effort rather than an individual effort.

8

DISCUSSION AND LIMITATIONS

This chapter consists of the discussion of the findings of the thesis and the limitations of this research.

8.1. DISCUSSION

The implementation of BIM in infrastructure projects is slowly emerging and spreading to various parts of the world [Thurairajah and Goucher Bsc, 2013]. But given that BIM was introduced in the construction industry 20 years ago, its progress is relatively slow, and organisations struggle with BIM 5D implementation. To outmanoeuvre this and succeed with BIM 5D, organisations need to understand the challenges which hamper their growth [Sardroud et al., 2018]. To succeed with BIM 5D, organisations need first to understand the challenges which hinder their growth [Sardroud et al., 2018]. Hence, the first part of the main - question *"What are the challenges faced by organisations while implementing BIM 5D for infrastructure projects?"*. Phase 1 (sub-question 1) of the research focused on the theoretical challenges faced while implementing BIM 5D in general. Phase 2 (sub-question 3) of the research focused on the practical challenges that infrastructure faced while implementing BIM 5D in the projects. Phase 2 found seven additional challenges. This was one of the research gaps aimed to be filled. It is found that for the infrastructure sector, the extra challenges arise due to the 3D model having inadequate information like inaccurate ground conditions, indistinct object separations and lack of object libraries, making the job of the cost-manager difficult. Another challenge detected in this thesis, which organisations face, is hesitance to give up old technology. For a large organisation, it is impossible to shift to 5D based costing directly. The organisations adopt several intermediate softwares, and the shift takes place in phases, and sometimes one of the intermediate phases is assumed to be BIM 5D, restricting the progress.

The high number of challenges experienced while implementing BIM 5D in projects can sometimes lead to professionals question the shift. To clear this doubt a few examples

found in literature and practical examples are stated. A study conducted by Liu and Hu, 2016 shows that using a 5D model for the construction of a substation, helped them achieve a better clash detection, reduced rework. This resulted in savings of 1.3 million Chinese Yuan. Not only this, the construction work achieved an efficiency of 70% by finishing the work three months ahead of time. Chahrour et al., 2020 showed that merely using the clash detection feature with BIM 5D, for a major infrastructure project helped reduce cost by around 20%. Arcadis has witnessed a couple of practical applications of the use of BIM 5D. In one project BIM 5D helped achieve Full-Time Equivalent (FTE) saving of 1.05 per month for the pre-tender estimates and 1.5 per month for cost estimates. In the other project, they achieved 20-30% of time-savings compared to traditional costing methods.

After presenting the evidence that incorporating BIM 5D in projects will help achieve the stated benefit, the focus shifts to how organisations can overcome these challenges. Hence, the second part of the main - question *"What changes need to be introduced to the use of BIM 5D for infrastructure projects in the future?"*. The answer to this question was found by first analysing the challenges and second taking lessons from the building sector since it is mature with BIM 5D when compared to infrastructure. The aim was to expand the knowledge the building sector has gathered, concerning BIM, to the infrastructure sector.

To consider what lessons from the building sector apply to infrastructure, the researcher compared the application of BIM in the building and infrastructure industry. The findings from the interview are compared with the differences found in the literature to depict its relevance. From the interviews, it was found that most BIM modelling softwares are more suited for buildings than infrastructure. This is because most BIM softwares are built, taking into account the Cartesian coordinate system making it unsuitable for infrastructure. Secondly, although the building industry has extensive BIM/BIM 5D related data, it is of no use to infrastructure because of the difference in structure and elements. And most importantly, with this research, additional challenges were identified relating to geography as infrastructure being horizontal projects even slight geographical variation is considered. Hence, due to the presence of these advantages, the BIM implementation in buildings is more advanced. Nevertheless, the building industry did take additional steps to enhance its BIM 5D implementation. Like building a cost database, constantly updating and sorting out the cost data, assigning sufficient BIM ambassadors to boost knowledge transfer, involving cost managers in the BEP and mainly by actually implementing BIM 5D in projects to recognise which way works best for them.

The set of recommendations created were based on the assumption that all organisations faced the same type of challenge and working structure as Arcadis. This is not always true as the BIM maturity of an organisation depends on the role it plays in the construction process. Although the results mentioned in Chapter 6 are specific to Arcadis but they can be generalised and applicable for other organisations as well. The recommendations target roles like Project Managers, BIM front runners are common to all organisations only the designation may vary, the BEP is a document universally

adopted when BIM is implemented in projects and organisations looking to incorporate BIM 5D have access to BIM 5D softwares. The only point which is not applicable to other organisations is collaborating with the GEC since only large organisations have operating companies.

However even if all the recommendations are taken into consideration it is still very difficult to achieve 100% automation especially when it comes to BIM 5D. Costs like material and labour can be standardised but will need to be updated regularly. The external factors will be difficult to automate as the cost depends on several external factors like the economy of the country, inflation, exchange rate between countries, supplier rates (which vary according to demand), unexpected ground conditions etc. Due to this, a certain percentage of the cost-estimate will not be automated and will at least need to be checked by a cost-estimator. But this will be a small percentage.

An important factor which needs to be taken into account for a successful BIM 5D implementation in infrastructure projects is making the clients more accepting to BIM 5D. There are two ways to approach this. One way is to fine-tune the BIM 5D process to suit the requirements of the client and make the process client specific. This method is working well for the Energy department in Arcadis, the Cost + model caters to the needs of their major client. The second way is making the use of BIM obligatory by the government, but this method is beyond the organisations control. Previous research has shown that BIM implementation is successful only in those countries whose governments have embraced BIM, for example, The United Kingdom, Australia and Italy [Katke, 2020]. Since, the organisation is client-driven, if the client never accepts BIM 5D it will prevent the organisation from reaching its full potential.

8.2. LIMITATIONS OF THIS RESEARCH

In this section the limitations of this thesis research which need to be considered while interpreting the result:

- There is limited literature present on the implementation of BIM 5D in organisations. There was just one paper found which spoke about management strategies in organisations for implementing BIM 5D, which is used to make the recommendations. If more literature was available on this topic, then the management strategies according to the role of the organisation would be been explained more elaborately.

- In Arcadis, BIM 5D has been implemented on Bridges and Train stations. The challenges identified in Phase 2 of the research are limited to just these two. There can be additional challenges which arise when implementing BIM 5D on several other type of infrastructure.

- The research is limited to one organisation, Arcadis. The challenges determined and the results validated were thus limited to consultancy organisations with a similar approach. The BIM maturity of an organisation depends on the role it plays

in the construction process so the recommendations provided in the thesis can be apt, out-dated or be way too forward.

- The research is limited to large scale organisations, who can afford to invest time and money on BIM 5D. As mentioned in the literature review, BIM implementation for small scale organisations can be difficult [Stanley and Thurnell, 2014].
- All the interviewees are fully supportive of BIM and BIM 5D. Due to the bias towards, they only highlighted how projects can benefit by using BIM and BIM 5D but none specified the downsides of using BIM, if there are any.

9

Conclusion and Future Recommendations

9.1. Conclusion

This research was directed towards the improvement of BIM 5D in organisations, who deal with infrastructure by taking lessons from the building sector. This was done by first understanding the challenges the infrastructure department faced, then the steps which the building industry took to enhance BIM 5D. From this, a set of recommendations were created for the infrastructure department to implement to enhance BIM 5D. The research was successful as the main question and the sub-questions are answered, which is shown in this chapter. First, the sub-questions 1 to 6 are answered and then we proceed to answer the main question.

SUB-QUESTIONS

1. What kind of problems do organisations encounter while implementing BIM and BIM 5D?

The answer to this sub-question was gathered by doing a literature review and it consists of Phase 1 of the research. BIM 5D offers a lot of benefits that help organisations raise the project value yet, there are various problems present which hamper the BIM 5D implementation process. But to date, there is limited research done on the implementation of BIM 5D in organisations.

Incorporating BIM 5D is not an easy task and there exist numerous challenges. There were 10 challenges found in literature: Technical and Non-Technical challenges. The technical challenges arise due to the softwares used, the high installation cost, the time required to install and understand the working of the softwares and the compatibility

of BIM softwares and data. The non-technical challenges arise due to the people factor: due to resistance to change, the time required for training the employees, unwillingness to take a risk and adapt to new software challenges and intangible benefits of BIM. Apart from this, the challenges are also divided into inter and intra organisational. Intra-organisational challenges arise due to non-standardised BIM definition and procedure and non alignment of BIM processes with the organisation's processes. Inter-organisational include incompatible softwares and data-sets.

These challenges are then compared with the challenges found in Arcadis to detect what additional challenges the infrastructure faces while implementing BIM 5D.

2. How is BIM and BIM 5D currently used within Arcadis?

It is important to first understand the current BIM and BIM 5D processes in Arcadis, to analyse the challenges Arcadis faced while implementing BIM and BIM 5D and find ways to overcome them. The answer to this sub-question was gathered by conducting interviews with 3 focus groups: BIM experts, Cost Managers with BIM 5D experience and Cost Managers without BIM 5D experience, within the infrastructure department of the organisation. This constitutes Phase 2 of the project. From the experts, we learnt that:

- Costing without BIM 5D is done in excel. Cost X and Cost + are the two BIM 5D softwares/programs used.
- Although Autodesk (Revit) is the most popular BIM software in the organisation, many of the infrastructure departments still use 2D-CAD softwares for designing.
- BIM 5D was adopted in the organisation very recently and is only applied to bridges and train stations. So the cost libraries in 5D are only limited to those.
- The support to the use of BIM 5D, by the top management, is increasing with time. The strategies promoting BIM implementation are increasing. Yet, the project managers are still hesitant to use BIM.
- BIM front runners are assigned to promote and guide project teams with the use of BIM in the organisation by providing their expertise.
- The BIM Execution Plan is a standard document that helps guide the BIM implementation in a project. It consists of the plan to be used by a project, details like the project data, the type of models, level of detail of the model, the kind of discipline models to be prepared, person in charge of the BIM modelling and the BIM Coordinator.
- GEC (Global Excellence Centres) are the operating companies of Arcadis which help the regional offices by offering their high expertise in BIM and BIM 5D and competitive labour costs.

3. What problems did Arcadis face while implementing BIM 5D for infrastructure projects?

The Phase 2 interviews disclosed the challenges faced by Arcadis when they implemented BIM 5D on infrastructure projects. There were 24 challenges found, which are summed up. They were divided into 4 categories: Process, Representation, Collaboration and Life cycle. The challenges related to Process arise due to misconceptions, unawareness and hesitance of individuals to use BIM, non-standard procedures and file-types, non-availability of BIM 5D software and unsuitable hardware. The challenges related to Representation arise due to incompatibility of the modelling software, lack of object libraries, insufficient information in the 3D model, additional work load on cost managers and lack of experience BIM staff. The challenges related to Collaboration arise due to insufficient knowledge sharing between departments, knowledge gap with the GEC and non-accessibility to project data. The challenges related to Life-cycle arise due to the lack of competition in the infrastructure sector.

These results helped identify specific challenges to infrastructure projects, which hadn't been identified previously during the literature review. They exist due to lack of collaborating between the designers and cost managers which lead to insufficient information in the 3D model. The results also helped understand that BIM 5D in the organisation is very limited, scattered and unorganised, as it has implemented only recently.

BIM 5D implementation in the organisation is limited to energy infrastructure and bridges at the moment. The challenges identified are limited to just these two types of infrastructure.

4. What steps were taken by the building sector to boost BIM/BIM 5D implementation?

Phase 3 interviews were conducted with BIM and BIM 5D experts from the building sector. It is seen that the building sector has various advantages over infrastructure, which helped it implement BIM/BIM 5D to higher maturity. These include the in-built Dutch Revit standards, which are only available for buildings and not infrastructure. The building department also has a customised method statement for costing, which helps explain the various types of measurements and establishes a standardised way of measuring surface areas, built-up areas and volumes.

In addition to this, the clients in the building department have been more accepting of BIM and thus have given ample opportunities for the building department to figure the approach which suits them best. This approach can be client specific. Apart from the advantages, the building department has brought about some changes in the working, which also helped them with BIM, which makes the organisational processes considerably structured. These steps primarily include a standard and a highly collaborative way of working, regularly updating the cost libraries, working together with the GEC, applying BIM 5D to projects, and actually realising the benefits offered by it.

5. What lessons can the infrastructure sector take from the building sector while implementing BIM 5D?

The steps taken by the building department were analysed to see which can be applied for the infrastructure department, taking into account the current work process in the infrastructure department, the challenges faced and the external factors which vary for buildings and infrastructure. This data was gathered from the Phase 3 interviews and during the literature study. To begin, the lessons to learn include involving the cost-managers in the BEP, making them aware of the information added to the model by designers and the additional information they need to add. Apart from this, the project teams should also pay attention to structuring the available cost data. The other pertinent point is using the available expertise, BIM front runners to improve the current process, increasing the BIM 5D implementation in the department, and thereby increasing the number of experienced BIM personnel. Finally, learn how to collaborate with parties within the organisation by working together on the BEP. Apart from the lessons, the points of improvement for both the departments were noted to minimise the risk of reinventing the wheel. These include promoting BIM 5D training to achieve a standard way of working, investing time in preparing the BEP and involving more people to increase the knowledge transfer and thus the BIM maturity of the departments. This concludes Phase 3 of this research.

6. What recommendations can be given to organisations (in infrastructure) to assist with their BIM 5D implementation?

The last sub-question brings together all the information collected in Phases 1, 2 and 3 to develop a set of recommendations that will help the infrastructure department achieve a high maturity BIM 5D implementation. The recommendations were divided based on the role of the organisation: Consultant, Client, Contractor [I. Y. Chan et al., 2018]. The recommendations for **Consultants** are:

1. Publicise the benefits of BIM and BIM 5D to Project Managers.
2. Utilize the expertise of BIM Front Runners.
3. Spend time preparing the BIM Execution Plan.
4. Encourage departments to invest in the BIM 5D software.
5. Work on the expansion of the cost database for BIM 5D.

These have been further divided specifically for individuals and teams.
The recommendations for **Clients** include:

1. Boost the BIM 5D knowledge of Project Managers.
2. Boost the BIM 5D knowledge with the help of BIM Front Runners.
3. BIM 5D training will boost BIM 5D knowledge.

4. Learn new skills from Contractors.

The recommendations for **Contractors** include:

1. Work towards the constant improvement of the BIM 5D process.
2. Promote the use of BIM 5D to Clients.
3. A strong BIM 5D can fasten the BIM 6D process.
4. BIM 5D combined with GIS offers added advantages

The assumption here is that the contractors are more mature in the BIM and BIM 5D implementation when compared to clients. This assumption was validated by several interviewees during the Validation interviews.
Although, the recommendations mentioned above will enhance the BIM 5D process in organisations, they require considerable time and cost investment initially. But, when compared with the benefits of BIM 5D once the process is perfected, it will be a valuable investment.

MAIN-QUESTIONS

What are the challenges faced by organisations while implementing BIM 5D for infrastructure projects? What changes need to be introduced to improve the use of BIM 5D for infrastructure projects in the future?

The answer to the first part of the main question was gathered in 2 ways. First by doing a literature study and second by means of interviews, although the ones detected were general challenges and the ones detected from interviews are specific to infrastructure.

The data from Phase 2, challenges faced by infrastructure projects while implementing BIM 5D (section 4.4), the data from Phase 3, lessons the infrastructure sector can learn from the building sector (section 5.5) and points of improvement for both chapters (section 5.6) are studied to produce a set of recommendations which will reduce the challenges faced by infrastructure projects while incorporating BIM 5D and thus improve the BIM 5D implementation in the organisation.
The final result i.e. the recommendations varied according to the role of the organisation. The recommendations mentioned above are for Consultancy organisations. The reasons for only mentioning this are that the challenges faced are specific to consultancy organisations and only this set of recommendations was validated by experts since Arcadis is a consultancy firm. The recommendations for the Clients and Contractor organisations were made on the assumption that they faced challenges similar to Consultants.

9.2. RECOMMENDATIONS FOR FUTURE RESEARCH

Due to the time constraint, not everything could be investigated in this thesis, so here are a few recommendations for future research:

- The challenges identified for infrastructure in this research are limited to energy infrastructure and bridges, hence the scope is limited. Investigating BIM 5D implementation further, on different types of infrastructure projects, to check if additional challenges arise.
- Since the thesis is restricted to Arcadis, a consultancy organisation, additional people from different organisations like client, contractor and also other consultancy, should be interviewed to see if they face any additional restrictions, than the ones mentioned in this research. These can be due to the management policies, exposure to BIM and the role of the organisation.
- Only the recommendations for consultancy organisation are validated in this research. For the future the recommendations with the client and contractor need to be validated. The recommendations for Consultancies can be validated with other consultancy organisation to see if they cater to other organisations as well.
- Investigate how schedule-based costing can be automated for infrastructure. A major part of the cost for infrastructure comes from the schedule since they last for a long duration. Find ways to on how BIM 4D and 5D can be incorporated together.
- Investigate why the government, clients of infrastructure projects, in the Netherlands is lacking with BIM implementation while other countries like Australia, United Kingdom etc. have started incorporating BIM for infrastructure projects.
- For a certain type of infrastructure like water infrastructure it is very difficult to implement BIM because it's mainly based on geography. Investigate ways to better incorporate geography in the 3-D model as it will help make BIM 5D implementation easier.

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Appendices

A

BIM Level of Detail and Maturity

BIM technology consists of various tasks. These tasks involve the generation and exchange of data and information among the stakeholders involved in the project. The extent of its ability to perform a given task and exchange the information involved is known as **The BIM Maturity** [Succar, 2010]. The Bew-Richards BIM Maturity Model, figure, depicts that 4 BIM Maturity levels are progressing from Level 0 to Level 3 [Jayasena, 2013].

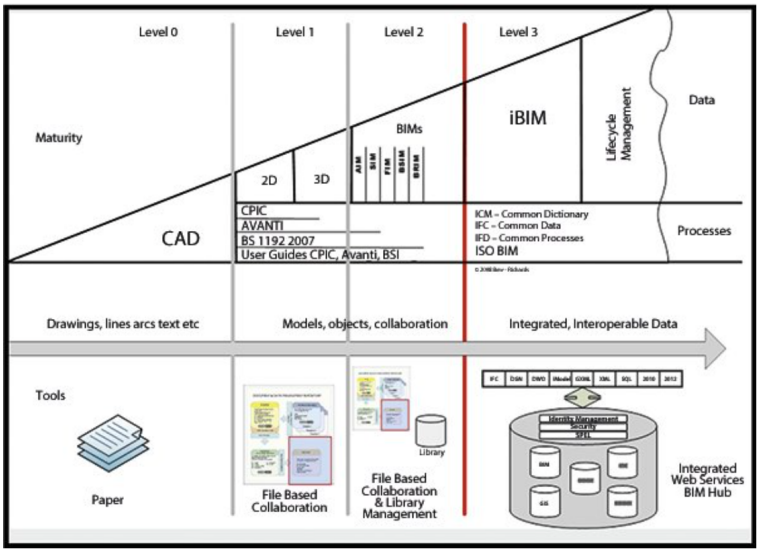

Figure A.1: The UK maturity Model (Bew Richards, 2008)

- **Level 0:** In this stage we use the paper drawing or computer-aided design (CAD) drawings to create the various drawings. This can be called the traditional way of working in the construction industry. [Sacks et al., 2018]. No information is produced or shared at these levels. No standards or processes are involved. The schedule and the cost of the project are prepared using basic Microsoft Office tools [Exel, 2020].

- **Level 1:** Levels 1 - 3 deal with varying degrees of modelling, collaboration and sharing of data. Level 1 consists of standardised structures and formats. This level includes specific 2D and 3D information, apart from geometric information, like cost, schedule, planning etc [Exel, 2020]. At this level, the information is not shared with the other members of the project.

- **Level 2:** In Level 2, the 3D environment also has data attached to it. The difference is that the attached data is created in separate discipline-based models. These separate models are combined to form a federated model while preserving their identity [Sacks et al., 2018]. The 3D models have 4D (planning) and 5D (cost) models attached to them.

- **Level 3:** In Level 3, all the construction parties involved work together in one integrated model [Sacks et al., 2018]. Apart from the 4D and 5D information models, the 3D model also consists of BIM 6D (energy models). This model is also referred to as iBIM (integrated BIM). This ensures better working and collaboration between designer and supplier, as both the parties, have access to timely information.

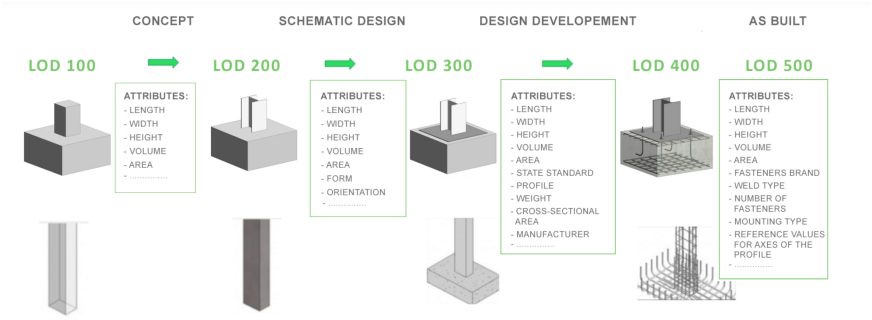

Figure A.2: Level of Detail ["BIM Advantages over CAD | BIM model | Cost of design error", 2018]

The BIM Models contain varying details about the geometry, planning, cost etc. **The Level of Detail (LOD)** concept was introduced to express the extent of detail assigned to a given BIM model. LOD creates a standardized definition of what completion means and eliminates chances of discrepancies associated with project completion. LOD ensures that the teams working in different departments communicate with each other in a better way with greater clarity. It ensures that all the teams are on the same page and

eliminate inconsistencies. With the help of LOD specifications, communication and collaboration become easier and faster making the project efficient. There are five levels of details which are LOD 100, LOD 200, LOD 300, LOD 400 and LOD 500 [Latiffi et al., 2015]. LOD 100 is a conceptual model with basic information. LOD 200 contains approximate data height, width, volume, location and orientation. It can also contain non-geometric information. LOD 300 contains accurate data of the quantity, size, shape, location and orientation as well as non-geometric elements attached to the geometric elements. It depicts the interface between the model and the various systems like electrical, plumbing etc. LOD 400 depicts the complete fabrication, assembly and details of the model. In addition to all the details in LOD 400, LOD 500 contains maintenance and operation assemblies [Latiffi et al., 2015].

B

INTERVIEWS - QUESTION BANK

B.1. PHASE 2

A Question Bank was prepared for Phase 2 keeping in mind the 4 elements required for a good BIM implementation:- Process, Representation, Collaboration, Life-cycle. The questions were asked depending on the background and expertise of the interviewee i.e. depending on the focus group.

Process

1. How would you describe BIM/What is your definition of BIM?
2. What are your thoughts on BIM? What are the advantages and disadvantages?
3. How supportive is the management to the use of BIM?
4. Is the budget and the time, allotted by the organisation for implementing BIM sufficient? Can you please elaborate on this?
5. Who is involved in BIM modelling? Does every project have an individual BIM team or experts? Or does the organisation have a department?
6. Is a standard procedure followed?
7. What is BIM 5D according to you?
8. How is the BIM 5D actually start for a project? Can you describe the process?
9. How is the BIM 5D process done? What kinds of data is considered while doing the costing process?
10. Do you make use of object libraries?
11. Are the object libraries inline with the standards set up the national/international codes?

12. What measures are taken to keep the libraries up to date?
13. What was your motivation behind the shift to BIM 5D? and who or what promoted the transition?
14. How did the BIM training process proceed? Who carried them out?
15. What was taught in this training process?
16. How helpful was the training process?
17. Are you thinking of proceeding with the training in the same way? Why/Why not?
18. What is the procedure if an employee, who has undergone training, needs some guidance? Who do they approach?
19. Do you have standard guidelines for the process?
20. Has incorporating BIM 5D has changed the way your department functions?
21. How and when do you incorporate the changes in design and planning in the costing?
22. Are the dynamic costs considered in BIM 5D? If yes, then how? If, no then at which stage are these costs considered?
23. How was the shift from traditional costing to BIM 5D?
24. How did your colleagues react to your shift? What do you think were the drivers for the different types of reactions?
25. Overall, how was your experience using BIM 5D?
26. Was your experience positive or negative? What steps did you take to enhance or minimise this experience?
27. Do you think BIM has the ability to change the way the organisation functions?

Representation

1. What is the software used for BIM? Do all the departments use the same software?
2. Do you think the organisation has the met the hardware and software requirements needed to implement BIM 4D 5D?
3. To what level of detail and maturity is a BIM model generally created?
4. How and in what manner is the data from the previous projects stored?

Collaboration

1. Does the software allow collaboration from various parties?
2. Can you elaborate a little more on the Information Management department? How does that department interact with the other departments?
3. Do you work with other organisations?
4. How is the collaboration between the various organisations?
5. Who has access to the models?
6. Who do you think should ideally have access to the models and why?
7. Does the collaboration affect the trust between the parties?
8. How are the people who don't have access to the models updated about the project progress? Does the method work well or is it inconvenient?

B.2. PHASE 3

In **Phase 3** BIM experts from the Building Industry are interviewed. In this phase, in addition to the questions asked in Phase 2, the following questions are asked:
Process

1. How mature do you think the BIM implementation is in your department?
2. Do you follow any guidelines for the BIM process?
3. How extensive and standard are these guidelines?
4. What was the reason behind making these guidelines?
5. What guidelines are followed in the department?
6. To what extent do you think the whole BIM process is standardised?
7. Do you think the challenges faced by incorporating BIM increase with the addition of every dimension or are the challenges faced the same?
8. How do you think these challenges can be eliminated or minimised?
9. Do you think the building department has managed to incorporate BIM 5D more successfully than infrastructure? Why or why not?
10. Do you think the for the building sector it is easier to implement BIM compared to infrastructure?

B.3. PHASE 4

In **Phase 4** the interviews are conducted to validate the results. The following questions asked are:

1. Do you have any comments/suggestions/improvements on the set of recommendations prepared?
2. How can you assess whether the recommendations will bring about an improvement or not?
3. Do you think these recommendations will be applicable for all infrastructure projects and in all organisations? If no, what changes do you suggest?
4. Would it be easy to follow the recommendations or do you think it will need some technical, organisational or managerial changes?
5. To what extent do you think these recommendations will improve the BIM 5D process for infrastructure in an organisation?

C

Interviews - Summary

The summaries of the interviewees conducted are given in this section. They are divided in sections, according to the phase they were conducted in.

C.1. Phase 2

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D

Challenges Score

The challenges were marked depending on the number of interviewees who interviewed them and were scored accordingly. The ones highlighted are the challenges found in this thesis. This was done for each of the focus groups and also and also overall. These are shown in the figures below.

		FG1						
	CHALLENGES	1.1	1.2	1.3	1.4	1.5	1.6	
1	Misconceptions and Unawareness regarding the working of BIM	x	x	x	x		x	0,83
2	Project managers hesitant to use BIM 5D	x		x	x	x	x	0,83
3	Project teams do not stick to standard procedures	x		x	x	x	x	0,83
4	Several departments do not have access to BIM 5D softwares	x	x			x	x	0,67
5	Hardware provided is not suitable to work with files of large size.	x				x	x	0,50
6	Non-standard file type	x						0,17
7	Interaction between software's	x						0,17
8	Hesitant to give up outdated technology			x		x	x	0,50
9	Unwillingness of clients to use BIM/BIM 5D	x	x	x	x	x	x	1,00
10	BIM is not cost efficient for small projects							0,00
11	Modelling software not suited for infrastructure (Revit)	x		x	x			0,50
12	Lack of availability of object libraries in the BIM 5D software			x	x	x	x	0,67
13	Object separation for cost-estimation in the 3D model.			x				0,17
14	Difficult to assess ground conditions		x					0,17
15	3D Design made is not up to the standard for cost managers to calculate cost							0,00
16	Cost Managers need to check design (double work)							0,00
17	Lack of experienced BIM staff	x	x	x	x		x	0,83
18	Few BIM ambassadors compared to the size of the organisation						x	0,17
19	Knowledge gap and lack of collaboration between regional offices and GEC			x	x			0,33
20	Knowledge sharing within and between the departments	x	x	x	x		x	0,83
21	Not everyone has access to BIM 360			x	x		x	0,50
22	Clients do not have access to BIM 5D softwares							0,00
23	Lack of competition in Infrastructure			x			x	0,33

Figure D.1: Challenges Score - Focus Group 1

		FG2				
	CHALLENGES	2.1	2.2	2.3	2.4	
1	Misconceptions and Unawareness regarding the working of BIM					0,00
2	Project managers hesitant to use BIM 5D					0,00
3	Project teams do not stick to standard procedures	x	x	x	x	1,00
4	Several departments do not have access to BIM 5D softwares	x	x	x	x	1,00
5	Hardware provided is not suitable to work with files of large size.					0,00
6	Non-standard file type	x				0,25
7	Interaction between software's					0,00
8	Hesitant to give up outdated technology	x			x	0,50
9	Unwillingness of clients to use BIM/BIM 5D	x	x		x	0,75
10	BIM is not cost efficient for small projects		x			0,25
11	Modelling software not suited for infrastructure (Revit)	x				0,25
12	Lack of availability of object libraries in the BIM 5D software	x	x		x	0,75
13	Object separation for cost-estimation in the 3D model.	x	x		x	0,75
14	Difficult to assess ground conditions	x	x		x	0,75
15	3D Design made is not up to the standard for cost managers to calculate cost	x	x		x	0,75
16	Cost Managers need to check design (double work)	x	x		x	0,75
17	Lack of experienced BIM staff	x				0,25
18	Few BIM ambassadors compared to the size of the organisation					0,00
19	Knowledge gap and lack of collaboration between regional offices and GEC					0,00
20	Knowledge sharing within and between the departments					0,00
21	Not everyone has access to BIM 360					0,00
22	Clients do not have access to BIM 5D softwares		x			0,25
23	Lack of competition in Infrastructure					0,00

Figure D.2: Challenges Score - Focus Group 2

		FG3		
	CHALLENGES	3.1	3.2	
1	Misconceptions and Unawareness regarding the working of BIM		x	0,50
2	Project managers hesitant to use BIM 5D	x		0,50
3	Project teams do not stick to standard procedures			0,00
4	Several departments do not have access to BIM 5D softwares		x	0,50
5	Hardware provided is not suitable to work with files of large size.			0,00
6	Non-standard file type			0,00
7	Interaction between software's			0,00
8	Hesitant to give up outdated technology			0,00
9	Unwillingness of clients to use BIM/BIM 5D	x		0,50
10	BIM is not cost efficient for small projects			0,00
11	Modelling software not suited for infrastructure (Revit)			0,00
12	Lack of availability of object libraries in the BIM 5D software	x		0,50
13	Object separation for cost-estimation in the 3D model.	x		0,50
14	Difficult to assess ground conditions	x		0,50
15	3D Design made is not up to the standard for cost managers to calculate cost	x		0,50
16	Cost Managers need to check design (double work)	x		0,50
17	Lack of experienced BIM staff			0,00
18	Few BIM ambassadors compared to the size of the organisation			0,00
19	Knowledge gap and lack of collaboration between regional offices and GEC			0,00
20	Knowledge sharing within and between the departments	x	x	1,00
21	Not everyone has access to BIM 360			0,00
22	Clients do not have access to BIM 5D softwares			0,00
23	Lack of competition in Infrastructure			0,00

Figure D.3: Challenges Score - Focus Group 3

	CHALLENGES	Overall
1	Misconceptions and Unawareness regarding the working of BIM	0,44
2	Project managers hesitant to use BIM 5D	0,44
3	Project teams do not stick to standard procedures	0,61
4	Several departments do not have access to BIM 5D softwares	0,72
5	Hardware provided is not suitable to work with files of large size.	0,17
6	Non-standard file type	0,14
7	Interaction between software's	0,06
8	Hesitant to give up outdated technology	0,33
9	Unwillingness of clients to use BIM/BIM 5D	0,75
10	BIM is not cost efficient for small projects	0,08
11	Modelling software not suited for infrastructure (Revit)	0,25
12	Lack of availability of object libraries in the BIM 5D software	0,64
13	Object separation for cost-estimation in the 3D model.	0,47
14	Difficult to assess ground conditions	0,47
15	3D Design made is not up to the standard for cost managers to calculate cost	0,42
16	Cost Managers need to check design (double work)	0,42
17	Lack of experienced BIM staff	0,36
18	Few BIM ambassadors compared to the size of the organisation	0,06
19	Knowledge gap and lack of collaboration between regional offices and GEC	0,11
20	Knowledge sharing within and between the departments	0,61
21	Not everyone has access to BIM 360	0,17
22	Clients do not have access to BIM 5D softwares	0,08
23	Lack of competition in Infrastructure	0,11

Figure D.4: Challenges Score - Overall

E

VALIDATION SHEET

	RECOMMENDATIONS	V.1	V.2	V.3	TOTAL/3
	Role - Consultant				
		SCORE (1-3)			
	General recommendations for consultancy organizations				
1	Publicise the benefits of BIM and BIM 5D to Project Managers	3	3	3	**3,0**
2	Utilise the expertise of BIM Front Runners	3	3	3	**3,0**
3	Spend time preparing the BIM Execution Plan	2	2	3	**2,3**
4	Encourage department to invest in the BIM 5D (Cost X) software	1	3	3	**2,3**
5	Work on the expansion of the cost data base for BIM 5D	1	1	3	**1,7**
	Recommendations specifically for individuals				
1	Create Reusable parts in BIM models	2	3	2	**2,3**
2	Take advantage of the facilities the GEC has to offer	2	3	3	**2,7**
3	Learn from contractors	2	2	2	**2,0**
	Recommendations specifically for teams				
1	Knowledge sharing with other departments	3	2	3	**2,7**
2	Infrastructure department should increase collaboration with the GEC's.	2	2	3	**2,3**

Figure E.1: Validation Sheet